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Exploring the nexus among hydroelectric power generation, financial development, and economic growth: Evidence from the largest 10 hydroelectric power-generating countries

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A R T I C L E I N F O

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A B S T R A C T

The hydroelectric power sector has significant standing in the global energy mix, and its intersection with financial development and economic progression has substantial implications for realizing sustainable development. To this end, this study aims to unravel the relationship among hydroelectric power generation, financial development and economic growth in the world's largest 10 hydroelectric energy generating countries for the period 1990–2020. The study uses an econometric battery comprising the Westerlund-Edgerton LM bootstrap, the Augmented Mean Group (AMG), panel-corrected standard errors (PCSE) and the Dumitrescu-Hurlin panel causality approaches. The AMG estimations, following confirmation of cointegration among variables, reveal that hydroelectric energy generation has significant positive effect on economic growth and financial development. Besides, a bilateral causality has been observed between hydroelectric power generation, economic growth, and financial development. The empirical estimations validate the feedback hypothesis within the context of selected countries. The study's findings provide policymakers with crucial insights to encourage both hydropower generation and consumption and improve financial markets' depth and accessibility to fuel sustainable and inclusive economic growth across the hydropower belt.

1. Introduction

Environmental degradation caused by climate change is a critical threat to sustainable development (SD), and the time is running out for us as a species to confront this life-threatening challenge. With this backdrop, it is imperative to look for alternative energy sources that can not only subside environmental degradation but also propel sustainable progression. In this respect, the hydroelectric energy is emerging as a promising solution. The hydroelectric energy is the most widely used renewable energy (RE) resource in various countries [1]. This type of energy has some advantages: (i) It is an environmentally friendly and efficient energy resource when used for its intended purposes. (ii) This resource provides the opportunity for irrigation as well as drinking water following energy production. (iii) It is a low capital-intensive energy resource. (iv) Hydroelectric power plants offer direct and indirect employment opportunities. (v) Carbon intensity is quite low compared to other energy resources such as petroleum and coal. (vi) Hydroelectric energy provides significant cost advantages over other types of RE resources, including solar and wind energy [2,3]. As hydroelectric energy is counted as one of the prime sources of renewable energy owing to its numerous benefits such as cost-effectiveness, capability to reduce carbon emissions, and the potential for job creation compared to traditional fossil fuels; a significant surge has been witnessed in hydroelectric energy generation across the globe in last two decades. This situation is illustrated in Fig. 1 and reveals the extent to which importance would be given to hydroelectric energy, as one of the RE resources. The world's hydroelectric power generation (HEPG), which was 2158,743 TW-hours in 1990, has become 4345,990 TW-hours in 2020.

As illustrated in Fig. 2, similar to Fig. 1, increase in the levels of

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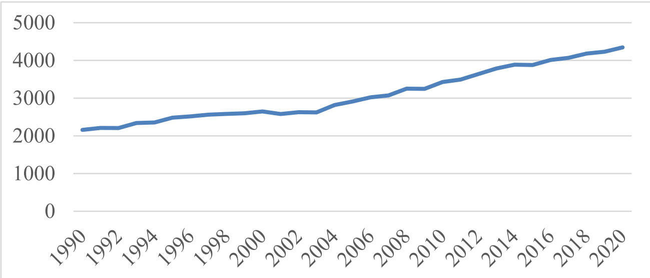

Fig. 1. World's HEPG (terawatt-hours, 1990–2020).
Source: Created by the authors using data from British Petroleum (2022).

HEPG have been observed in the top 10 hydroelectric energy-generating countries. The share of these countries in the world's HEPG is illustrated in the pie chart in Fig. 3, according to the period 1990–2020 averages. Accordingly, the world's HEPG is at 3089,505 TW-hours and those 10 countries account for a total of 2106.663 TW-hours. Those production capacities indicate that approximately 70% of the world's hydroelectric energy is being generated by those 10 countries. As seen in Fig. 3, the highest generation devolves on China, Canada, Brazil, the USA, Russia, India, Norway, Japan, Sweden, and Turkey with approximately 18%, 12%, 11%, 9%, 6%, 3%, 4%, 3%, 2%, and 1%, respectively.

The relationship between hydroelectric power generation and economic growth and financial development is complex and involves many factors. This relationship covers the issues of how hydroelectric power generation can affect economic growth and contribute to financial development. To understand this relationship, the effect of HEPG on economic growth (EG) and financial development (FD) will be examined in this study. In other words, it will be revealed whether hydroelectric power generation has an impact on economic growth and financial development. In the study, the data of the 10 largest hydroelectric energy-generating countries for 2021 are utilized. Considering the contribution of HEPG to the economy and the role of the financial sector in supporting HEPG sector, we observed that various aspects of such an important energy resource have not been adequately studied by previous studies. In this respect, it is of utmost importance on behalf of policymakers and stakeholders to grasp the nuances between hydroelectric power generation, financial development and economic development as harnessing the potential clean energy avenues and robust financial sector are second to none for sustainable economic progression.

This study contributes to the literature in five different aspects. i) There are quite limited number of studies regarding the association between HEPG and EG. In these studies, no research study has been found in the sample of the top 10 hydroelectric energy-generating countries. ii) No empirical research exists on the association between HEPG and FD. In this context, this study would reveal the first findings on this relationship. iii) Determining the relationship between the aforementioned variables by employing the second-generation AMG estimation method is another distinctive feature of the study, as it accounts for endogeneity and cross-sectional dependence issues iv) The results of the analysis obtained from the study can be a guide in mitigating the adverse effects of climate change through the usage and generation of clean energy. Additionally, robustness testing was carried out with the PCSE method, and this method will increase the reliability of the findings. v) The study reveals the importance of the hydroelectric energy resource in achieving the SD goals of the countries. Additionally, determining the impact of hydroelectric power generation on FD and EG can help develop energy policies, and achieve environmental sustainability and economic development goals. Moreover, understanding the impact of hydroelectric power generation on financial development is of great importance in terms of developing the energy sector and economic policies and promoting the use of sustainable energy resources. The findings from this study can be used to evaluate the financial sustainability of projects and determine strategies to supply future energy demand. This study contributes to some aspects of the major challenges confronted by this modern world i.e., catalyzing clean and sustainable energy elements such as hydroelectric power in the context of environmental and economic sustainability and capability of the financial sector in realizing sustainable goals. The specific takeaway of this study is to redefine energy and endorse the contribution of the financial sector for the utility of sustainable energy resources.

This study is comprised of five parts. After the introduction, the literature on the relationship between RE EG and FD is reviewed in the second part. In the third part, the model and method with the dataset and the empirical findings obtained in the fourth part are presented. In the last part of the study, concluding remarks are made and recommendations for policymakers have been presented along with some directions for future research work.

2. Literature review

2.1. The nexus between RE and EG

The majority of the studies in the literature have explored the nexus between energy consumption (EC) and EG. This nexus has been investigated in the literature in terms of the following four hypotheses: According to the growth hypothesis, the rise in EC levels encourages EG. The primary source of EG is EC. Therefore, a reduction in EC or energy supply shocks would lead to economic contractions. This hypothesis points out a unilateral causality from EC to EG ([4]; Tiwari,2011; Pao, Li, and Fu, 2014 [5]; Roula 2016 [6,7]; Dogan et al., 2022). The conservation hypothesis suggests that EG increases EC. Accordingly, positive or negative shocks in EC do not affect EG. This hypothesis confirms that the causality works in the reverse direction of the causality suggested by the growth hypothesis ([8–11]; Altay, Topcu, and Dogan, 2022). According to the neutrality hypothesis, EC and EG are not mutually affected by each other. In this case, the reduction in EC would

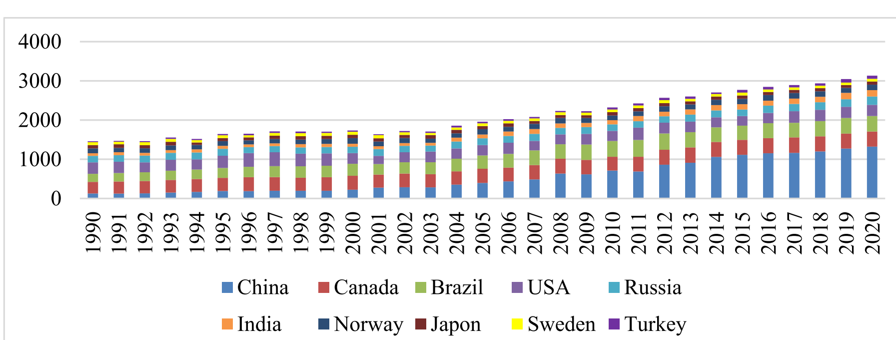

Fig. 2. HEPG of top 10 countries included in the analysis (terawatt-hours, 1990–2020).
Source: Created by the authors using data from British Petroleum (2022).

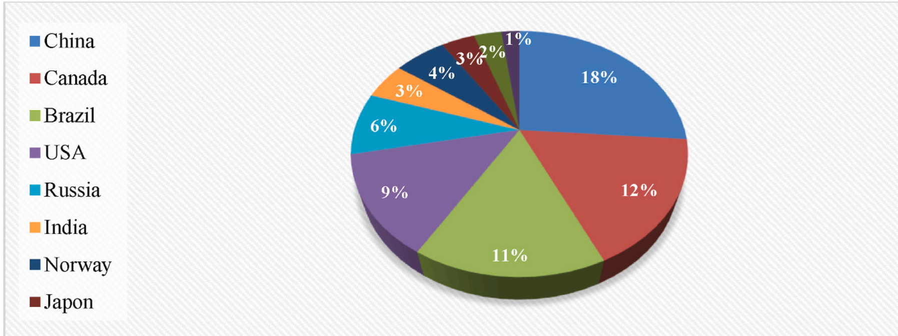

Fig. 3. Shares of countries included in the analysis of World's HEPG (1990–2020 average).
Source: Created by the authors using data from British Petroleum (2022).

not have any effect on EG. Likewise, EG activities would not affect EC. Therefore, production activities would be shifted towards less energy-intensive sectors such as the service sector. This hypothesis reveals that no causality exists between the relevant variables [9,12–16]. The feedback hypothesis becomes valid whenever EG and EC mutually affect each other. This hypothesis emphasizes bilateral causality among the relevant variables ([17–20]; Shahbaz et al.,2016; [21–23]).

As seen in the literature, although there are various studies in terms of the relevant hypotheses regarding the energy-EG nexus, the role of hydroelectric energy on growth has not been adequately examined in current studies. Abakah [24], one of the studies examining the association between hydroelectric energy and EG, examined the relationship between EG and three energy resources in terms of Ghana's economy. The study concluded that there was a negative relationship between coal consumption and EG, and that hydroelectric and oil consumption increased EG. Okafor [25] examined the causality between petroleum, coal, and hydroelectric EC (HEC) and EG for the economies of Nigeria and South Africa. The causality results indicated the presence of a bilateral causality between hydro energy and EG for both countries. Yildirim et al. [26] asserted that the neutrality hypothesis was valid between hydroelectric energy and EG in their analysis of the USA over the period 1949–2010.

Ziramba [27] examined the link between HEC and EG for African countries using the data obtained between 1980 and 2009. The analysis findings confirmed the validity of the neutrality hypothesis for Egypt, the feedback hypothesis for Algeria, and the conservation hypothesis for South Africa. Ohler and Fetters [28] explicated the association between EG and HEPG for 20 OECD members between 1990 and 2008. Research results showed the existence of a long-term and positive relationship between the production of biomass, hydroelectricity, waste, and wind energy and growth. Bildirici [29] investigated the causality between the environment, EG and HEC for 15 countries. The study detected a bilateral causality between EG and HEC for all countries except for Austria, Germany, and the UK. Solarin and Ozturk [30] analyzed the causal relationships between HEC and growth for Latin American countries; a bilateral causality for Argentina and Venezuela; and a unilateral causality for Brazil, Chile, Colombia, Ecuador, and Peru.

Apergis et al. [31] investigated the relationship between HEC and EG in the top-10 hydroelectric energy-consuming countries using the data obtained between 1965 and 2012. The findings indicated that a unilateral causality existed from the real GDP per capita to HEC per capita in the short- and long-run throughout the pre-1988 period. In the post-1988 period, they revealed a bilateral causality between those variables. Bildirici [32] investigated the relationship between EG and HEC employing the ARDL method. The short-run causality results determined a unilateral causality from EC to EG for high-income OECD countries. Another finding from the study was the presence of unilateral causality from EG to EC for Finland, France, Mexico, the USA, and Turkey. Bildirici and Gökmenoglu [14] examined the association between EP, EG and HEC for G7 countries between 1961 and 2013. They concluded that HEC caused EG across the G7 countries. A bilateral causality was detected between those variables in some countries. Ummalla and Samal [2] stated that HEC had a positive effect on EG in the analysis they conducted in China between 1965 and 2016.

Solarin et al. [3] established that variables such as HEC, fossil fuel consumption, capital, FD, and globalization had a positive effect on EG in the case of China between 1970 and 2014. The analysis findings confirmed the validity of the long-term feedback hypothesis between the variables. Pata and Aydin [1] tested the validity of the EKC hypothesis between 1965 and 2016, and also investigated the causality between HEC and EG by performing the Fourier Toda-Yamamoto causality test. They found a unilateral causality from HEC to EG for Brazil. Therefore, they concluded that HEC assumed a crucial role in the implementation of EG policies in China and Brazil. Bello et al. [33] examined the causal associations between HEC and EG in their study of the Malaysian economy using the time-series data obtained between 1971 and 2017. According to the empirical findings, a causality from HEC to GDP was detected. The analysis results revealed that there was a need for capital investments that could have led to more financing and human capital to improve hydroelectric facilities.

2.2. The nexus between RE and FD

According to Sadorsky [34], the theoretical effect of FD on EC emerges through the direct effect, business effect, and welfare effect. According to the direct effect, as the level of FD increases, consumers can resort to cheap and easy borrowing to purchase durable goods. This situation causes more EC. According to the business impact, improvements in financial activities help businesses access financial capital easily and at less cost. This development increases the production volume of enterprises and causes energy demands to rise. Finally, according to the wealth effect, increased transactions in the stock market create a wealth effect. Thus, consumers' and businesses' confidence in the market increases. This environment of economic confidence stimulates the economy and increases energy demand. When the relationship between FD and RE is evaluated theoretically in the literature, developments in financial activities encourage the use of environmentally friendly energy resources by reducing RE investment project costs ([35,36]; Shahbaz et al., 2021). Similarly, developments in the securities market also increase the demand for RE by shifting capital allocation towards environmentally friendly energy projects (Minier et al., 2009; [34,37–39]). Besides RE, Mahmood [40] linked FD and trade to CO2 and obtained that there is substantial implications of FD and trade for CO2 emissions.

Numerous studies investigating the effect of FD on RE exist in the extant literature. Nonetheless, there is no study investigating the determinants of FD in the context of hydropower. The effect of RE on FD is evaluated within the context of causality in some of the studies [41–45].

Among the studies explicating the nexus between RE and FD, Lin et al. [46], Wu and Broadstock [47], Paramati et al. [38], and Shahbaz et al. [39] concluded that FD increased the level of renewable EC (REC). Burakov and Freidin [41] examined the causality between FD, EG and REC over the period 1990–2014 in the case of Russia. The findings confirm that no causal relationship existed from REC to EG and FD, but a bilateral causality existed between EG and FD. Similarly, Hassine and Harrathi [42] found evidence that no causality existed between REC and FD in the short-run for GCC countries over the period 1980–2012. Kutan et al. [48], Razmi et al. [49], and Raza et al. [50] found a positive association between REC and FD in Brazil, China, India and South Africa; Iran; and 15 countries that consume the most RE, respectively. Anton and Nucu [51] investigated the effect of FD on REC for 28 EU countries by using the data obtained over the period 1990–2015. The study findings indicated that FD increased the level of REC. Lahiani et al. [52] analyzed the effect of FD on REC in the US economy between 1975Q1 and 2019Q4 with the NARDL model. The empirical results revealed the long-term asymmetric effect of overall and stock-based FD measures. Mukhtarov et al. [43], in their study of the Azerbaijani economy over the period 1993–2015, found that FD encouraged REC, and that a bilateral causality existed between FD and RE. Wang et al. [44], in their study using the data obtained for the Chinese economy over the period 1997–2017, revealed that a unilateral causality existed from FD to REC. On the other hand, Khan et al. [45], using the data obtained over the period 2000–2014, concluded that the FD they made in the BRI was the most important determinant of RE. A bilateral causality existed between RE and FD.

Zhang and Rezzak (2022) investigated the effect of economic policy uncertainty, FD, environmental governance, and informal economy on REC in BRICST countries. Economic policy uncertainty was detected to reduce REC, FD enhanced environmental regulations, and the informal economy significantly increased RE. established countries must ponder the environmental aspects of energy consumption, imports, and economic growth while devising trade, energy, and public policies (Mahmood, Saqib, Adow, & Abbas [53]. Nonetheless, Pata et al. [54] explicated the effect of FD on REC in the USA between 1980 and 2019. FD encouraged high rates of REC in the medium- and long-run. Yi et. al [55]. argued that EG, FD, and economic globalization had a positive effect on REC. They concluded that economic policy uncertainty significantly reduced such consumption.

Besides, RE and FD studies have determined whether macroeconomic variables relate to environmental pollution. In this respect, Mahmood et al. (2023a) and Mahmood et al. [56] validated the environmental Kuznets curve in the context of China and other developing and emerging economies. In another study, Atif Awad (2017) ascertained that environmental degradation can be reversed. In a nutshell, variables such as conventional energy and financial development among others play a vital role in shaping the environmental dynamics of a country and the transition from dirty energy and clean energy for sustainable development is the major cry of the day. In this respect, this study aims to unravel the nexus between hydroelectric power generation, financial development, and economic growth in the largest 10 hydroelectric power-generating countries.

3. Theoretical underpinning, data and methodological framework

3.1. Theoretical underpinning

Growth theory provides a reasonable basis for the potential impact of hydropower vis-a-vis the economic growth of countries. In this respect, the resource-based growth model of Sachs & Warner [57] is pertinent. It explicates the role of abundant natural resources in bolstering economic growth. The energy transition theory by Rogelj et al. [58] postulates the utility of hydropower as a clean and robust renewable energy source, predominantly for developing and emerging economies. The impact of hydropower on financial development is theoretically backed through lenses of financial development (FD) and economic growth (EG) theories King & Levine [59,60]. The existing literature on the financing of renewable energy by Hepner et al. [61] is continuously progressing, as recently endorsed by the recent research of Wang et al. [62], which delineates novel approaches of financing; highlighting the role public-private collaborations, specifically targeting hydropower initiatives in the context of developing countries. Unraveling the interwoven relationships among HPEG, FD, and EG demands a broad range of theoretical rationales. Taking insights from growth theory, energy transition models, and financial development literature, we intend to put forward informed policy insights aimed at accomplishing sustainable economic growth via the strategic utilization of hydropower resources.

Hydroelectric power generation can increase a country's energy security, provide an environmentally friendly energy source, create employment, stimulate investments, and contribute to infrastructure development. To this end, hydroelectric power generation plays an important role in development projects and is important for many countries in supplying their energy needs and supporting economic growth. In this study, we analyze the effect of HEPG on FD and EG. The data of the 10 largest hydroelectric power-generating countries worldwide in 2021 are utilized in the study. These top 10 countries are China, Canada, Brazil, the USA, Russia, India, Norway, Japan, Sweden, and Turkey, respectively. The annual data obtained over the period 1990–2020 are used in the study. In this study, the control variable was not added to the model to determine its direct effect on hydroelectric power generation FD and EG. A similar approach is also found in the literature [23,63,64]. In this context, the following models are developed by taking the logarithms of the variables to predict the relationship.

$$lnEG_{it} = \beta_0 + \beta_1 lnHEPG_{it} + \vartheta_t \quad (1)$$

$$lnFD_{it} = \beta_0 + \beta_1 lnHEPG_{it} + \vartheta_t \quad (2)$$

In Eqs. (1) and (2), $i = 1, \ldots, N$ denotes cross-sectional units; $t = 1, \ldots, T$ denotes time; and ε_{it} represents error terms. β_1 denotes the parameters measuring the effect of independent variables on the dependent variable (Table 1).

The cross-sectional dependence (CSD) should be considered in panel data analysis. In this case, the results obtained in the developed panel models would be biased and inconsistent [65–67].

To test the CSD in this study, Breush–Pagan's LM test developed by Breusch and Pagan [68], Pesaran scaled LM (CD_{LM}) and Pesaran CD tests developed by Pesaran [67], and Bias-Corrected Scaled LM (LM_{adj}) test developed by Pesaran et al. [69] are performed. In these tests; rejecting the H_0 hypothesis and accepting the H_1 hypothesis indicate the existence of a CSD between the series. These four performed tests are expressed as given in Eqs. (3)–(6), respectively:

$$LM = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \widehat{\rho}_{ij}^{\,2} \quad (3)$$

Table 1
Variables, descriptions, and data sources.

Variables used in the study	Abbreviation of variables	Unit of the variables	Source
Hydroelectric Power Generation	HEPG	Hydro Generation - TWh	BP Statistical Review of World Energy
Economic Growth	EG	GDP (constant 2015 US$)	World Bank
Financial Development	FD	Domestic credit to the private sector (% of GDP)	World Bank

$$CD_{LM} = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \left(T\widehat{\rho}_{ij}^{\,2} - 1\right) \tag{4}$$

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=1+1}^{N} \widehat{\rho}_{ij} \right) \tag{5}$$

$$LM_{adj} = \left(\frac{2}{N(N-1)}\right)^{1/2} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \widehat{\rho}_{ij}^{2} \frac{(T-K-1)\widehat{\rho}_{ij} - \widehat{\mu}_{Tij}}{\upsilon_{Tij}} \sim N(0,1) \tag{6}$$

In panel data analysis, it is necessary to test the slope homogeneity following the testing of the CSD. The presence of heterogeneous slope coefficients is determined by the Δ tests estimated by Pesaran, Ullah, and Yamagata [69]. Nonetheless, if heteroscedasticity and multicollinearity exist in regression errors, Δ tests are performed. The HAC version of the homogeneity test is as seen in Eqs. (7)–(10):

$$\Delta_{HAC} = \sqrt{N} \left(\frac{N^{-1} S_{HAC} - k}{\sqrt{2k}} \right) \tag{7}$$

$$S_{HAC} = \sum_{i=1}^{N} T(\widehat{\beta}_i - \widehat{\beta})' \left(\widehat{O}_{iT} V_{iT}^{-1} \widehat{O}_{iT}\right) (\widehat{\beta}_i - \widehat{\beta}) \tag{8}$$

$$\widehat{\beta} = \left(\sum_{i=1}^{N} T \widehat{O}_{iT} V_{iT}^{-1} \widehat{O}_{iT} \right)^{-1} \sum_{i=1}^{N} \widehat{O}_{iT} \widehat{V}_{iT}^{-1} X_i' M_T y_i \tag{9}$$

$$\widehat{V}_{iT} = \widehat{\Gamma}_i(0) + \sum_{j=1}^{T-1} K\left(\frac{j}{M_{iT}}\right) [\widehat{\Gamma}_i(j) + \widehat{\Gamma}_i(j)'] \tag{10}$$

In the case of the CSD, the 2nd-generation panel unit root tests should be performed. In the study, the Cross-Sectionally Augmented IPS (CIPS) and ADF (CADF) panel unit root tests developed by Pesaran [70] are preferred according to the CSD test results. Pesaran [70] used the expanded version of the ADF unit root test with the lagged cross-sectional averages. Moreover, the 1st difference of this regression eliminates the correlation between units. This approach is known as the CADF. Pesaran [70] used Eqs. (11) and (12) for the CADF unit root test:

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + u_{it} \tag{11}$$

$$u_{it} = \gamma f_t + \tag{12}$$

In the nonexistence of autocorrelation, the CADF regression is as given in Eq. (13):

$$\Delta y_{it} = \alpha_i + \rho_i y_{i,t-1} + d_0 \overline{y}_{t-1} + d_1 \Delta \overline{y}_t + \varepsilon_{it} \tag{13}$$

The term $\overline{y}$ in Eq. (13) is the average of all observations with respect to time. In the presence of autocorrelation, the equation can be expanded as given in Eq. (14) by adding the first-order differences of y_{it} and $\overline{y}_{it}$ into the equation:

$$\Delta y_{i,t} = \alpha_i + \rho_i y_{i,t-1} + c_i \overline{y}_{t-1} + \sum_{j=0}^{p} d_{i,j} \Delta \overline{y}_{t-j} + \sum_{j=0}^{p} \beta_{i,j} \Delta y_{i,t-j} + \mu_{i,t} \tag{14}$$

To calculate the CIPS statistic in Eq. (15), the *t*-statistics of the lagged variables are averaged:

$$CIPS = \frac{1}{N} \sum_{i=1}^{N} CADF_i \tag{15}$$

It is necessary to select the appropriate cointegration test in line with the findings following the determination of the CSD, homogeneity, and stationarity. Accordingly, Westerlund and Edgerton's (W–E) (2007) Panel LM bootstrap cointegration test is performed.

W–E's (2007) cointegration test, which takes into consideration the CSD, relies on the Langrange test multiplier developed by McCoskey and Kao [71]. The H_0 of the test implies that "There is a cointegration relationship", whereas the H_1 implies that "There is no cointegration relationship" [72]. It is seen in Eq. (10) from which the panel cointegration test is derived.

$$\gamma_{it} = \alpha_i + x_{it}' \beta_{it} + Z_{it} \tag{16}$$

$$Z_{it} = \mu_{it} + V_{it}\; V_{it} = \sum_{J=1}^{t} \eta_{ij} \tag{17}$$

The *t* index in Eq. (17) denotes the time-series, *i* represents the cross-sectional unit, and Z_{it} is the error term. In Eq. (18), the partial sum process of Z_{it} is expressed by S_{it}^2, and the long-run variance of μ_{it} is expressed by $\widehat{\omega}_i^{-2}$. The LM statistics are as follows:

$$LM_N^+ = \frac{1}{NT^2} \sum_{i=1}^{N} \sum_{t=1}^{t} \widehat{\omega}_i^{-2} S_{it}^2 \tag{18}$$

In the case of the CSD and slope heterogeneity in panel data, one of the most suitable estimation methods is the AMG estimator developed by Eberhardt and Teal [73] and Eberhardt and Bond [74]. The AMG estimation technique, which has significant advantages over classical estimators, can also make estimations specific to panel countries. The AMG method is based on a two-step process [74]. The first step is shown in Eq. (19):

$$\Delta X_{it} = \delta_i + \beta_i \Delta Y_{it} + \gamma_i A_t + \sum_{t=2}^{T} \delta_i \Delta D_t + \varepsilon_{it} \tag{19}$$

The model estimated in the second step is as shown in Eq. (20):

$$\widehat{\beta}_{AMG} = N^{-1} \sum_{i=1}^{N} \widehat{\beta}_i \tag{20}$$

In the second step shown in Eq. (20), the time dummy variable is included in the regression for each cross-sectional unit. AMG estimates are obtained by averaging individual country estimates.

Standard errors were corrected with the robust panel-corrected standard error (PCSE) approach developed by Beck–Katz (1995), which is resistant to heteroscedasticity, autocorrelation and CDS problems, and the method is shown in Eqs. (19)–(21):

$$y_{it} = x_{it}\beta + \varepsilon_{it} \tag{21}$$

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_m \end{bmatrix} = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_m \end{bmatrix} \beta + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_m \end{bmatrix} \tag{22}$$

$$\sum [\varepsilon\varepsilon'] = \Omega = \begin{bmatrix} \sigma_{11}I_{11} & \sigma_{12}I_{12} & \dots & \sigma_{1m}I_{1m} \\ \sigma_{21}I_{21} & \sigma_{22}I_{22} & \dots & \sigma_{2m}I_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{m1}I_{m1} & \sigma_{m2}I_{m2} & \dots & \sigma_{mm}I_{mm} \end{bmatrix} \tag{23}$$

Dumitrescu and Hurlin's (D–H) (2012) causality test yields accurate outcomes in heterogeneous panels, in cases of N > T or T > N, and CSD (Dumitrecu and Hurlin, 2012: 1451). The linear model through which it tests the causality between X and Y is as follows.

$$y_{i,t} = \alpha_i + \sum_{k=1}^{K} \beta_{ik} y_{i,t-k} + \sum_{k=1}^{K} \gamma_{i,k} X_{i,t-k} + \varepsilon_{it} \tag{24}$$

4. Empirical findings

In this part of the research study, the correlation and descriptive statistics among the HEPG, EG and PD variables used in the study are presented (see Tables 2 and 3). Also, Westerlund's (2013) slope homogeneity and CSD test results are revealed. Then, Pesaran's (2007) CADF and CIPS unit root and W-E's (2007) bootstrap cointegration test results are presented. Subsequently, AMG coefficient estimation and DH causality test results are evaluated.

The logarithms of the HEPG, EG, and FD are taken. The correlation

Table 2
Summary statistics and Correlation matrix.

	HEPG	EG	FD
Mean	2.101	12.10	−0.254
Std. dev..	0.3973	0.6558	0.149
Max..	3.121	14.94	−0.034
Min..	0.729	9.872	−0.708
Obs..	310	310	310
HEPG	1.0000		
EG	0.5506	1.0000	
FD	0.3666	0.3895	1.0000

Table 3
Cross-sectional dependence test results.

Variables	HEPG	EG	FD
Breush–Pagan LM	401.190* (0.000)	389.346* (0.000)	952.120* (0.000)
Pesaran scaled LM	36.491* (0.000)	35.243* (0.000)	94.564* (0.000)
Bias-corrected scaled LM	36.325* (0.000)	35.076* (0.000)	94.398* (0.000)
Pesaran CD	9.872* (0.000)	9.881* (0.000)	30.608* (0.000)

analysis results reveal a positive ($r = 0.55$) relationship exists between HEPG and EG. Similarly, a positive ($r = 0.36$) relationship exists between FD and HEPG. In other words, there is a stronger correlation between EG and HEPG compared to FD. As a result of the analysis, it is understood that the probability value of the variables is lower than 0.05. The H_0 implying that "there is no CSD" is rejected. In other words, the CSD exists for all series.

The H_0, which expresses the presence of slope homogeneity for both models developed in the research, is rejected. In other words, there is slope heterogeneity for these two models.

In Table 5, Pesaran [70] CADF and CIPS tests, one of the second-generation panel unit root tests performed in the case of CSD, are performed to investigate whether HEPG, EG, and are stationary (see Table 4). According to the results, the series is stationary at both level and first difference. In other words, the hypothesis of H_0 implying that "series contain unit roots" is rejected.

After determining that the series do not contain a unit root in Table 6, the long-term cointegration relationship is detected by performing the W–E's LM Bootstrap (2007) test. Bootstrap–p value should be taken into account due to the CSD among the series. Since the Bootstrap-p value exceeds 0.10 in both models, the H_0 hypothesis of the W–E's LM Bootstrap test is accepted. In line with these results, it is understood that there is a cointegration relationship (see Table 7).

A positive and statistically significant relationship exists between HEPG and EG ($p < 0.01$). In other words, HEPG has an increasing effect on EG. According to country-specific results, there is a positive correlation between HEPG and EG, consistent with the panel results for China, Brazil, Russia, India, Norway, and Turkey. HEPG assumes a crucial role in EG. Nevertheless, a negative relationship is found between HEPG and EG for Canada. No significant association exists between HEPG and EG for countries such as the USA, Japan, and Sweden. In other words, HEPG is not effective on EG for these economies.

Table 8 presents the direction of the relationship between FD and HEPG, and the coefficient estimation results. A significant and positive association exists between HEPG and FD ($p < 0.01$). In other words, HEPG positively affects FD. The country-specific results claim that a

Table 4
Slope homogeneity test results.

	Model 1	Model 2
$\tilde{\Delta}$	6.790* (0.000)	4.641* (0.000)
$\tilde{\Delta}$ adj	8.141* (0.000)	6.595* (0.000)

Table 5
CADF and CIPS unit root test results.

Variables	CADF test statistic for constant		CIPS test statistic for constant	
	Level	First Difference	Level	First Difference
HEPG	0.398***	1.353***	1.010*	−11.285***
EG	0.836***	2.430***	1.809**	−9.634***
FD	0.922***	3.752***	−1.364*	−11.688***

Table 6
Westerlund-Edgerton's LM bootstrap cointegration test results.

	LM statistic	Asymptotic-p-value	Boostrap-p-value
LMN^T (Model 1)	6.852	0.004	0.505
LMN^T (Model 2)	4.975	0.001	0.471

Table 7
Long-term AMG coefficient estimator results (Model 1).

Model 1	$EG_{it} = \beta_0 + \beta_1 HPEC_{it} + \vartheta_t$		
Dependent Variable: EG	AMG		
Panel	Coefficient	Standard Error	Probability
HEPG	**0.613*****	0.197	**0.002**
China			
HEPG	**1.007*****	0.042	**0.000**
Canada			
HEPG	**−26.15*****	4.126	**0.000**
Brazil			
HEPG	**0.619*****	0.095	**0.000**
United States			
HEPG	−0.065	0.237	0.782
Russia			
HEPG	**1.241***	0.643	**0.054**
India			
HEPG	**1.460*****	0.196	**0.000**
Norway			
HEPG	**0.542****	0.270	**0.045**
Japan			
HEPG	0.097	0.115	0.402
Sweden			
HEPG	−0.044	0.243	0.856
Turkey			
HEPG	**0.687*****	0.139	**0.000**

Table 8
Long-term AMG coefficient estimator results (Model 2).

Model 2	$FD_{it} = \beta_0 + \beta_1 HPEC_{it} + \vartheta_t$		
Dependent Variable: FD	AMG		
Panel	Coefficient	Standard Error	Probability
HEPG	**0.167*****	0.027	**0.000**
China			
HEPG	**0.251*****	0.030	**0.000**
Canada			
HEPG	0.198	0.200	0.322
Brazil			
HEPG	**0.224****	0.093	**0.016**
United States			
HEPG	**0.211***	0.120	**0.078**
Russia			
HEPG	0.111	0.278	0.688
India			
HEPG	**−0.144****	0.067	**0.031**
Norway			
HEPG	−0.179	0.150	0.233
Japan			
HEPG	0.143	0.140	0.306
Sweden			
HEPG	0.134	0.105	0.205
Turkey			
HEPG	**0.149*****	0.051	**0.004**

positive association exists between FD and HEPG, consistent with the panel results for China, Brazil, the United States, and Turkey. In other words, HEPG has an important role in increasing FD. These results are congruent to the findings of Apergis and Payne [75] in the extant literature. A negative relationship has been observed between HEPG and FD for India. These outcomes suggest that hydroelectric power generation (HPEG) does not come effective in terms of financial development in India. These outcomes can be related to several factors, such as, regulatory barriers, institutional constraints or inadequate infrastructure, which may impede the positive effect of HEPG on FD (Joshi and Ahmed [76]. No significant association exists between HEPG and FD in terms of developed countries, namely, Canada, Russia, Norway, Japan, and Sweden. In other words, HEPG is not effective on FD in these countries. The neutral association between HPEG and FD in developed countries entails that other factors, such as human capital and technological innovation may exhibit more vitality in driving financial development.

In Table 9, the effect of hydroelectric power generation on EG and FD with the PCSE method is examined. As a result of the PCSE method, it has been determined that hydroelectric power generation positively affects both economic growth and financial development. In other words, the increase in hydroelectric power generation accelerates financial development and economic growth. The results align with the findings of Anton and Nuku (2020). The findings of the PCSE method and the AMG method are consistent. This consistency imply that our results are robust. These outcomes suggest that supporting hydroelectric power generation can attain financial development and sustainable economic development thereby endorsing the United Nations' Sustainable Development Goals.

After estimating the panel and country-specific long-term coefficients, the causality between the HEPC, EG, and FD in Table 10 is investigated by performing the DH test. Accordingly, a bilateral causality exists between HEPG and EG. Besides, a bidirectional causality is detected between FD and HEPG. The feedback hypothesis becomes valid within the context of selected countries. The feedback hypothesis imply that policymakers need to be cognizant while taking decision pertaining to FD and HEPG, as changes in one variable can have marked impact on the other. It is observed that the bilateral causality between HEPG and EG is consistent with the studies of Okafor [25] for the Nigerian and South African economies, and Ziramba [27] for the Algerian economy, however, it is compatible with Yildirim (2012), who stated the nonexistent of any causality. A bilateral causal relationship between FD and HEPG appears to be consistent with the results of Mukhtarov et al. [43], however, it is not compatible with the studies of Hassine and Harrathi [42] and Burakov and Freidin [41], which do not confirm the causality. Based on the above causal findings it is proposed that policymakers need to ponder the intricacies and interdependencies among HEPG, FD and EG, and FD while taking decisions, in the context of their countries (see Table 2).

5. Conclusion and Policy Implications

In this research study, the effect of HEPG on EG and FD is examined in the. In the study, the data of the world's largest hydroelectric energy-generating countries between 1990 and 2020. For empirical analysis, the second-generation panel data analysis methods are employed. The

Table 9
Robustness Check.

Variable(s)	(Model 1)	(Model 2)
	EG	FD
HPEC	6.75*** (4.06)	2.41*** (3.71)
Observations	310	310
R-squared	0.7107	0.6043
Number of groups		10

Table 10
Dumitrescu-Hurlin panel causality test results.

	W-statistic	Z-Bar statistic	Probability
Model 1			
lnHPEC↛ lnEG	**5.030*****	9.012	**0.000**
lnEG↛ lnHPEC	**9.272***	1.920	**0.054**
Model 2			
lnHPEC↛ lnFD	**2.411*****	3.155	**0.001**
lnFD↛ lnHPEC	**17.42*****	7.455	**0.000**

analysis determines that HEPG has a positive effect on EG and FD. Besides, a bilateral causality was found between HEPG and EG and FD. HEPG is determined as an important driving force for FD and EG in these countries. These findings reveal the validity of the feedback hypothesis. The finding that HEGP increased EG in the study is consistent with the finding found by Abakah [24] for the Ghanaian economy. On the other hand, Bildirici and Gökmenoglu [14] for G7 countries and Solarin et al. [3] for China reached similar findings in their study. On the contrary, Yildirim et al. [26] confirm the neutrality hypothesis in the relationship between HEC and EG for the USA. In other words, HEC does not affect EG. On the other hand, Ziramba [27] reaches similar findings for Egypt. When the analysis results are evaluated in the context of the causality relationship between HEGP and EG, they are parallel to the bidirectional causality finding between these two variables found by Okafor [25] for Nigeria and South Africa. On the other hand, Bildirici [29] detects a bidirectional causality relationship between variables in 12 of the 15 countries included in the analysis. Bildirici [32] finds unidirectional causality from EG to HEC for Finland, France, Mexico, the USA, and Turkey. Additionally, Pata and Aydin [1] reach similar findings for the Brazilian economy. In contrast, Bello et al. [33] state that there is no causality finding between these two variables for Malaysia.

The study has some policy recommendations within the context of the analysis results. In terms of the sustainability of EG and FD, it is necessary to enhance the policy practices that support HEPG to reduce the foreign dependence of these countries on energy and to conduct clean environment activities. In this context, it is crucial to increase the number of hydroelectric power plants. Nevertheless, environmental degradation should be prevented by paying attention to the use of environmentally friendly technologies in the establishment of these power plants. The public should provide the necessary support to private institutions and organizations for the installation of hydroelectric power plants. For instance, the establishment of hydroelectric power plants by the private sector and the incentives for the generation of this energy can be realized in the form of tax refunds and subsidies and the government should pave the way for installing these power plants. In this way, the use of fossil-based energy resources can be reduced and environmental quality can be improved. It is also imperative that increasing the number of hydroelectric power plants is beneficial, due care should be taken to prevent environmental degradation. This can be achieved via the use of modern environmentally friendly technologies to establish these power plants.

As a result, hydroelectric energy is an important renewable energy source in ensuring sustainable development and financial development in the countries that produce the most hydroelectric energy. It will also make significant contributions to reducing the current account deficit by reducing the level of foreign energy dependency in these countries. Policymakers directing the country's investments largely to hydroelectric power plants can make significant contributions to meeting the energy needs of these countries and preventing global warming, as hydro energy creates minimal negative environmental impact, has low operation and maintenance costs, and most importantly, is local. Hence, the higher authorities of the selected countries are advised to support local energy production by investing in hydroelectric power plants, as this exercise does not only create jobs but provide stimulus to the local economies. The support of research and development activities in this sector augment efficiency which, in turn, appease environmental related issues. The introduction of small-scale projects in off-grid communities will further enhance energy accessibility and decrease the reliance on fossil fuels. It is worth noting that a developed financial sector not only paves the way for the new hydroelectric power projects, which trims the cost of capital, but it also espouses innovation in the hydroelectric industry by injecting funds for research and development of novel technologies. Due diligence is required to ensure liquidity of this sector as hydroelectric power energy sector, financial development and sustainable economic growth go hand-in-hand.

Since there are no studies in the literature focusing on hydroelectricity production as a determinant of financial development, the analysis results cannot be evaluated in the context of the effect of HEPG on FD and the causality relationship between these two variables. Therefore, it can be said that the relationship between HEPG and FD is an untouched and suitable area for research for economists, financiers, and other interested researchers. The uniqueness of this study is that it directly examines the long-term relationship and causality between HEC and FD. For this reason, this study investigated the relationship between HEPG and EG and FD. It is worth noting that we have considered hydroelectric power generation as main source of clean energy in this study, which is one of its limitations. The benefits of hydropower may also result in financial risks stipulated to its production volatility. Therefore, we propose that to minimize risks, the energy mix should be further extended, complementing hydropower with other clean energy sources of energy such as solar wind and geothermal energy. Moreover, the effect of other renewable resources such as wind, solar, and geothermal energy on EG and FD can be examined in a larger sample. Additionally, the association between HEPG and ecological footprint or carbon emission may be investigated. These findings can be evaluated in terms of the related countries and the relevant period. The research question at hand also can be analyzed in the context of the EKC hypothesis in terms of both developed and developing countries. Thus, the results obtained in this study may serve as a blueprint for future pertinent research endeavors.

Data Availability section

Data will be made available upon reasonable request.

CRediT authorship contribution statement

Assad Ullah: Supervision, Writing – review & editing, Visualization. **Betul Altay Topcu:** Writing – review & editing. **Mesut Dogan:** Conceptualization, Methodology, Supervision, Writing – original draft. **Muhammad Imran:** Writing – review.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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