



Promoting environmental sustainability: A policy perspective on hydroelectric power generation, foreign direct investments, and financial development

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ABSTRACT

In today's rapidly evolving world, characterized by the menace of global warming and the ever-pressing call for sustainable energy solutions, the trilogy of hydroelectric power generation, foreign direct investment, and environmental quality is a compelling and indispensable dimension; all of which necessitate simultaneous consideration. In this quest, this research article aims to explore the nexus between hydroelectric power generation, foreign direct investment, and sustainability—within the framework of financial development. To this end, we have utilized annual data of the world's ten largest hydroelectric power-generating countries in the year 2021 for the period 1992–2019, and utilize the Westerlund-Edgerton LM Bootstrap, Augmented Mean Group, and Dumitrescu-Hurlin panel bootstrap causality methods as our main econometrics' batteries. Based on the empirical outcomes that study entails that financial development, foreign direct investments, and increasing economic growth reduce the environmental quality. We observed that hydroelectric power generation is an important driving force on environmental quality. The empirical outcomes further infer that as the financial development levels of countries increase, the positive impact of hydroelectric power generation on environmental quality becomes more significant. The study findings will help policymakers to organize environmental quality strategies that are more realistic and accurate.

1. Introduction

Since the 1990s, global energy demand has been on the rise due to rapid industrialization, urbanization, and EG Ref. [1,2]. However, this surge in energy consumption has negative implications for our planet. It is widely recognized that the extensive utilization of fossil fuels leads to environmental hazards by releasing carbon dioxide (CO₂) emissions ([3–5]; Dogan et al., 2023; [6]). The significant levels of energy consumption in economies contribute to the emission of various greenhouse gases, resulting in severe impacts on climate change. Greenhouse gas emissions and climate change primarily stem from fossil fuel usage and human activities [7]; Pata and Kumar, 2021; [8]. Consequently, renewable energy's economic and environmental sustainability and its influence on EG and development have gained increasing attention, as

countries increasingly shift towards using renewable energy sources ([9, 10]; Dogan et al., 2022).

Accelerating the adoption and effective utilization of renewable energy is crucial for countries striving to achieve sustainable development goals (SDGs). Energy plays a pivotal role in economic development and social well-being, and renewable energy holds the key to a future free from the influences of climate change [11,12]. In the international context, an increase in commercial openness in terms of the trade relationship with renewable energy may lead to more energy consumption. It can be said that renewable energy helps the integration of developing and developed countries in international trade [13]. Countries that rely on renewable energy resources are likely to experience less vulnerability to economic crises as they reduce their dependence on imported fossil fuels [14]; Pata and Kumar, 2021.

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Carbon emissions are greenhouse gases released into the atmosphere as a result of human activities and directly affect environmental quality [15,16]. Carbon emissions resulting from processes such as the burning of fossil fuels, industrial production, and agricultural activities cause various negative effects, especially global climate change. Rising carbon emissions increase the greenhouse gas concentration in the atmosphere, bringing problems such as climate change and air pollution [6,17]. As a result, environmental problems such as unhealthy air quality, water and soil pollution, and loss of biodiversity arise. Therefore, steps such as reducing carbon emissions and switching to sustainable energy sources are important to preserve environmental quality and leave a healthier environment for future generations.

Fig. 1 shows the hydroelectric power generation of 10 countries' carbon emissions per capita in metric tons. From 1992 to 2019, the carbon emission amounts of countries have approached each other. There is not much change in the metric tons per capita carbon emissions of these countries in the period 1992–2005. Especially after 2012, the metric tons per capita carbon emissions of these countries began to decrease (see Fig. 1).

Hydroelectric power generation is a type of energy formed as a result of converting the kinetic energy generated by the flow of water into electricity [18]. Hydropower is an important energy resource in the renewable energy sector. Hydropower contributes to achieving renewable energy targets and supports water/energy supply security [19]. Hydroelectric power plants are preferred among various energy sources because they are reliable and require low capital. Hydroelectric power plants that generate electricity are environmentally friendly. The paper discusses the positive correlation between favorable environmental characteristics and FDI inflows, emphasizing the significance of implementing sustainable development practices and fostering a favorable investment climate., as they produce clean, renewable energy with high efficiency. They are essential in terms of energy affordability and provide long-lasting, domestically sourced resources that are not reliant on external factors [4].

As can be understood from Fig. 2, there is an increase in hydroelectric power generation in the top 10 countries that produce the most hydroelectric energy. The world hydroelectric power generation is 3089.505 TW-hours, and this energy production of 10 countries is 2106.663 TW-hours. These production capacities show that about 70 % of the world's hydroelectric energy is produced by ten countries. The maximum production, respectively, is approximately 18 %, %12, %11, %9, %6, %3, %4, %3, %2, and it was realized by China, Canada, Brazil, U.S.A., Russia, India, Norway, Japan, Sweden, and Turkey with a share of 1 %.

In a world where countries are increasingly integrated into each other in the context of globalization, reducing barriers to international trade further increases the importance of environmental regulations in shaping a country's comparative advantage [20]. Economic globalization has gradually gained momentum, which triggers the rapid spread of foreign direct investment worldwide [21]. In addition to foreign direct investment (FDI) 's contributions to the country's economy, another

important matter is its environmental impact. The impact of FDI on the environment manifests itself directly or indirectly. The introduction of FDI can positively affect EG. In contrast, higher EG rates can lead to higher pollution levels by enabling greater consumption of natural resources. Therefore, multinational companies choosing to move from a country with "strict" environmental standards to a country with "weak" environmental standards in order to minimize costs will lead to several problems [22]. Qamruzzaman [23] obtained a positive correlation between FDI inflows and environment, suggesting that FDI propels sustainable development practices and a conducive investment climate is in favor of environmental sustainability. The work of Duodo (2021), Izadi et al. [24] and Chaouachi and Balsalobre-Lorente (2023) also endorse similar outcomes in the literature. In another study, Pradhan et al. [25] studied the nexus between FDI and environmental degradation in the context of BRICS nations, and concluded that the use of clean technologies and attracting more direct foreign investment sponsor environmental awareness. Huo et al. (2023) highlighted the favorable impact of FD, TO (trade openness), and FD on environmental sustainability. They suggest that trade can be augmented via introducing lower-taxation policies, and enhancing competition pertaining to financial markets may boost environmental sustainability. Environmental sustainability calls for a balance between economic prosperity and ecological sustainability which is one of the major challenges confronted by the economies. As energy sources fuel our economies, they also traditional methods engender carbon footprints, especially traditional energy sources. Against this backdrop, this study attempts to determine whether hydropower, FDI and FD preserve environmental sustainability. The selection of these variables is based on the fact that hydropower appeases greenhouse gas emissions and bolsters energy security and FDI assists not only in attracting clean technologies but also aids in infrastructure development. It is also worthy of mentioning that the notion of "pollution havens," on behalf of FDI should not be ignored. The ultimate key lies in the fact that investments beneficial for the environment must be welcomed, necessitating carrots like tax breaks for clean investments, and sticks such as carbon taxes for polluters. A strong financial system assists in channeling funds towards advanced technologies that support sustainable practices. Measures such as green bonds and environmental disclosure regulations and carbon taxes are indicators of the transition toward green practices. Such practices empower investors to opt for investments that promote environmental goals.

Economies whose FDs are gaining momentum are growing on the one hand and demanding more energy sources on the other, which increases greenhouse gas emissions and turns into a universal problem and increases environmental concerns in all developing and developed countries [26]. Faced with environmental challenges, emerging markets strive for long-term structural transformations and use environmental regulations as the main policy tool for industrial improvement [27]. One of the important factors that increase carbon emissions in a country is FD that can influence environmental change and EQ (Konuk, 2023). Countries that want to achieve SDG are becoming more sensitive to environmental issues to achieve FD [28]. Because the financial sector

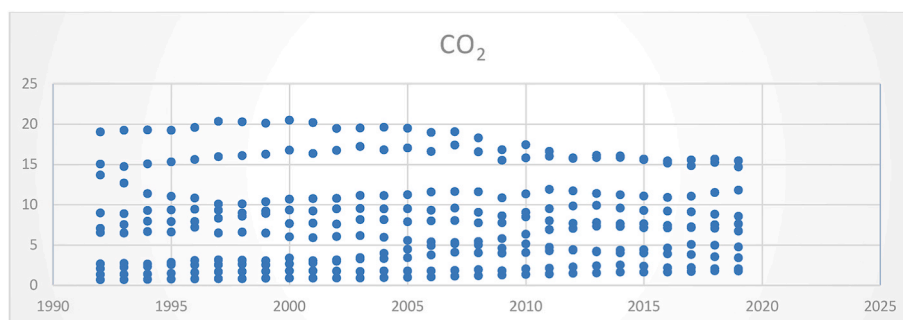


Fig. 1. Hydroelectric Power Generation of 10 Countries Carbon Emissions (metric tons per capita).

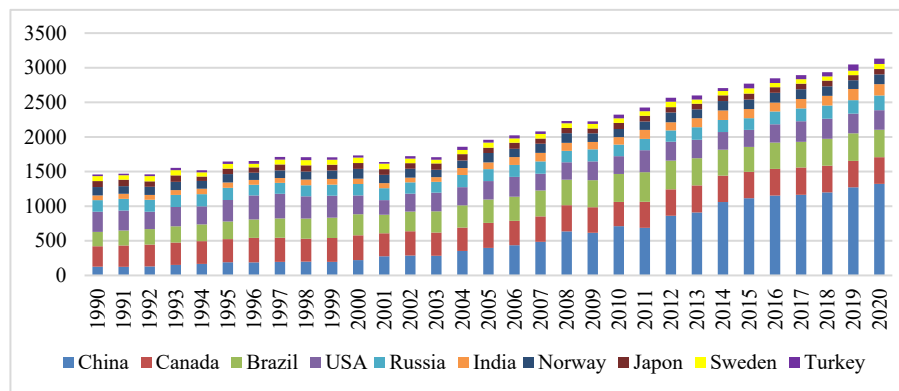


Fig. 2. Hydroelectric Power Generation of 10 Countries included in the Analysis (Terawatt-hours).

assumes a crucial role in the development and stability of an economy [29]. The financial sector of every country can be a force for economic expansion and stability, but the issue that needs to be emphasized is that the financial sector should not ignore the fact that it can also bring harmful environmental effects [30]. FD within a country, for instance, can provide a reduction in borrowing costs and financial risk, greater transparency between borrowers and lenders, access to abundant financial capital, and energy-efficient products as well as the latest technology [31]. The growth in the financial sector can promote the availability of resources for investment goals, which leads to industrial growth and the expansion of the production base. FD can help create new infrastructure facilities by stimulating industrial growth, which can positively affect energy consumption [32].

The relationship between renewable energy consumption and environmental quality is a frequently discussed topic. Many studies show that renewable energy has a positive effect on environmental quality ([33]; Ulucak et al., 2020; Alharthi et al., 2021; Alharthi et al., 2021 [34, 35]; Osman et al., 2023). On the other hand, there is insufficient research examining the relationship between hydroelectric power generation, a renewable energy source, and environmental quality (Bildirici and Gokmenoglu 2017; Destek and Aslan 2017; [16,36]). These studies were researched in terms of G7, US, UK, Malaysia, and Turkey countries. As a result, the link between hydroelectric power generation and environmental pollution has received very little attention in the literature.

This study aims to explicate the influence of hydroelectric power generation (HYDRO) and FDI on the clean environment. The study will also determine financial development's (FD) role on EQ. For this purpose, the ten largest hydropower-generating countries of the world (China, Canada, Brazil, U.S.A., Russia, India, Norway, Japan, Sweden, and Turkey) in the year 2021 were used and the data from the period of ranges from 1992 to 2019. In addition, the study would contribute to the literature in 5 different ways. i) There are quite few studies examining the association between hydroelectric power generation and the environment in literature. These studies did not include research on the largest hydroelectric energy generating sample. As a production capacity, about 70 % of the world's hydroelectric energy is produced by these 10 countries. In this context, the findings are crucial in terms of determining how hydroelectric energy has an impact on EQ. ii) No empirical studies examining the role of FD in the effect of HYDRO and FDI on the clean environment exist. In this context, this study will contribute to revealing new empirical findings related to this relationship and expanding the environmental literature. iii) There is no consensus in the empirical findings regarding the effect of FDI on the environment in the literature. In this study, the use of data from the ten developed and developing countries that produce the largest hydroelectric energy and the impact of FDI on the environment will give the opportunity to see and compare the impact of FDI on the environment on a country-by-country basis within the framework of the Pollution Haven Hypothesis. iv) The analysis results obtained from the study may be of a guiding

nature in eliminating the negative impacts of climate change through the production and use of clean energy. In addition, it would contribute to policy development aimed at reducing the magnitude of CO₂ emissions and increasing environmental protection, which are among the SDG of countries. The identification of other factors affecting carbon emissions will be able to help policymakers to regulate their EQ strategies more realistically and accurately. v) Deciphering the relationship among variables by the D-H panel bootstrap causality method is another contribution that the study can provide to the literature.

Following the introductory part of the study, literature summaries on carbon emission and hydroelectric power generation, FD, EG, the impact of FDIs on the clean environment has been presented in the second part. The third part includes the variables, dataset, model and method employed in the study. The fourth part consists of the empirical findings. The last part finalizes the study and offers relevant policy implications.

2. Literature review

2.1. Hydropower energy and environment

Hydropower is a renewable energy source that is widely used in many countries [37]. Increasing cheap hydroelectric power generation can contribute to achieving EG and SDG [38]. The rapid increase in pollution and CO₂ content in the atmosphere created by the industrial era leads to an increasing global warming and greenhouse effect. In addition, the increasing prices of fossil fuel resources and natural fuels, such as oil and gas, which are being depleted, have led to the shift towards renewable energy resources [39]. Hydropower usage has gradually expanded despite both its technical characteristics and environmental impacts. Hydropower assumes a main role in the transformation of the global energy system [15,40]. Another reason why hydroelectricity is considered one of the most important renewable energy resources is that it requires low capital, does not emit CO₂ compared to other energy sources, and the benefits it provides, such as being considered more reliable and effective, are taken into account [41]. It is also very important to strengthen the role of hydroelectric dynamics in mitigating CO₂ emissions [35].

According to the literature, assessing the connection between hydroelectric energy and CO₂ emissions is not easy. Studies have found that hydroelectric power generation reduces CO₂ emissions ([18,42]; Ulucak et al., 2020 [36]; Bilgi et al., 2021; Alharthi et al., 2021; Chan et al., 2022; Alsaleh and Abdul-Rahim, 2022; [43]) is included in the literature. Contrary to these studies, a positive association exists between hydroelectric power generation and CO₂ [44]; Pata and Kumar, 2021; [34], in addition, no significant association exists between both variables [45]. There are also studies indicating (2015; [46]). When the causality relationship results were examined; Bildirici (2014), in his study with Belgi, Icelandic and the UK data, could not find a significant causal relationship between HYDRO and CO₂. Lau et al. [47] Malaysia;

Bildirici and Gokmenoglu (2017) found a unilateral causality from CO₂ to HYDRO for the G7 countries. Destek and Aslan (2017) found a bilateral causality between CO₂ and HYDRO in terms of the UK and the USA.

2.2. Financial development and environment

Theoretically, the influence of FD on CO₂ emissions can be based on the following reasons: The first of these is the income effect, per capita income may increase due to FD, which may allow people to buy more energy-intensive goods, or vice versa [48]. Another effect is the scale effect (SE) provided by the rise in production. If FD in the production process paves the way for energy-intensive technologies, increases in carbon emissions can be seen. On the other hand, if FD encourages environmentally-friendly technologies, carbon emissions can fall. The capitalization effect related to investment is that if FD encourages investment in environmentally-friendly sectors, it can support EQ and contribute to reducing sustainable development problems [49].

There is no consensus in the research conducted on FD and EQ in the literature. In the studies in the first group of the research, it is seen that FD positively impacts EQ. In these studies, it is found that FD improves EQ by reducing CO₂ emissions ([50,51]; Alom and Uddin, 2017 [52–54]; Gokmenoglu et al., 2022; [55,56]). The second group consists of studies deciphering that no significant link exists between FD and CO₂ emissions [57–63]. The last group consists of studies that found that EQ decreases in places where FD is high, in other words, FD increases CO₂ emissions [64]; Al-Mulali et al., 2015; [65–70]; Ahmad et al., 2021; [17,71,72].

2.3. Foreign direct investment and environment

Two concepts regarding the relationship between FDI and pollutant emissions are gaining importance. These are; pollution haven (PHH) and pollution halo hypotheses [73]. According to the PHH, multinational companies will direct pollution-intensive industries to countries with less stringent environmental regulations to avoid high-cost regulatory compliance in their own countries [74]. This situation turns developing countries into "pollution havens" and these countries are exposed to more environmental pollution (EP) [75]. The pollution halo hypothesis assumes that multinational companies spread their clean technologies to developing/host countries through the export of modern technologies. Multinational firms have the latest technologies compared to their local counterparts and tend to spread clean technologies that are less harmful to the environment [76]. Then, FDI inflows can help mitigate environmental pollution. If the impact is indirect, FDI can indirectly affect pollutant emissions by affecting EG. The third concept that should be taken into account regarding the relationship of FDI on the environment is the SEs hypothesis [29]. FDI can provide capital to establish a new enterprise or expand the scale of existing enterprises. In this case, FDI will encourage production growth and provide an increase in pollution emissions. This type of effect is called the SE. As a result, multinational FDI can contribute to the host country's industrial production, and therefore, the overall pollution level, and a SE can occur to the extent that it increases environmental degradation (ED) [77]. With the introduction of FDI, both new technologies and modern management methods are introduced to the host country. Since most of the new technologies are more environmentally-friendly than those used in developing countries, foreign-owned companies using new technologies usually have higher environmental performance than local firms. Therefore, FDI can reduce the intensity of pollution emissions; as a result, pollution emissions will tend to decrease. This type of effect is usually called the technology effect [78].

FDI can positively and negatively affect the environment, based on which channel or size is dominant. The literature on the environmental influences of FDI uses various approaches and gives contradictory results. The negative and positive impacts of FDI entry on EP have been identified in the literature. Studies which asserted that FDI had a

negative influence on the environment by increasing greenhouse gas emissions (an increase in FDI increases ED; PHH) [4,29,64,79–87] is available. However, another expression that the FDI flow has a complex effect on ED, and studies that find that the final impact of FDI on the environment depends on the total impact of other factors, factors such as technology, company scale and structure, are also included in the literature ([88–92]; Yan and An, 2017; [93,94]). Studies arguing that the introduction of FDI has a positive influence on EP (a rise in FDI, reducing ED; the pollution halo hypothesis) are included in the literature [77,95–102]; Ahmad et al., 2021; [103–105].

2.4. Economic growth and environment

The association between EG and EQ is explained by the Environmental Kuznets Curve (EKC) assuming that the association between the environment and economic development is similar to the inverse U-curve [106]. According to Grossman and Krueger [107], a reduction in trade barriers would usually influence the environment by expanding the scale of economic activity, changing the composition of economic activity, and leading to a change in production techniques. The EKC hypothesis states that the level of EP will increase as a country's per capita national income grows, but it will begin to decrease as rising incomes exceed a milestone. In other words, it assumes that ED increases when per capita income is relatively low, but that it will start to decrease when per capita income reaches a certain point, a turning point [108, 109].

Many studies examined the association between EG and EP and there is no consensus between these variables. In the studies conducted in terms of the impact of EG and its relationship with the environment, different countries or groups of countries have been focused on. Numerous empirical studies indicate that the association between EG and environmental impact is positive [108,110–115]; Ahmed et al. 2021; [116–120]. In addition, studies depict a significant association between EG and CO₂ emissions but do not confirm the EKC hypothesis [121–124]. Nevertheless, an inverse association exists between EG and CO₂ emissions [125–128]. Studies showing that this is the case are included in the literature. The agri-food sector is vital to human livelihood, as it addresses global food crises. However, it is a fact that the agri-food sector is immune to environmental hazards; therefore, it should go hand in hand with environmental sustainability [129]. One of the primary challenges faced by the agricultural sector is sustainability. In this regard, the role of economic, energy, and environmental aspects is essential for sustainability [130,131]. Nabavi-Pelesaraei et al. [132] and Ghasemi-Mobtaker et al. [133] assert that uncertainty regarding energy efficiency, economic outcomes, and environmental issues poses a significant challenge to cultivation patterns. In a similar study, Moosavi-Nezhad et al. [134] found that abrupt climate changes and the increased demand for energy and food production contribute to food insecurities. Addressing the technical aspects of agriculture not only enhances agricultural yield but also improves energy efficiency, thereby reducing production costs [135].

3. Data and methodological framework

In this study, the effects of hydroelectric power generation (HYDRO), foreign direct investment (FDI), financial development (FD), and economic growth (GDP) on carbon emissions (CO₂) will be determined. This study used the largest hydroelectric power generating countries worldwide in 2021 (data for 1992–2019 were used (see Table 1)). These countries are China, Canada, Brazil, U.S.A., Russia, India, Norway, Japan, Sweden, and Turkey respectively.

In this study, the Augmented Mean Group (AMG) method was used to determine the long-term relationship between variables. There are two main reasons for choosing this method. First, the AMG method can address heterogeneity and provide a suitable framework for modeling situations where different subgroups may have different dynamic

Table 1
Definitions of variables.

Variables	Descriptions	Sources
CO ₂	CO ₂ emissions (metric tons per capita) Thus	WDI
HYDRO	Hydro Generation – TWh	Bp Statistical Review of World Energy
FD	Domestic credit to private sector by banks (% of GDP)	WDI
FDI	Foreign direct investment, net inflows (% of GDP)	WDI
GDP	GDP per capita (constant 2015 US\$) Thus	WDI

properties. Additionally, thanks to its ability to make parameter estimates, it can analyze time-varying effects more precisely. Secondly, this study used the largest hydroelectric power generating countries. This sample group consists of developed and developing countries. The impact of hydroelectric power generation on environmental quality may vary between developed and developing countries. In this context, this method, which can predict country-specific and panel results, was preferred.

The following model has been developed by taking the logarithm of the variables to predict the association between the variables.

$$CO_{2it} = \beta_0 + \beta_1 HYDRO_{it} + \beta_2 FD_{it} + \beta_3 FDI_{it} + \beta_4 GDP_{it} \theta_t \quad (1)$$

It is necessary to determine the cross-sectional dependence (CSD) in panel data analysis. The Breusch-Pagan LM test, developed by Breusch and Pagan [136], Pesaran scaled L.M. (to test CSD), was used in this study. CD_{LM} and Pesaran CD test developed by Pesaran [137], and Pesaran, Ullah, and Yamagata [138] developed by Bias-Corrected Scaled L.M. (LM_{adj}), the test has been applied. These tests used are shown in equations (2)–(5), respectively:

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

$$CD_{LM} = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^N (T\hat{\rho}_{ij}^2 - 1) \quad (3)$$

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij} \right) \quad (4)$$

$$LM_{adj} = \left(\frac{2}{N(N-1)} \right)^{1/2} \sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij}^2 \frac{(T-K-1)\hat{\rho}_{ij} - \hat{\mu}_{Tij}}{v_{Tij}} \sim N(0, 1) \quad (5)$$

This study will test the slope homogeneity after determining CSD. This test is determined by Δ tests calculated by Pesaran, Ullah, and Yamagata [138]. However, if serial correlation and heteroscedasticity exist in regression errors, Δ tests developed by Blomquist and Westerlund [139] are performed. The H.A.C. version of the homogeneity test created depending on the Delta test is expressed in Equations (6)–(9):

$$\Delta_{HAC} = \sqrt{N} \left(\frac{N^{-1} S_{HAC} - k}{\sqrt{2k}} \right) \quad (6)$$

$$S_{HAC} = \sum_{i=1}^N T(\hat{\beta}_i - \hat{\beta})' (\hat{O}_{it} V_{it}^{-1} \hat{O}_{it}) (\hat{\beta}_i - \hat{\beta}) \quad (7)$$

$$\hat{\beta} = \left(\sum_{i=1}^N T \hat{O}_{it} V_{it}^{-1} \hat{O}_{it} \right)^{-1} \sum_{i=1}^N \hat{O}_{it} V_{it}^{-1} X_i M_T Y_i \quad (8)$$

$$\hat{V}_{it} = \hat{\Gamma}_i(0) + \sum_{j=1}^{T-1} K \left(\frac{j}{M_{it}} \right) [\hat{\Gamma}_i(j) + \hat{\Gamma}_i(j)'] \quad (9)$$

In case of CDS, the 2nd generation panel unit root tests are used. In this context, Cross-Sectionally Augmented ADF (CADF) and Cross-Sectionally Augmented IPS (CIPS) panel unit root tests developed by Pesaran [140] were used. Pesaran [140] uses Equations (10) and (11) for CADF unit root test:

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + u_{it} \quad (10)$$

$$u_{it} = \gamma f_t + \varepsilon_{it} \quad (11)$$

CADF regression is used with Equation (12) if no autocorrelation exists in the factor or error term:

$$\Delta y_{it} = \alpha_i + \rho_i y_{i,t-1} + d_0 \bar{y}_{t-1} + d_1 \Delta \bar{y}_t + \varepsilon_{it} \quad (12)$$

If there is an autocorrelation in the factor or error term, the equation y_{it} and \bar{y}_{it} the 1st differences of are added and this equality is shown in Equation (13):

$$\Delta y_{i,t} = \alpha_i + \rho_i y_{i,t-1} + c_i \bar{y}_{t-1} + \sum_{j=0}^p d_{ij} \Delta \bar{y}_{t-j} + \sum_{j=0}^p \beta_{ij} \Delta y_{i,t-j} + \mu_{i,t} \quad (13)$$

in order to calculate the CIPS statistic in Equation (14), the averages of the t-statistics of the delayed variables are taken:

$$CIPS = \frac{1}{N} \sum_{i=1}^N CADF_i \quad (14)$$

Then, after the mentioned preliminary tests, Westerlund and Edgerton's [141] Panel L.M. bootstrap cointegration test based on the Lagrange test multiplier developed by McCoskey and Kao [142] was preferred.

$$\gamma_{it} = \alpha_i + x'_{it} \beta_{it} + Z_{it} \quad (15)$$

$$Z_{it} = \mu_{it} + V_{it} \quad V_{it} = \sum_{j=1}^t \eta_{ij} \quad (16)$$

The t-index in equation (16) is the time series and i is the cross-sectional unit, Z_{it} and it shows the term error. In Equation (17), Z_{it} the partial sum of the error term is S_{it}^2 , μ_{it} if the long-term variance of is $\hat{\omega}_i^{-2}$ it can be expressed with. The L.M. statistic in which the cointegration test tests the cointegration for the whole panel in econometric models with the bootstrap critical values of the L.M. test in the case of CDS is as follows:

$$LM_N^+ = \frac{1}{NT^2} \sum_{i=1}^N \sum_{t=1}^T \hat{\omega}_i^{-2} S_{it}^2 \quad (17)$$

In the case of CSD and slope heterogeneity in panel data, the AMG estimator developed by Eberhardt and Bond [143] and Eberhardt and Teal [144] is one of the appropriate methods. The AMG method is based on a two-stage process, and the first one is shown in Equation (18):

$$\Delta X_{it} = \delta_i + \beta_i \Delta Y_{it} + \gamma_i A_t + \sum_{t=2}^T \delta_i \Delta D_t + \varepsilon_{it} \quad (18)$$

The predicted model in the second stage is as in equation (19):

$$\hat{\beta}_{AMG} = N^{-1} \sum_{i=1}^N \hat{\beta}_i \quad (19)$$

in the second stage, shown in Equation (19), the time dummy variable is included in the regression for each horizontal cross-sectional unit. AMG estimates are obtained by taking the average of individual country estimates.

At the next stage, the association between variables was used in the bootstrap causality test of Dumitrescu and Hurlin (2012), which is the second-generation approach. In addition, this approach is ideal for the panel when it is $T > N$ or $T < N$. This booster causality test is based on the equation below:

$$y_{it} = \alpha_i + \sum_{k=1}^K \gamma_i^k y_{i,t-k} + \sum_{k=1}^K \beta_i^k x_{i,t-k} + \varepsilon_{it} \tag{20}$$

where K , α_i , β_i^k , and t denote the lag length, the countries, the slope coefficients, and time, respectively. In addition, two test statistics are known as \bar{W} and \bar{Z} are used in this procedure. They are expressed as follows:

$$\bar{W} = \frac{1}{N} \sum_{i=1}^N W_i \tag{21}$$

$$\bar{Z} = \sqrt{\frac{N}{2K}} (\bar{W} - K) \tag{22}$$

4. Empirical findings

In this part of the study, the findings on the relationship between HYDRO, FD, FDI and GDP are included.

Table 2 shows the outcomes of correlation analysis and descriptive statistics. According to the results, an inverse association exists between HYDRO and CO₂ ($r = -0.15$). On the other hand, a positive and strong correlation exists between FD and CO₂ ($r = 0.66$). In addition, a positive association exists between GDP and CO₂ ($p = 0.13$).

Table 3 shows the results of the CSD test for the variables of the model developed in the study. Due to the fact that their critical value is 0.05, "there is no CSD", the established hypothesis H₀ of the figure is rejected and there is a CSD for all series.

Table 4 presents the outcomes of slope homogeneity for this research. According to this test result developed by Blomquist and Westerlund [139], which expresses the existence of slope homogeneity, the hypothesis H₀ is rejected. In other words, slope heterogeneity exists for the model developed in the study.

In Table 5, it was investigated whether or not the variables CO₂, HYDRO, FD, FDI, and GDP used in the study were stationary. The second-generation Pesaran [140] CADF and CIPS tests in the case of CSD were performed. According to the results, all series are stationary at the first difference. In another expression, H₀, which is established in the form "series are unit-rooted" with the hypothesis is rejected.

In Table 6, the Westerlund-Edgerton LM Bootstrap (2007) test was performed to determine whether the series had a long-term cointegration relationship. Due to the fact that there are CDS, the Bootstrap-p value should be taken into account. In accordance with these results, in the model developed in the study, the series act together in the long run. With another expression, it is understood that the series has a cointegration relationship.

The coefficient estimation of the variables in the model developed in the research was examined with the AMG estimator (see Table 7). A negative and statistically significant relationship exists between hydroelectric power generation (HYDRO) and carbon emission (CO₂) ($p < 0.01$). In other words, increasing hydroelectric power generation reduces carbon emissions from the point of view of the countries studied in the study. Solarin et al. [4] China and India, Bello et al. [145] Malaysia,

Table 2
Summary statistics and correlation matrix.

	CO ₂	HYDRO	FD	FDI	GDP
Mean	7.917612	188.6333	598896	2.204462	9.440.12
Std. dev.	5.570691	196.8592	.1875439	2.253408	7.400.13
Min	.6900704	24.0099	.2308473	-5.061605	2.250.11
Max	20.46981	1272.538	.9188426	22.95396	8.840.14
Obs	280	280	280	280	280
CO ₂	1.0000				
HYDRO	-0.1554	1.0000			
FD	0.6632	-0.0287	1.0000		
FDI	-0.0380	0.1975	0.0801	1.0000	
GDP	0.1397	0.0345	0.0106	-0.0445	1.0000

Ummalla and Samal (2018) China, Sinaga et al. [146] found similar results for Malaysia.

A significant and positive association exists between FD and CO₂ ($p < 0.05$). In other words, FD has an increasing effect on carbon emission. These findings obtained by Pata [46] in Turkey; Shoaib et al. [147]'s D₈ and G₈ countries; Kihombo et al. [148]'s WAME economies; Ahmed, Zhang and Cary [149] it is consistent with the findings of the study conducted by the Japanese sample. Also, FDIs increase carbon emissions. In other words, as FDIs increase in terms of the countries used in the research sample, carbon emissions also increase. The findings obtained from Sapkota and Bastola [81]; Rafindadi et al. [82]; Opoku and Boachie [84]; comply with the findings of authors such as Pata et al. [87]. Lastly, a positive association exists between GDP and CO₂ ($p < 0.05$). Increasing economic growth enhances CO₂ emissions. Similarly, Baloch et al. [68] 59 B.R.I. countries, Majeed and Mazhar [150] 131 countries, Khan et al. [151] detected a positive association between EG and EQ for 184 countries.

Table 8 shows the results of the AMG estimator for the influence of hydropower generation on CO₂ in a country-specific way. Upon examining the analysis results, it is understood that the impact of hydroelectric power generation on CO₂ is statistically significant and negative in the United States, Russia, Norway, Japan, Sweden countries. Meaning, the rise in hydroelectric power generation boosts the EQ in these countries. The common characteristic of these countries is that their FD and the level of national income per capita are higher than the other countries used in the analysis. As a result, as countries' development level increases, hydroelectric power generation's positive impact on EQ becomes more significant.

Consistent with the panel results, increasing FD in Canada, Brazil, the United States, Norway and Turkey reduces EQ. Growth in the financial sector can increase non-renewable energy consumption by encouraging industrial growth, which can damage EQ. In addition, this situation can be associated with the fact that financial institutions fulfill the financial needs of individuals, causing a rise in the purchasing power of society.

From the point of view of Canada, Brazil and Sweden, there is a positive relationship between DFI and CO₂. Nonetheless, there is an inverse relationship between DFI and CO₂ from the point of view of Russia and Japan countries. The PHH can explain the detection of different results according to countries. Thus, the increase in GDP per capita for Canada, U.S.A., Norway, Sweden reduces CO₂, whereas the increase in GDP per capita for India, Turkey and Brazil also increases CO₂. The EKC hypothesis can explain this situation. Carbon emission increases when per capita income is relatively low, but when per capita income reaches a certain point, carbon emission begins to decrease. In other words, GDP usually increases CO₂ in developing countries and decreases CO₂ in developed countries.

In Table 9, the causality between the CO₂, HYDRO, FD, FDI and GDP variables was examined by the D-H bootstrap test. According to these results, there is a bilateral causality between CO₂ and HYDRO. Support and Aslan [152] have reached similar results for the U.K. and U.S. countries. In contrast, Lau et al. [47] Malaysia; Declarant and Gokmenoglu (2017) found a unilateral causality from CO₂ to HYDRO for the G7 countries. Besides, unilateral causality from FD to CO₂ is determined. These findings exhibit similarities with the findings of authors such as Kihombo et al. [148], Majeed and Mazhar [150], and Akinsola et al. [153]. Besides, a bilateral causality is determined between GDP and CO₂. These results comply with the findings of Sarcodie (2019) and Kihombo et al. Other researchers obtaining similar outcomes include Saqib [154]; Dogan and Shah [155]. Finally, unilateral causality from FDI to CO₂ is determined.

5. Concluding remarks

In this study, the influence of hydroelectric power generation and FDIs on the clean environment was examined within the framework of

Table 3
CSD test results.

Variables	CO ₂	HYDRO	FD	FDI	GDP
Breush-Pagan LM	875.12***	507.454***	564.654***	704.345***	833.533***
Pesaran scaled CD _{LM}	65.21***	56.653***	63.318***	85.653***	46.712***
Pesaran CD	15.231***	7.936***	15.343***	16.453***	16.352***

Note: * denotes significance at 1 % level.

Table 4
Slope homogeneity test results.

	$\tilde{\Delta}$	$\tilde{\Delta}_{adj}$
Model	12.748***	14.535***

* denotes significance at 1 % level.

Table 5
CADF and CIPS unit root test results.

Variables	CADF test statistics for constant & trend		CIPS test statistics for constant & trend	
	The Level	the first difference	The Level	the first difference
CO ₂	-1.345	-3.145***	-1.462	-4.174***
HYDRO	-1.259	-3.067***	-1.946	-5.264***
FD	-1.783	-4.194***	-2.285	-5.881***
FDI	-1.463	-3.458***	-1.845	-4.751***
GDP	-2.012	-4.821***	-1.594	-4.264***

Note: denotes significance at 1 % level.

Table 6
Westerlund-Edgerton LM bootstrap cointegration test results.

Model	L.M. Statistics	Asymptotic p-value	Bootstrap p-value
LMN ^T	12.861	0.0000	0.651

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

$CO_{2\ i,t} = \beta_0 + \beta_1 HYDRO_{i,t} + \beta_2 FD_{i,t} + \beta_3 FDI_{i,t} + \beta_4 GDP_{i,t} + \vartheta_{i,t}$			
Dependent Variable: CO ₂	AMG		
Dashboard	Coefficient	Standard Error	z
HYDRO	-0.0070624***	.0024005	-2.94
FD	2.526339**	1.25429	2.01
FDI	.0572393**	.0244485	2.34
GDP	7.7813**	3.9613	1.96
Wald chi ²	37.21		
Prob. > chi ²	0.000		

Note: ***, and** indicate 1 %, and 5 % significance levels.

the role of FD. The study used data of 10 of the world’s largest hydroelectric power generating countries 1992–2019. The study underscores that hydroelectric power generation is a driving force for EQ in the countries included in the sample. Specifically we determine that hydroelectric power generation’s positive impact on EQ becomes more significant as the FD levels and per capita national incomes increase.

This study offers a number of policy recommendations in the context of the analysis results. Policy implementations supporting hydroelectric power generation should be increased to realize clean environment activities in terms of sustainability of FD. In this context, increasing the number of hydroelectric power plants and the installation of hydroelectric power plants by the public sector of the private sector and incentives for the production of this energy are very important. Thus, the improvement of EQ can be achieved by increasing the use of renewable energy resources. The countries studied in the study should take measures to reduce the pressure on the environment while achieving their

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

$CO_{2\ i,t} = \beta_0 + \beta_1 HYDRO_{i,t} + \beta_2 FD_{i,t} + \beta_3 FDI_{i,t} + \beta_4 GDP_{i,t} + \vartheta_{i,t}$				
		Coefficient	Standard Error	Probability
China	HYDRO	.0022635	.0023013	0.325
	FD	6.161119	4.069685	0.130
	FDI	.1435322	.1334434	0.282
	GDP	2.232313	0.96	0.335
Canada	HYDRO	-0.0091592	.0076844	0.233
	FD	3.184008	1.359158	0.019
	FDI	.0749293	.0445033	0.092
	GDP	-7.350016	4.19016	0.079
Brazil	HYDRO	-0.0015558	.0016816	0.355
	FD	1.449604	.5465099	0.008
	FDI	.0433006	.0156629	0.006
	GDP	1.490012	2.21013	0.000
United States	HYDRO	-0.0094944	.0038601	0.014
	FD	12.5108	2.393427	0.000
	FDI	.1747145	.1796718	0.331
	GDP	-7.740013	2.547117	0.000
Russia	HYDRO	-0.032461	.0157168	0.039
	FD	4.211094	3.467157	0.225
	FDI	-0.3502909	.1547458	0.024
	GDP	1.180012	1.18012	0.136
India	HYDRO	.0003156	.0014543	0.828
	FD	-0.3586744	.4348428	0.409
	FDI	.0349472	.0267677	0.192
	GDP	5.3513	6.7714	0.000
Norway	HYDRO	-0.01247	.0071755	0.082
	FD	3.217255	1.380556	0.020
	FDI	.011379	.0346031	0.742
	GDP	-5.620012	3.39012	0.097
Japan	HYDRO	-0.0109594	.0075824	0.098
	FD	-1.228881	1.560151	0.431
	FDI	-0.4710044	.2828205	0.096
	GDP	.16120	1.34013	0.108
Sweden	HYDRO	-0.01777	.0060701	0.003
	FD	.3373318	.7685014	0.661
	FDI	.0287517	.0096077	0.003
	GDP	-1.22011	1.30012	0.000
Turkey	HYDRO	-0.0048285	.0039126	0.217
	FD	2.559082	.8786448	0.004
	FDI	.0212473	.044255	0.631
	GDP	2.50012	4.74013	0.000

Table 9
D-H panel bootstrap causality test results.

Hypothesis	W-stat.	Zbar-stat.	Bootstrapped p-value
HYDRO ≠ CO ₂	3.784	5.148	0.000
CO ₂ ≠ HYDRO	3.249	4.125	0.000
FD ≠ CO ₂	2.848	3.358	0.000
CO ₂ ≠ FD	1.037	0.365	0.724
FDI ≠ CO ₂	2.883	3.425	0.000
CO ₂ ≠ FDI	1.203	0.426	0.543
GDP ≠ CO ₂	5.295	8.036	0.000
CO ₂ ≠ GDP	6.310	9.976	0.000

EG goals. In addition, among the 10 largest hydroelectric power generation countries, especially developing countries, it is necessary to use environmentally-friendly technologies instead of outdated ones depending on fossil fuel consumption, to support these activities by the state and to invest in this area. In addition, sustainable hydropower

projects should be designed, as ED and problems related to electricity generation can negatively affect hydropower energy. It is also very important to strengthen the role of hydroelectric dynamics in minimizing carbon emissions. As a result, it can be said that hydropower energy is considered an important element in maintaining EQ.

The study highlights that the FD levels of countries are also important in making hydroelectric power generation effective on EQ. These countries need to have well-developed financial institutions to ensure sustainable development. It is especially crucial to allocate funds to financial research and development, promote green finance and facilitate the development of financial institutions. The findings indicate the necessity of financial reforms that will help protect or improve the environment to reduce the carbon emissions of FD. In addition, it would be useful for policy makers to direct financial resources to green energy consumption and production, and to provide incentives and support to projects and applications in this area by the government.

The contributions of foreign direct investments to economic growth may also bring environmental impacts. In order to reduce these negative effects, it may be beneficial to implement various strategies and adopt a green growth model. Investments should be directed to environmentally friendly technologies and applications. Changing to environmentally friendly production processes can reduce waste production by increasing energy efficiency. It is important to establish strong environmental standards and regulations across the country. Incentive tax policies and regulations can be effective in directing investors to environmentally friendly practices.

This study has several limitations in investigating the relationship between CO₂, HYDRO, FD, FDI and GDP. The findings obtained should be evaluated in terms of the countries studied in the research within the framework of the relevant period and the developed model. In future studies, the effect of hydroelectric power generation on EQ and the validity of N-shaped EKC curve can be examined from the point of view of different country groups. Finally, research on the impact of renewable resources such as hydropower energy, wind, solar and geothermal on EG and FD for developed and developing countries will further augment the energy literature and offer useful insights to the policymakers.

CRedit authorship contribution statement

Mesut Dogan: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Suna Sahin:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Assad Ullah:** Writing – review & editing, Writing – original draft, Validation, Conceptualization. **Adnan Safi:** Writing – review & editing, Conceptualization.

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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Data availability

The data that has been used is confidential.

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