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RESEARCH ARTICLE

Moderating the effect of globalization on financial development, energy consumption, human capital, and carbon emissions: evidence from G20 countries

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Abstract
The policy debate on the financial development and dynamic of carbon dioxide (CO_2) emission is topical. Globalization can affect this relationship by making financial investments in green energy and environment-friendly technology, as environmental sustainability is the primary concern for modern society. This study proposes a newly formulated conceptual framework to explore globalization's moderating role on exoplanetary variables (financial development, energy consumption, human capital, and gross domestic product) and CO_2 emission. We employed Fixed Effect Ordinary Least Squares (FE-OLS), Driscoll–Kraay standard error approach (D–K), and Dumitrescu and Hurlin's (2012) panel causality test. Our sample of the study comprised full and subsamples of G20 countries (excluding the European Union) from 1986 to 2018. The results indicated that financial development and human capital decreased carbon emissions, while GDP and energy consumption substantially increased carbon emissions during the study time. Further, globalization moderated the positive impact of financial development and human development on carbon emissions. A sustainable environmental agenda is achieved by a stronger financial system, encouraging green finance, and including technical education that improves production efficiency. However, globalization moderated the negative impact of energy consumption and GDP on carbon emission. Besides, we also reported the bidirectional causal relationship of GDP to energy consumption. Our empirical research provides new insights for policymakers and governments to formulate country-based policies to protect environmental quality while achieving sustainable economic goals.

Keywords Financial development · CO_2 emission · Globalization · Energy consumption · Human capital · Gross domestic product · Causality

JEL classification B26 · G0 · F6 · P28 · Q5 · E24 · C5

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Introduction

For the past few decades, the twin concerns of global warming and climate change have become subjects of debate, discussion, and concern among researchers, scholars, policymakers, governments, and private entities in the world. The purpose of this debate is to identify the primary hazards of climate change and global warming for the ecosystem and environment on a broad-scale (Eren et al. 2019; Wang and Chen 2014). Due to the significant increase in greenhouse gases (GHGs), which are a combination of carbon dioxide (CO_2), water vapor, nitrous oxide, methane, and chlorofluorocarbons, global warming and climate change are caused. Environment-based studies observed that the primary source of global warming and climate change is the increase in emissions of GHGs such as CO_2, methane, and nitrous oxide (Adger and Fischlin 2018; Özokcu and Özdemir 2017).

According to the International Panel on Climate Change, Fifth Assessment Report, human activities (after the industrial revolution growth in economy and population) are the primary sources of GHG emissions. This transformation is the cause of climate change, global warming, rising sea levels, melting ice caps, and floods (Adger and Fischlin 2018; Wang and Wang 2017). Many scholars and policymakers emphasized minimizing the impact of GHG emissions, which is considered a key factor of climate change and can be disastrous for the global environment (Bhattacharya et al. 2017; Mundaca 2017). If timely action is not taken to reduce the impact of GHG emissions, which is also a primary objective or goal of the Paris Climate Conference (COP21), the prevalence of GHGs could double from their pre-industrial levels by 2035. Economic activities are the primary source of CO_2 growth (a component of GHGs), and it is also a cause for alarm for policymakers and other stakeholders (Zhong et al. 2010; Ozturk and Acaravci 2013; Auffhammer and Carson 2008). The current situation indicates that if timely actions are not taken regarding GHG emissions, there are chances of a 2°C increase annually in global temperature. It is a consensus among environmental experts and scientists that an increase in GHG emissions will severely affect humanity and nature (Deschenes 2014; Mackay 2008).

Different economic and noneconomic factors, which include financial development (FD), gross domestic product (GDP), energy consumption (EC), globalization (GB), urbanization (URB), and human capital (HC) have been linked with CO_2 emissions. The past studies of Khan et al. (2017), Wang et al. (2020), and Akif and Asumadu (2019) also investigated the relationship between FD, GDP, EC, renewable energy, GB, URB, and HC with CO_2 emissions.

For the past few years, in the energy economics literature, the nexus between FD, economic growth, and CO_2 is highly focused. FD is crucial as it is the source of financial resources linked with economic growth and environmental quality (Khan et al. 2017). FD and economic growth are linked together as financial lending by institutions to private creditors can grow the economy in the long run (Khan 2001). However, it is still unclear whether FD causes environmental degradation or improvement. The past studies have no censuses among them; some researchers (Zhang 2011; Saud et al. 2020; Anton and Elena 2020) claim that FD leads to economic growth but causes CO_2 emissions. However, others (Shahbaz et al. 2013; Tamazian et al. 2009; Omoke et al. 2020) observe that efficient use of energy and FD reduce carbon emissions. Further, yet other researchers (Gök 2020; Amin et al. 2020) believe the difference in econometric techniques, sample sizes, and different FD proxies provide mixed results.

GB is a phenomenon that directly or indirectly links with human beings socially, economically, and politically. To achieve the desired growth of the economy, trade and investment are involved in industrialization and URB, causing environmental degradation. The conventional forms of energy, a vital source of economic activities, are the primary causes of CO_2 and SO_2 emissions (Mishkin 2009; Shahbaz et al. 2015). GB causes an increase in demand for goods and services, leading to increased FD activities (Gökmenoğlu and Taspinar 2016). Moreover, due to economic growth, GB leads to an increase in energy demand, which directly impacts environmental quality (Ozatac et al. 2017).

There is no consensus in the literature on GB and CO_2 emission; as Akadiri et al. (2019) argued, GB and energy usage are positively correlated with CO_2 emission. Further, GB increases the pace of the economic growth of emerging countries but is the cause of environmental degradation (Wijen and Van Tulder 2011). GB also causes FD, which positively impacts CO_2 emissions (Doytch and Uctum 2016). Conversely, countries with high and middle income have a negative relation between GB and CO_2 emissions (Dreher 2006; Jorgenson and Givens 2014; Li et al. 2015; Shahbaz et al. 2019).

Over the past few decades, the nexus between EC, economic growth, and CO_2 emissions have sought much attention. EC plays a vital role in economic growth, but it also causes environmental degradation (Owusu 2018). EC continuously causes ecological degradation in different countries (Ahmad et al. 2016). Moreover, the production of goods and services and economic growth increase energy demand, causing CO_2 emissions (Gerard et al. 2017). Economists are worried about the growth of the economy but simultaneously have concerns about environmental issues (Kaika and Zervas 2013). Similarly, some studies (Jacques and Keho 2016; Ahmad et al. 2016) used the environmental Kuznets curve (EKC) to analyze economic growth and its impact on environmental quality. Economic growth was observed initially by environmental degradation, but ecological degradation decreased after achieving a certain threshold. Numerous studies have mixed findings regarding the nexus of EC, economic growth, and CO_2 emissions (Jahangir et al. 2011; Riti et al. 2017a, b; Gao and Zhang 2014; Ahmad et al. 2016; Haseeb et al. 2018; Özokcu and Özdemir 2017).

CO_2 is associated with the HC of all countries. However, many analysts (World Economic Forum 2017) argued the inconsistency of outcomes related to climate change could be attributed to the omission of HC. Despite the role of HC in determining the EC and carbon emission of a country, most of the past EKC studies overlooked this variable (Khan 2020). Costantini and Monni (2008) stated that investing in HC is crucial for a sustainable environment. If a country's human development level is high, it directly impacts the environmental quality, education, and technical research, increasing the pro-environmental measures. All that can be achieved by generating environmental awareness and encouraging a healthy lifestyle (Lan et al. 2012; Bano et al. 2018). Khan (2020) stated that HC growth also correlates with GDP and CO_2 emissions, supporting the argument. At the initial stage of HC development, education promotes nonrenewable energy, causing more CO_2 emissions, but after reaching a particular threshold of schooling, it decreases pollution emissions by promoting new techniques of energy generation and environmental awareness.

Further, several past studies examined the direct impact of GB on FC, EC, GDP, and carbon emissions, such as the pioneering study of Mishkin (2009), which investigated the effect of GB on FD and GDP. He revealed that due to GB, financial markets opened for the foreign capital within the country and lowered the cost of borrowing, which led to more investment in different projects. Likewise, Kandil et al. (2015) argued GB positively impacts FD and GDP. Moreover, FD is an important determinant of GDP growth, as it boosts financial and economic activities, resulting in a rise in energy demand (Sadorsky 2011; Shahbaz et al. 2018a). However, GB and FD also have an impact on climate change or environmental quality. Zafar et al. (2019) analyzed the impact of GB, FD, and GDP on carbon emissions. Due to GB, financial activities raise the demand for EC, also causing carbon emission (Shahbaz et al. 2018a). However, some studies (Haseeb et al. 2018; Shahbaz et al. 2019) stated through GB, new technology can be exported from developed economies to developing economies, enhancing energy efficiency and minimizing carbon emission. Thus, the impact of GB can be negative or positive (Zafar et al. 2019). Nevertheless, none of the past studies use an indirect channel to examine the role of GB (moderation) between FD, EC, human development, and GDP on carbon emission. Therefore, unlike the past studies, we incorporated the moderating effect of GB in our framework.

This study focuses on The Group of Twenty or G20 countries, an international economic cooperation forum comprising two-thirds of the world population, with 80% of world GDP and three-quarters of global trade. Due to the rise in demand and EC in 2018, almost 1.8% CO_2 emissions were reported. In G20 countries, 82% of the energy mix came from fossil fuels, even though in 2018, there was a 5% rise in renewable energy. Due to CO_2 emission and global warming, annually, 16,000 fatalities and 142 billion losses in the economy were reported from 1998 to 2017. Globalization is another important factor that links with climate change as global trade and integration impact the environment positively and negatively. Moreover, G20 countries trying to promote green finance policies, such as Brazil and France, are only developing economics with climate-related disclosure, and on the other hand, China and India have green loan incentive policies. However, Indonesia is the only G20 country that has a climate risk assessment policy for financial institutions (Paramati et al. 2017; IEA, OECD 2018; Climate Transparency 2019; Brandi et al. n.d.).

Many past studies investigated the nexus of macroeconomic and other variables with CO_2 emission in the above argument. Many studies have contradictory outcomes regarding FD, economic growth, and EC on CO_2 emissions. Moreover, the relationship between GB, EC, and CO_2 also lacks consensus. Many research studies have mixed results regarding HC development and CO_2 but due to these mixed findings and lack of consensus, it is hard for policymakers to formulate the policy (Liu et al. 2019). Moreover, changes in the sample size, different econometric techniques, and proxies also cause mixed results (Amin et al. 2020). New climate-related financial and other economic policies in G20 countries still create a gap in evaluating the possible impact on environmental quality and posing questions, such as whether more factors impact CO_2 emissions. Based on the literature, we can assert that FD, GB, EC, human development, and economic growth impact CO_2 emissions. Therefore, the framework of our study is based on FD, GB, EC, GDP, HC, and CO_2 emission.

This study contributes to the body of existing literature, particularly in finance, energy, and ecology. First, this empirical study uses GB as the moderator to examine the impact of FD, EC, human development, and GDP on carbon emission. As per the author's knowledge, none of the past studies used GB as a moderator among explanatory variables and carbon emissions. Second, past studies are unclear regarding whether these above variables improve the environmental quality. To counter this climate change problem, the moderating role of GB between explanatory variables and carbon emission would give the policymakers and institutions a road map to formulate new regulations, policies, and environmental quality techniques. Third, this study employs Fixed Effect Ordinary Least Squares (FE-OLS) (Pesaran 2004), D–K (Driscoll and Kraay 1998) standard error approach for panel data, and the Granger causality test proposed by Dumitrescu and Hurlin (2012). Fourth, instead of a single country, the sample size of the study consists of a full and subheterogeneous sample that is composed of developed and developing G20 countries (excluding the European Union), namely, Australia, Argentina, China, Canada, France, Germany, Indonesia, India, Italy, Japan, Korea, Mexico, Russia, South Africa, Saudi Arabia, Turkey, UK, and the USA. Finally, this study uses the most extensive possible sample size from 1986 to 2018.

The rest of the study's road map is as follows: "Literature review" is related to past literature, "Data and methodology" is based on econometric techniques and data sources, second last section provides "empirical findings", and last section based on "Conclusion and policy recommendations".

Literature review

Many toxic gases and other harmful factors cause environmental degradation and climate change. Among these gases, CO_2 emission is the primary source of climate change and environmental pollution. Past studies showed no censuses between FD and CO_2 emissions. Therefore, this study investigates the impact of FD with the moderating and mediating role of GB and energy consumption on CO_2. Here, we report findings of some past studies exploring the relationship between CO_2 emission, financial development, GB, EC, GDP, and HC.

Relationship between financial development and CO_2 emissions

Since the first study on the environment employing the concept EKC by Grossman and Krueger (1995), many scholars and researchers have examined the nexus between FD and CO_2 emissions. Khan (2001) argued economic growth depends on financial institutions, as it lands on private creditors. Due to financial lending, economic activities take place, which also impacts environmental quality (Khan et al. 2017). Based on the past literature, the nexus of FD and CO_2 has no consensus. For instance, one school of thought argued FD improves the quality of the environment. Zioło et al. (2020) stated that conventional finance is replaced by sustainable finance, such as by imposing taxes on anti-environmental industries, providing funds for research and development (R&D), and low carbon technology, which back pro-environmental solutions. The study's findings indicated a strong relationship between financial instruments (FD of the R&D sector, environmental taxes) and GHGs. Ozturk and Acaravci (2013) examined the nexus of FD, EC, trade, and CO_2 emissions in Turkey. By employing a bound F-test for co-integration, results confirmed the existence of a long-run relationship between FD, GDP, trade, and CO_2. The findings also endorsed the existence of the EKC hypothesis in Turkey. In the case of Malaysia, Islam et al. (2013) reported financial energy could reduce energy use by increasing energy efficiency, which improves the quality of the environment. Similarly, in the case of Indonesia, Shahbaz et al. (2013) used the ARDL test to confirm that FD and trade openness improve the quality of the environment. Further, other studies (Tamazian et al. 2009; Omoke et al. 2020) also supported that FD reduces CO_2 emissions.

Conversely, the other school of thought supported the findings that FD causes environmental degradation. As Charfeddine et al. (2018) stated, FD offers low borrowing and interest rates with lesser constraints for development projects. Due to the low cost of borrowing, firms and the household sector easily invest in purchasing machinery, equipment, and durable goods, resulting in an increase in energy demand and causing carbon emissions (Zhang 2011). Khan et al. (2017) examined the nexus between FD, EC, and carbon emission in 34 upper-middle-income countries. Findings showed FD and EC caused carbon emissions. Likewise, Saud et al. (2020) explored the relationship between EC and carbon emission in one belt, one road countries. By employing the pool mean group test, results indicated FD adversely impacted the environmental quality. Shahzad et al. (2017) explored the relationship between carbon emissions, EC, trade openness, and FD in Pakistan. By using ARDL, results showed FD and trade openness caused 0.2475% and 0.165% carbon emissions, respectively. However, Salahuddin et al. (2015) reported an insignificant impact of FD on carbon emission.

Globalization as moderator

One of the ignored determinants affecting FD, EC, human development, GDP, and CO_2 emissions is GB in recent literature. The pioneering study of Mishkin (2009) investigated the impact of GB on FD and GDP. He argued that GB is a key factor that stimulates the financial sector, as it lowers the cost of borrowing, leading to more investments in different projects, thus increasing the GDP. Similarly, Kandil et al. (2015) indicated GB is directly related to FD and GDP. However, to attain economic growth, energy is a vital determinant for the production of goods and services and causes CO_2 emissions. In 25 developed economies, GB increased energy demand and caused carbon emission (Shahbaz et al. 2018a, b, c, d). To extend the argument, Shahbaz et al. (2017) analyzed whether economic growth causes environmental degradation, which is the source of GB and EC in Japan. Kamran et al. (2019) conducted a study to analyze the nexus of GB, economic factors, EC, and CO_2 in Pakistan. Using the ARDL approach, results indicated that GB, FD, and EC positively correlated with CO_2 emissions in the short and long run.

Further, Shahbaz et al. (2015) reported economic growth and energy cause CO_2 emissions, but FD and GB mitigate the impact of energy on the environment in the long run. Similarly, many studies indicated that GB and FD improve the quality of the environment. Zafar et al. (2019) and Shahbaz et al. (2018a, b, c, d) argued that GB improves environmental quality by making financial investments and conducting financial activities through trade. Moreover, studies (Haseeb et al. 2018; Shahbaz et al. 2019) found that through GB, new technology can be exported from developed economies to developing economies, enhancing energy efficiency. Thus, the impact of GB can be negative or positive. Zafar et al. (2019) examined the impact of FD and GB on CO_2 based on the EC of OECD countries. The outcomes of the study indicated FD and GB enhance the environmental quality by reducing the CO_2 effects. Zaidi et al. (2019a, b) conducted a study on Asia-Pacific Economic Cooperation (APEC) countries using GB, FD, and CO_2 emissions as determinants. By using the CUP-FM and CUP-BC approaches, results showed that FD and GB reduce the effect of CO_2 emissions. However, economic growth and EC cause CO_2 emissions, as found by a study conducted in India by Shahbaz et al. (2015). The results indicated the EC caused CO_2 emissions, but FD and GB mitigate the impact of energy on the environment in the long run.

In the light of the above literature, it is evident that many past studies examined the direct relationship of GB with FD, EC, GDP, and carbon emission. It is clear that GB is a key determinant that impacts FD and carbon emission. Now, the world is like a global village; though countries are making combined efforts for the development of the economy, these efforts are also causing harm to the global climate. Therefore, the role of GB is very important to attain sustainable economic development as it can help in green investment, facilitate the efficient use of energy, and increase human development. Nevertheless, without any proper econometric investigation, it is hard to identify the moderating impact of GB on the above determinants. Therefore, unlike the past studies, we have formulated a new framework by incorporating GB as a moderator to investigate the impact of FD, EC, human development, and GDP on carbon emission.

Energy consumption and CO_2 emissions

Energy is crucial for the growth and development of the economy because it is used as input in producing goods and services. Due to high growth in emerging economies, the energy demand increases, which is also alarming for environmental quality (Mukhtarov et al. 2020). FD plays a vital role in economic growth and considers it a determinant that increases energy demand. As FD works as fuel in the economy, it provides investment and FDI, minimizes financial risk and cost of borrowing, increases transparency, and stimulates energy demand (Sadorsky 2010). Moreover, Zhang (2011) found that the industrial sector invests in machinery and equipment, increasing energy usage and CO_2 emissions.

Likewise, Chen et al. (2016) explored the nexus of EC, GDP, and carbon emission in 188 countries from the period between 1993 and 2010. By employing a vector error correction model (VECM), results showed unidirectional causality from EC to carbon emission. Further, Khan et al. (2017) also analyzed the nexus of EC and carbon emission in 34 countries. Results indicated a direct relationship between EC and carbon emission. To extend the argument, Ahmad et al. (2016) examined the long- and short-run relationship between EC, GDP, and carbon emission in India. By employing the ARDL approach, results confirmed the existence of EKC at the aggregated and disaggregated levels. Moreover, EC is a cause of carbon emission. For it, Riti et al. (2017a, b) studied the impact of EC and FD on carbon emIT issions from 90 countries. By applying the dynamic ordinary least squares (DOLS), findings showed that EC and GDP are the main drivers of environmental degradation. Further, some researchers (Jahangir et al. 2011; Gao and Zhang 2014; Ahmad et al. 2016; Haseeb et al. 2018; Özokcu and Özdemir 2017) also studied the nexus of EC and carbon emission and confirmed that energy is the main source of carbon emission.

Human capital and CO_2 emissions

Costantini and Monni (2008) examined the role of human development, economic growth, and sustainable development by using the Resource Curse Hypothesis (RCH) and EKC. Outcomes endorsed the investment in HC and institutional quality to build a sustainable development path. Similarly, Lan et al. (2012) also confirmed that the impact of financial direct inflow (FDI) on CO_2 emissions is highly dependent on HC.

Moreover, areas with low HC have high CO_2 emissions due to FDI. Asghar et al. (2020), therefore, supported increasing the HC. Bano et al. (2018) conducted a research study in Pakistan to analyze the relationship between HC and CO_2 emissions. Using the ARDL and VEC model, results suggested that a long-run relationship exists between HC and CO_2 emissions. Furthermore, it has been suggested that education can improve the HC, which can encourage a reduction in CO_2 emissions. Khan (2020) used the datasets of 122 countries to explore the relationship of ED and CO_2 with human development. The findings initially reported an increase in the HC causes more EC, but additional schooling reduces the CO_2 emissions after achieving a particular threshold. Yao et al. (2020) investigated the nexus of HC and CO_2 in 20 OECD countries. Long-run estimated results indicated that additional tertiary schooling increases CO_2 emissions, but another additional tertiary education year helps reduce the CO_2 emissions.

The findings of studies by Bashir et al. (2019) and Sarkodie et al. (2020) differed from the previous research as results indicated that HC, EC, trade, income level, and natural resources worsened the carbon and environmental degradation functions in China.

Economic growth and CO_2 emissions

Environmental degradation is a global phenomenon that is a hazard to sustainable development. However, economic growth plays a primary role in both sustainable development and changes in the climate. The determinant or proxy of economic growth is the GDP. Growth in GDP can be achieved when economic activities occur in the form of producing goods and services, although these activities cause environmental degradation. Grossman and Krueger (1991) conducted a study on the nexus of economic growth and environmental degradation using a sample size of 42 countries. The study results indicated that growth in economic activities initially caused environmental degradation, but the same started to decline after reaching a certain threshold. Akif and Asumadu (2019) analyzed the nexus of economic growth, EC, FD, and ecological footprint. Using AMG and heterogeneous panel causality methods, results indicated an inverted U-shaped relationship between economic growth and ecological footprint. Mahmood and Alkhateeb (2017), Moutinho et al. (2017), and Shahbaz et al. (2016) also showed the U-shaped inverted EKCs in Saudi Arabia, Portuguese and Spanish economies, and global economies, respectively.

Although Özokcu and Özdemir (2017) investigated the nexus of income and CO_2 emissions in the context of EKC in 26 OECD countries, the results are not supported by the EKC hypothesis, as their models showed an N-shape relationship. This indicated that environmental degradation is not solved automatically by economic growth. Owusu (2018) examined the nexus of EC, economic growth, and CO_2 emissions in Ghana. Using the ARDL approach, results indicated that energy consumption is vital for economic growth, causing CO_2 emission in Ghana. Charfeddine et al. (2018) noted that economic growth strongly links with EC, which adversely affects Qatar's environmental policies. A summary of the literature is given in Table 1.

Figure 1 represents the conceptual framework of the study, which indicates the moderation effects between variables. This empirical model shows the moderating effect of GB on FD, EC, HC, GDP, and CO_2.

Data and methodology

Sample size and thermotical model

This empirical research uses secondary data. The sample size is selected based on the availability of data. The data sample size consists of 33 years from 1986 to 2018, including 627 panel observations and 19 cross-sections. The sample of the study is based on annual data, which is from G20 countries. The block of G20 countries includes developed and developing countries (excluding the European Union), which are as follow: Australia, Canada, France, Germany, Italy, Japan, Republic of Korea, UK, USA, Argentina, Brazil, China, India, Indonesia, Russia, Mexico, Saudi Arabia, South Africa, and Turkey. This study uses a full sample based on 19 countries and subsamples for 10 developing countries, subsample A, and nine developed countries, subsample B. The framework of our models is specified as follows:

$$CO_2 = f\ (FD, GB, EC, HC, GDP, FD{*}GB) \tag{1}$$

$$CO_2 = f\ (FD, GB, EC, HC, GDP, EC{*}GB) \tag{2}$$

$$CO_2 = f\ (FD, GB, EC, HC, GDP, HC{*}GB) \tag{3}$$

$$CO_2 = f\ (FD, GB, EC, HC, GDP, GDP{*}HC) \tag{4}$$

This study obtained the annual secondary data from various sources, shown in Appendix Table 10. CO_2 emission is a dependent variable of the study, whereas FD, EC, HC, and GDP are independent variables. Besides, GB is the moderators of the study. All variables (except the FD index and GB index) are transformed into a natural logarithm form. For FD, which is the main explanatory variable of our research, similar to past studies (Shahbaz et al. 2013; Tamazian et al. 2009; Omoke et al. 2020) we expect a positive impact on CO_2 emissions. Past studies (Mukhtarov et al. 2020; Sadorsky 2010; Xu et al. 2020; Shahbaz et al. b; Shao et al. 2019) showed EC is the cause of CO_2 emissions. Based on these outcomes, we expect a positive impact of EC on CO_2 emissions in G20 countries. GB, which is a booster for the economy, can improve the environmental quality by making investments and conducting trade. Therefore, like past studies (Zafar et al. 2019; Shahbaz et al. 2018a, b, c, d), we expect GB to negatively impact CO_2 emissions.

HC plays a vital role in optimal EC, green economy, and environmental quality. It is also crucial in reducing CO_2 emissions through education. Following some studies (Costantini and Monni 2008; Lan et al. 2012; Bano et al. 2018; Khan 2020), a negative correlation between HC and CO_2 emission is indicated. Hence, we also assume a negative relationship between HC and CO_2 emissions. Past studies (Akif and Asumadu 2019; Mahmood and Alkhateeb 2017; Moutinho et al. 2017; Shahbaz et al. 2016; Özokcu and Özdemir 2017; Charfeddine et al. 2018) report a positive relationship between GDP and CO_2 emission. We expect a positive impact of GDP on CO_2 in G20 countries.

Further, we use GB as a moderator to check the impact of FD, ECP, HC, and GDP on CO_2 emission, which is represented as follows: $(FD_{it} * GB_{it})$, $(EC_{it} * GB_{it})$, $(HC_{it}{*}GB_{it})$, and $(GDP_{it}{*}GB_{it})$. We expect $(FD_{it} * GB_{it})$ and $(HC_{it}{*}GB_{it})$ to be negatively correlated with CO_2; however, $(EC_{it} * GB_{it})$ and $(GDP_{it}{*}GB_{it})$ will positively correlate with CO_2 emission.

Table 1 Summary of literature of CO_2 emissions, energy consumption, and economic growth

Scholar name and year	Size of sample and region	Econometric technique	Findings
Bosah et al. (2020)	15 countries including G7 countries (1971–2014)	NARDL and nonparametric causality test	Long-run nonlinear co-integration exists in Cameron, Congo Republic, Zambia, Canada, and the UK. However, Granger causality indicates the existence of volatility.
Ali et al. (2019)	USA (1973–2015)	Wavelet correlation, wavelet covariance, maximal overlap discrete wavelet transforms	EC is positively correlated with CO_2 in the long, medium, and long run. Unidirectional causality exists between ECP and CO_2.
Asumadu-Sarkodie and Owusu (2017b)	Ghana (1972–2012)	ARDL	Unidirectional causality relationships exist between CO_2 and ECP, whereas there is a bidirectional causality relationship between electricity production and hydroelectric to CO_2 emission.
Armeanu et al. (2019)	11 countries from Central and Eastern European states (2000–2016)	Panel data regression (fully modified and dynamic ordinary least square)	In a nonlinear and linear relationship, GDP, ECP, and REC are correlated. Although, GDP is positively correlated with CO_2.
Owusu (2018)	Ghana (1960–2015)	Toda–Yamamoto and Granger causality test	All the variables are co-integrated with each other. In the Granger causality test, there is a feedback relationship between ECP and CO_2.
Bakirtas and Akpolat (2018)	Emerging markets (1971–2014)	Dumitrescu–Hurlin panel Granger causality test	There is Granger causality between GDP and ECP and between URB and ECP and GDP.
Jacques and Keho (2016)	12 countries (1971–2010)	Bound test to co-integration and Granger causality test	In the long run, ECP and GDP cause CO_2, and in the short-run, GDP causes CO_2 in Congo Democratic Republic, Nigeria, and Ghana.
Saidi and Hammami (2015)	58 countries (1990–2012)	Dynamic panel data	GDP is positively correlated with ECP, and CO_2 is positively correlated with ECP.
Cowan et al. (2014)	5 BRICS countries (1990–2010)	Panel causality test	A bidirectional relationship exists in India between CO_2 ECP.
Hooi and Smyth (2010)	5 ASIAN countries (1980–2006)	Panel VEC model	Unidirectional Granger causality exists in the long run between ECP and GDP, although in the short run, it is seen between CO_2 emission and ECP.
Summary of literature of financial development, energy consumption, and CO_2			
Khan et al. (2017)	34 countries (2001–2014)	VECM model GMM	Mixed results for FD, CO_2, GDP, and ECP.
Eren et al. (2019)	India (1971–2015)	Maki co-integration, DOLS test, and VECM	FD, GDP, and RECP are positively correlated, and bidirectional relation exists between FD, GDP, and RECP.
Saud et al. (2020)	1 belt, 1 road countries (1990–2014)	PMG	Feedback effects of FD and GB on CO_2.
Zhang (2011)	China	Co-integration theory, Granger causality, variance decomposition	FD is positively associated with CO_2 emission.
Omoke et al. (2020)	Nigeria (1971–2014)	NARDL	FD is negatively correlated with CO_2.
Ozturk and Acaravci (2013)	Turkey (1960–2007)	Bounds *F*-test for co-integration test yield	No significant effect of FD on CO_2 is seen but the EKC hypothesis is supported in Turkey.
Islam et al. (2013)	Malaysia (1971–2009)	VECM	ECP impacts the GDP and FD in the short and long run.
Shahzad et al. (2017)	Pakistan (1971–2011)	ARDL	FD is positively correlated with CO_2 in the short and long run, although a unidirectional relationship exists between FD, ECP, and CO_2.
Summary of literature of globalization energy consumption, financial development, and CO_2			
Shahbaz et al. (2018a, b, c, d)	25 developed economies (1970–2014)	Westerlund co-integration, common correlation effect means group and augmented mean group test	GB cause of CO_2 emissions.
Haseeb et al. (2018)	BRICS countries (1995–2014)	Westerlund co-integration and DSUR test	ECP and FD are positively correlated with CO_2, whereas GLOB and URB are negatively correlated. There is a bidirectional relationship between ECP, FD, and GDP with CO_2, and a unidirectional relationship of GLOB and URB with CO_2.
Kamran et al. (2019)	Pakistan (1971–2016)	ARDL	FD, ECP, and GLOB are positively correlated with CO_2.
Zafar et al. (2019)	OECD (1990–2014)	Westerlund co-integration, continuously updated fully modified ordinary least squares and continuously updated bias-corrected test	GLOB and FD improve environmental quality. Moreover, a bidirectional relationship between EC and CO_2 exists, whereas there is a feedback relationship between GDP, GLOB, and CO_2.

Table 1 (continued)

Scholar name and year	Size of sample and region	Econometric technique	Findings
Shahbaz et al. (2019)	87 countries (1970–2012)	Cross-correlation approach	U-shaped relationship EKC between GLOB and CO_2 exists.
Zaidi et al. (2019a, b)	OECD (1990–2016)	Continuously updated fully modified ordinary least squares and DSUR	There is a positive correlation between GLOB and HC with FD. Feedback results of GLOB, GDB, and HC on FD exist.
Summary of literature of human capital and CO_2			
Costantini and Monni (2008)	(1970–2003)	2SLS	Intuitional quality and human development are positively correlated with environmental quality.
Lan et al. (2012)	China	Pool regression	FDI impact on CO_2 is correlated with HC.
Asghar et al. (2020)	Pakistan (1995–2017)	ARDL	A long- and short-run relationship exists between ECP, HCI, and air pollution.
Bano et al. (2018)	Pakistan (1971–2014)	ARDL and VECM	A long-run relationship exists between HC and CO_2, whereas the Granger causality shows a bidirectional relationship.
Khan (2020)	122 counties (1980–2014)	Hansen threshold model	HC improves the environmental quality.
Yao et al. (2020)	20 OECD countries (1970–2014)	Panel AMG and CCEMG	HC initially causes CO_2 emission, but after reaching a certain threshold, it reduces CO_2 emission.
Bashir et al. (2019)	Indonesia (1985–2017)	VECM	No causality relationships exist between HC, CO_2, GDP, and ECP.
Sarkodie et al. (2020)	China (1961–2016)	SIMPLS, ARDL	HC and ECP are correlated with CO_2. An increase in RECP and HC reduces CO_2 emissions.

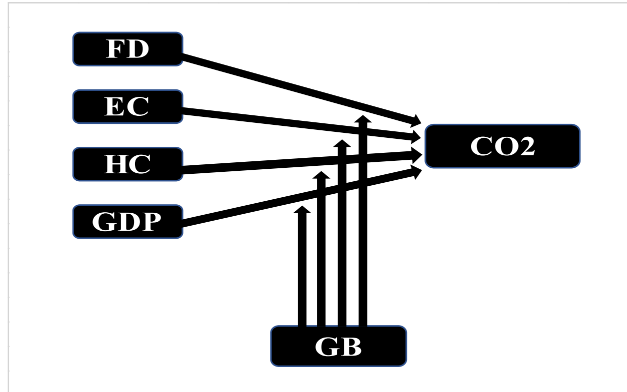

Fig. 1 Conceptual framework

To examine the impact of independent variables on CO_2 emission, our research is based on the following equation:

$$CO_{2it} = \beta 0_{it} + \beta 1_{it}FD_{it} + \beta 2_{it}GB_{it} + \beta 3_{it}EC_{it} + \beta 4_{it}HC_{it} + \beta 5_{it}GDP_{it} + \mu_{it} \quad (5)$$

In Eq. (2), t represents time period 1986 to 2018, i indicates cross-sections, ln shows the natural logarithm, and β is the elasticity. For example, $\beta 1$ indicates the elasticity of CO_2 emission for FD, which is expected to be a positive value since CO_2 emission is directly proportional to FD in G20 countries.

Empirical modeling

The econometric equations, which represent the moderating effect of GB on FD, EC, HC, GDP, and CO_2 emissions, can be as follows:

$$CO_{2it} = \beta 0_{it} + \beta 1_{it}FD_{it} + \beta 2_{it}GB_{it} + \beta 3_{it}EC_{it} + \beta 4_{it}HC_{it} + \beta 5_{it}GDP_{it} + \beta 6_{it}FD_{it}{*}GB_{it} + \mu_{it} \quad (6)$$

$$CO_{2it} = \beta 0_{it} + \beta 1_{it}FD_{it} + \beta 2_{it}GB_{it} + \beta 3_{it}EC_{it} + \beta 4_{it}HC_{it} + \beta 5_{it}GDP_{it} + \beta 6_{it}EC_{it}{*}GB_{it} + \mu_{it} \quad (7)$$

$$CO_{2it} = \beta 0_{it} + \beta 1_{it}FD_{it} + \beta 2_{it}GB_{it} + \beta 3_{it}EC_{it} + \beta 4_{it}HC_{it} + \beta 5_{it}GDP_{it} + \beta 6_{it}HC_{it}{*}GB_{it} + \mu_{it} \quad (8)$$

$$CO_{2it} = \beta 0_{it} + \beta 1_{it}FD_{it} + \beta 2_{it}GB_{it} + \beta 3_{it}EC_{it} + \beta 4_{it}HC_{it} + \beta 5_{it}GDP_{it} + \beta 6_{it}GDP_{it}{*}GB_{it} + \mu_{it} \quad (9)$$

Cross-sectional dependency test

A panel-based study has chances of cross-sectional dependency (CD) issues. Overlooking or without taking corrective action, issues of CD data can forecast biased results and misleading information. Therefore, following some studies (Saud et al. 2018), before probing stationarity properties of the framework, the CD test must be conducted. This empirical study using the Lagrange multiplier (LM) and cross-sectional approach suggested by a previous study (Pesaran 2004) is represented as follows:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=0}^{N-1}\sum_{j=i+1}^{N}\rho_{ij}\right) \quad (10)$$

Here, CD represents the cross-sectional dependence, T indicates the time, and N is the cross-sectional correlation. Moreover, between i and j, the cross-sectional correlation of errors is defined by ρ_{ij}. To investigate the CD, we use the following equation (LM test):

$$y_{it} = \alpha_{it} + \beta_i x_{it} + \mu_{it} \quad (11)$$

Here, i represent the cross-sections and t indicates time. For both methods, the null hypothesis indicates the cross-sections between the variables are independent, and the alternative hypothesis explains cross-sections are dependent on each other.

Panel unit root test

After confirming the cross-sections between the variables through the CD test, the next step is to examine the variables' integration order. Therefore, we use the second generation Cross-sectional augmented Im-Pesaran-Shin and Cross-sectional augmented Dickey-fuller statistic (CIPS and CADF) unit root test by Pesaran (2007). These tests address cross-sectional issues while examining the unit root order of variables. The CIPS test equation is as follows:

$$y_{it} = \alpha_{it} + \beta_i x_{it-1}\rho_i T + \sum_{j=0}^{n} {}_{it}\Delta x_{i,t-j} + \mu_{it} \quad (12)$$

Here, x_{it} and μ_{it} represent variables and residuals; moreover, i and t are the cross-section in and time in the panel data. The null hypothesis for CIPS and CADF explains the data series have unit roots and the alternative hypothesis indicates the stationarity of the data. The CADF is used to estimate the CIPS test, as follows:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} CADFi \quad (13)$$

Panel causality test

To conduct the causality analysis, we adopt the test by Dumitrescu and Hurlin (2012), which is based on the 1969 Granger test (individual Wald statistic averaged non-causally across the cross-section). Empirically, we estimate this test as follows:

$$y_{it} = \alpha_i + \sum_{j-1}^{J}\lambda_j^i y_{i(t-j)} + \sum_{j-1}^{J}\beta_j^i X_{i(t-j)} + \mu_{it} \quad (14)$$

Here, x and y represent the number of observations, while β_{ji} and λ capture autoregressive parameters and regression coefficients. The null hypothesis shows no causal relationship between the variables and the alternative hypothesis indicates the relationship between the selected variables.

Panel estimation techniques

We employed Pesaran's (2004) FE-OLS, which have individual intercepts and also allow for heterogeneous serial correlation across panel data variables. Traditionally, to estimate the results for panel data, we use a fixed or random-effects model. However, the random-effects model is suitable for unobserved heterogeneity between cross-sections due to the constant variables over time but varies among the cross-sections. Thus, we consider that the random effect model is appropriate for large cross-sections N, and the cross-sections are randomly used for the given sample (Hadri 2000). Further, the fixed-effects model addresses omitted variables and keeps them constant over time for cross-sectional heterogeneity, so the fixed-effects model is suitable for small cross-sections N (Arellano 2003). Our study consists of (N = 19) cross-sections having six explanatory variables (k = 6) with 33 observations (T = 33). Hence, similar to a previous study (Anwar et al. 2021), our sample data indicates that the size of cross-sections is less than observations $N < T$; therefore, we select the FE-OLS.

Moreover, for confirmation of our findings, similar to Ullah et al. (2021), we also use Driscoll and Kraay's (1998) standard error approach for G20 countries to gauge the impact of explanatory variables on CO_2 emission (with the role of moderation and mediation). The D–K technique addresses the issue of CD for the robust estimator. Further, we can take an average of products between explanatory variables and residuals and then use the weighted heteroscedasticity and autocorrelation consistent estimator (HAC) values with a stranded error that was recently incorporated. It is considered one of the best techniques to address the heteroscedasticity and spatial and serial dependency in data (Jalil 2014; Özokcu and Özdemir 2017). Finally, D–K also handles balance and unbalanced panel and missing values. It captures the general form of CD and temporal dependence. The estimation of the equation for pooled ordinary least squares is as follows:

$$CO_{2it} = \alpha_o + X_{it}^{*}\beta + \mu_{it} \quad (15)$$

Here, CO_2 is the dependent variable, X indicates a set of control variables, i = 1, 2, …19 (19 countries of G20 block), and t represents the time period (t = 33).

Empirical results and discussion

Table 2 represents the descriptive statistics for panels A, B, and C. In panel A, the mean value of CO_2 (indicating the quality of

Table 2 Descriptive statistics

	CO_2	FM	GB	EC	HC	GDP
Panel A (G20)						
Mean	1.77	0.55	66.78	7.84	2.79	27.87
Median	2	0.5	67.3	8.1	2.8	27.8
Maximum	3.2	1	91.1	9	3.8	30.5
Minimum	−0.6	0	30.9	5.8	1.4	26
Standard deviation	0.87	0.21	13.72	0.79	0.63	1.01
Skewness	−0.57	0.19	−0.41	−0.57	−0.18	0.37
Kurtosis	2.46	1.93	2.5	2.49	1.77	2.75
Panel B for developing countries						
Mean	1.36	0.39	57.4	7.34	2.31	27.34
Median	1.37	0.4	60.3	7.3	2.3	27.3
Maximum	3.2	0.6	73	8.9	3.5	30
Minimum	−0.6	0	30.9	5.8	1.4	26
Standard deviation	0.88	0.11	10.24	0.75	0.43	0.82
Skewness	0	0.04	−0.68	0.11	0.44	0.66
Kurtosis	2.14	3.24	2.65	2.34	2.8	3.32
Panel C for developed countries						
Mean	2.23	0.72	77.08	8.39	3.32	28.44
Median	2.2	0.8	78.9	8.3	3.4	28.4
Maximum	3	1	91.1	9	3.8	30.5
Minimum	0	0.3	46	7.3	2.4	26.2
Standard deviation	0.58	0.14	8.8	0.37	0.31	0.87
Skewness	−1.06	−0.55	−1.11	0.13	−0.78	0.32
Kurtosis	4.71	2.48	4.25	2.48	2.68	3

Note. CO_2, FM, GB, ECP, HC, and GDP represent carbon dioxide emission, financial development, globalization, energy consumption, human capital, and gross domestic product, respectively

environment) is 1.77, with a minimum and maximum range of −0.6 to 3.2 CO_2 metric tons per capita. The financial development index, which combines the financial institution and financial market index, has an average value of 0.55with a 0 to 1 range. The mean value of EC is 7.84 for the G20 countries, ranging from 5.8 to 9 metric tons per capita. Similarly, the HC or average year of education in G20 countries is 2.79, with a range of 1.4 to 3.8. The GDP per capita has an average of US$27.87, ranging from US$26 to 30.5. Finally, GB, which is used as the moderator of the study, indicates the average value of 66.78 with a range of 30.9 to 91.1.

In Table 3, we report the correlation between all the variables of the study. CO_2 emission, which represents the environmental quality, is positively correlated with FD and GDP. Further, CO_2 emission is highly and positively correlated with GB and ECP. Finally, environmental quality is positively correlated with HC, which indicates that education can improve the quality of the environment. The results also showcase the relatively weak correlation between all dependent variables, which shows the weak evidence of multicollinearity, one of the concerns of our empirical study.

Table 3 Correlation matric full sample

Variables	**CO_2**	**FD**	**GB**	**ECP**	**HC**	**GDP**
CO_2	1					
	–					
FD	0.47	1				
	0.00	–				
GB	0.53	0.78	1			
	0.00	0.00	–			
EC	0.89	0.61	0.66	1		
	0.00	0.00	0.00	–		
HC	0.66	0.8	0.82	0.8	1	
	0.00	0.00	0.00	0.00	–	
GDP	0.3	0.61	0.52	0.37	0.56	1
	0.00	0.00	0.00	0.00	0.00	–

Note. *P* value is in parentheses; ***1%, **5%, and *10%—significant levels

The reported results for panels A, B, and C in Table 4 show the CD of our study. Results specify the existence of CD, as the null hypothesis of no-CD is rejected. It confirms all the variables of G20 countries are highly dependent. Moreover, in our empirical framework, explanatory variables exceed the cross-sectional units. Therefore, while estimating the model using FE-OLS, we use a fixed-effect, which is in line with the study by Hunjra et al. (2020).

Appendix Table 11 presents the results of the CIPS and CADF unit root tests, which are proposed by Pesaran (2004). Reported results indicate that for the CIPS test, the null hypothesis of the unit root test is rejected, and the alternative hypothesis is accepted at the level, which indicates all the variables are stationary. However, in the CADF test, except for CO_2 emission (which is stationary at the first difference), all the variables are stationary at the level.

The panel regression estimator results from the FE-OLS are reported in Table 5. FD, which is the main explanatory variable of our empirical study, is statistically significant and in a negative correlation with CO_2 emission, which suggests that a

Table 4 Cross-sectional dependence test (CD test)

Test	Panel A		Panel B		Panel C	
	Statistic	*P* value	Statistic	*P* value	Statistic	*P* value
Breusch-Pagan LM	618.91	0.00	167.64	0.00	210.11	0.00
Pesaran scaled LM	23.19	0.00	11.87	0.00	19.45	0.00
Pesaran CD	6.68	0.00	−1.72	0.05	6.99	0.00

Note. The *P* value is in parentheses; ***1%, **5%, and *10%—significant levels

Table 5 Full-sample (G20 countries) panel A (FE-OLS) for CO_2 emission

Variables	1	2	3	4	5	6
Constant	-11.40***	-9.24***	-13.2***	-13.5***	-13.9***	-11.3**
	(-1.3)	(1.15)	(1.3)	(1.25)	(1.183)	(2.43)
FDit	-0.31**	-0.42***	1.51***	0.055	0.15	-0.53***
	(-0.12)	(0.12)	(0.33)	(0.126)	(0.118)	(0.13)
GBit	-0.010***		-0.002	0.060***	0.032***	-0.159***
	(-0.002)		(0.003)	(0.008)	(0.004)	(0.03)
ECit	0.45***	0.46***	0.33***	0.801***	0.079	0.95***
	(-0.086)	(0.08)	(0.083)	(0.087)	(0.08)	(0.026)
HCit	-0.07	-0.24***	-0.09	-0.026	-1.132***	-0.04
	(-0.096)	(0.079)	(0.09)	(0.088)	(0.128)	(0.057)
GDPit	0.34***	0.25***	0.43***	0.29***	0.471***	-0.32***
	(-0.07)	(0.066)	(0.069)	(0.066)	(0.063)	(0.088)
FDit*GB			-0.024***			
			(0.0041)			
ECit*GBit				0.009***		
				(0.001)		
HCit*GBit					-0.018***	
					(0.001)	
GDPit*GBit						0.005***
						(0.0013)
R2	0.938	0.991	0.992	0.992	0.993	0.992
Adjusted R2	0.222	0.991	0.991	0.992	0.993	0.994
S.E. of regression	0.037	0.087	0.0874	0.087	0.081	0.088
F-statistic	398.01	3452.3	3202.1	3191.5	3708.9	3498.9
Prob (f-statistic)	0	0	0	0	0	0
Durbin w.stat	0.33	0.28	0.28	0.281	0.32	0.33

Note. The *t* value is in parentheses; ***1%, **, 5%, and *10%—significant levels. Moreover, CO_2, FD, GB, EC, HC, and GDP represent carbon dioxide emission, financial development, globalization, energy consumption, human capital, and gross domestic product

1% increase in FD can decrease the CO_2 emission by −0.31% across the full panel of G20 countries (Column 1). It shows that in G20 countries, FD improves the environmental quality by cutting down the CO_2 emission, which in line with past findings (Shahbaz et al. 2013; Tamazian et al. 2009; Omoke et al. 2020; Zaidi et al. b). The negative impact of FD on CO_2 emissions indicates the shift of G20 countries from conventional finance to sustainable finance or green finance through an efficient financial system and lower restrictions. Another reason could be imposing tax restrictions on the anti-environmental industries, encouraging the R&D, and providing funds for low carbon technology, which help in reducing CO_2 emission.

GB, which is also a moderator of our study, has a significant and negative correlation with CO_2 emission (Column 1), which suggests that a 1% increase in GB can decrease CO_2 emission by −0.010%. It shows that in G20 countries, GB also improves the quality of the environment, which is consistent with the previous findings (Zafar et al. 2019; Shahbaz et al. 2018a, b, c, d; Haseeb et al. 2018; Shahbaz et al. 2019). It indicates that G20 countries make more financial investment and encourage trade activities through GB, which allows importing the energy-efficient technology, hence improving the environment quality. Moreover, GB encourages innovation through new production techniques that help to start new activities. When global competition between organizations increases, it improves the quality of products and services, which also helps address environmental issues.

EC, which is an important determinant of the study, is significant and positively correlated with CO_2 emission, as a

1% increase in energy emission leads to a 0.45% increase in environmental degradation (column 1). These findings suggest that EC is the key driver of CO_2 emission. In G20 countries, the massive demand for energy causes environmental degradation, which is in line with previous studies (Mukhtarov et al. 2020; Sadorsky 2010; Xu et al. 2020; Shahbaz et al. 2018a, b, c, d; Shao et al. 2019). Xu et al. (2020) argued FD decreases the cost of borrowing with a low rate of interest, intense restrictions for creditors, and funding in the high EC projects. As a result, Zhang (2011) found that the industrial sector makes the investment in machinery and equipment, which increases the EC and CO_2 emissions. On the other, FD increases the buying power of the household sector (purchase of the real estate, automobiles, and household appliances), which raises the energy demand and causes environmental degradation.

Similarly, HC is negatively correlated with CO_2 emission (columns 1–6); however, in columns 2 and 5, HC is statically significant and has a positive impact on CO_2 emission. An increase in the level of education can reduce CO_2 emission, which improves the environment's quality. The role of HC in reducing the CO_2 emission for G20 countries is crucial, encouraging technical research and education and raising awareness for pro-environmental activities can improve the quality of the environment. Our findings are consistent with previous studies (Lan et al. 2012; Bano et al. 2018; Khan 2020).

GDP is significant and positively correlated with CO_2 emissions, as a 1% increase in GDP leads to a 0.34% increase in CO_2 emissions (column 1). This suggests that an increase in economic growth causes environmental degradation. It also supports the EKC hypothesis and is in line with the findings of previous research studies (Moutinho et al. 2017; Shahbaz et al. 2016; Özokcu and Özdemir 2017; Charfeddine et al. 2018).

Further, Table 5 presents the impact of explanatory variables (FD_{it}*GB, EC_{it}*GB_{it}, HC_{it}*GB_{it}, and GDP_{it}*GB_{it}) on CO_2 emissions with a moderating role GB, for which there are diverse findings. Findings show that when GB interacts with FD (FD_{it}*GB), CO_2 emission increases by 0.017% at a 1% significance level (column 3). This indicates that GB, FD, and FDI help developing countries' investors to invest in R&D and advance technology (energy efficiency), which boosts the economy and improves environmental quality. Further, due to GB, countries are globally integrated, which helps the financial institutions to improve their financial systems and make investments in green projects. Last but not least, special projects banks that help the ally countries to make the policies regarding green finance, which also helps in reducing CO_2 emission. These findings also support the argument of some previous studies (Tamazian et al. 2009; Saud et al. 2018; Shahbaz et al. 2020). Likewise, the interaction between GB and HC (HC_{it}*GB_{it}) negatively impacts CO_2 emission, which suggests a −0.018% decrease in CO_2 emission at a significance level of 1% (column 5). This suggests that the world's mutual efforts for the improvement of HC are important from an environmental quality perspective. A high level of HC in a country can reduce CO_2 emissions. Globally, the mitigating role of HC in cutting down the CO_2 emission is linked with education, and research encourages pro-environmental activities. Global integration and mutual efforts create a sense of environmental awareness and healthy lifestyle.

However, an interaction effect between GB and EC (ECit*GB_{it}) on CO_2 emission is positive and significant, which indicates a 0.009% increase in CO_2 emission at a 1% significance level. It shows that due to global integration, international capital markets are open for local investors. This further decreases the cost of borrowing and debt conditions. As a result, private investors quickly get financial support for high EC projects, leading to CO_2 emission. On the other hand, FD increases the buying power of the household sector (purchase of the real estate, automobiles, and household appliances), which raises the energy demand and causes environmental degradation. It also supports the arguments of previous studies (Zhang 2011). Similarly, the interaction between GB and GDP (GDP_{it}*GB_{it}) also has a positive impact on CO_2 emission, with a magnitude of 0.005% at a 1% significance level. This shows that to achieve economic growth, trade and industrialization are important, and due to GB, international markets facilities for trading activities lead to an increase in the EC and also escalate CO_2 emission. Moreover, developing countries make more investments that boost the economy at the cost of environmental degradation. FD is vital for economic growth, as it is the source of foreign investment through GB, decreases the cost of borrowing, and escalates the energy demand (Akif and Asumadu 2019; Sadorsky 2010; Ozatac et al. 2017).

We ensure our results are robust by using the D–K standard error estimation model (Driscoll and Kraay 1998). Table 6 presents the robustness results, which are in line with the findings of the FE-OLS (Table 5). In Table 6, results of the D–K error estimation for all the variables (without interaction), namely, FD, GD, EC, HC, and GDP, (with interaction terms) FDit*GB, ECP_{it}*GB_{it}, HC_{it}*GB_{it}, and GDP_{it}*GB_{it} have consistent results with the FE-OLS estimations.

Tables 7 and 8 represent panels B and C (developing and developed countries of the G20 block). Results indicate (as given in column 1) that panels B and C follow the same pattern as panel A in G20 countries. As the FD, GD, and HC (HC insignificant in panels A and B) improve the quality of the environment for developed and developing countries in panels B and C, these determinants are negatively correlated with CO_2 emission. However, EC and GDP positively correlate

Table 6 Robust results through Driscoll–Kraay (DK) standard error estimation

Variables	1	2	3	4	5	6
Constant	−11.4*** (−0.93)	−9.25*** (0.91)	−13.24*** (1.56)	−14.3*** (1.128)	−13.9*** (1.074)	−12.3** (1.57)
FD_{it}	−0.319* (−0.16)	−0.43*** (0.16)	1.51* (0.83)	0.138 (0.142)	0.156 (0.152)	−0.53*** (0.109)
GB_{it}	−0.010*** (−0.002)		−0.003 (0.004)	0.10*** (0.032)	0.03*** (0.01)	−0.16*** (0.023)
EC_{it}	0.453** (−0.188)	0.46*** (0.18)	0.33* (0.18)	0.94*** (0.135)	0.079 (0.215)	0.95*** (0.015)
HC_{it}	−0.073 (−0.096)	−0.24*** (0.09)	−0.098 (0.1)	−0.044 (0.086)	−1.13*** (0.219)	−0.045 (0.106)
GDP_{it}	0.344*** −0.097	0.25*** (0.09)	0.43*** (0.11)	0.27*** (0.072)	0.47*** (0.095)	−0.32*** (0.057)
FD_{it}*GB			−0.024** (0.01)			
EC_{it}*GB_{it}				0.01*** (0.003)		
HC_{it}*GB_{it}					−0.01*** (0.004)	
GDP_{it}*GB_{it}						0.006*** (0.001)
N.obs	627	627	627	627	627	627
N.group	19	19	19	19	19	19
F-statistic	135.49	138.19	145.87	149.4	81.55	90.23
Prob (*F*-statistic)	0	0	0	0	0	0
R-squared	0.3	0.288	0.34	0.39	0.44	0.37

Note. The *t* value is in parentheses; ***1%, **, 5%, and *10%—significant levels. Moreover, CO_2, FD, GB, EC, HC, and GDP represent carbon dioxide emission, financial development, globalization, energy consumption, human capital, and gross domestic product

with CO_2 emission, suggesting these determinants cause environmental degradation.

Moreover, for moderation, unlike panel A (column 3), in panels B and C (that is, Tables 7 and 8 for developing and developed countries, respectively), the interaction between FD and GB (FD_{it}*GB_{it}) for CO_2 emission is positive and significant (while it is insignificant for panel C). This indicates that global integration, foreign direct investments, and economic activities are taking place, causing environmental degradation. To support the argument, Gokmenoglu and Taspinar (2016) stated GB increases the demand for goods and services, which leads to financial activities and also causes CO_2 emission. Further, in panel B

Table 7 Subsample (developing countries) panel B (FE-OLS) for CO_2 emission

Variables	1	2	3	4	5	6
Constant	−10.5*** (0.744)	−9.75*** (0.59)	−6.28*** (0.55)	−11.39*** (0.62)	−11.61*** (0.65)	−11.36** (2.64)
FD_{it}	−0.51*** (0.081)	−0.54*** (0.079)	−2.68*** (0.61)	−0.23*** (0.072)	−0.39*** (0.071)	−0.25* (0.12)
GB_{it}	−0.002* (0.001)		−0.011*** (0.004)	0.051*** (0.004)	0.021*** (0.002)	−0.104** (0.044)
EC_{it}	1.035*** (0.064)	1.08*** (0.058)	1.22*** (0.02)	1.37*** (0.061)	0.872*** (0.058)	1.24*** (0.019)
HC_{it}	−0.039 (0.048)	−0.08* (0.041)	−0.28*** (0.043)	0.03 (0.041)	0.740*** (0.087)	−0.28*** (0.043)
GDP_{it}	0.172*** (0.042)	0.131*** (0.034)	0.0002 (0.015)	0.104** (0.036)	0.197*** (0.037)	−0.21** (0.096)
FD_{it}*GB			0.044*** (0.01)			
EC_{it}*GB_{it}				−0.007*** (0.0006)		
HC_{it}*GB_{it}					−0.011*** (0.0011)	
GDP_{it}*GB_{it}						0.004** (0.001)
R^2	0.989	0.99	0.99	0.992	0.993	0.95
Adjusted R^2	0.98	0.989	0.98	0.992	0.993	0.951
S.E. of regression	0.092	0.093	0.092	0.077	0.08	0.199
F-statistic	2222	2379.3	3202.1	2076.6	2957.4	1076.763
Prob (*F*-statistic)	0	0	0	0	0	0
Durbin w.stat	0.261	0.28	0.28	0.281	0.32	0.33

Note. The *t* value is in parentheses; ***1%, **, 5%, and *10%—significant levels. Moreover, CO_2, FD, GB, EC, HC, and GDP represent carbon dioxide emission, financial development, globalization, energy consumption, human capital, and gross domestic product

Table 8 Subsample (developed countries) panel C (FE-OLS) for CO_2 emission

Variables	1	2	3	4	5	6
Constant	−7.39*** (−1.01)	−7.53*** (1.016)	14.3*** (3.5)	31.4*** (4.06)	23.9*** (4.23)	32.7*** (5.17)
FD_{it}	−0.561* (−0.27)	−0.71*** (0.25)	0.27 (1.66)	0.30* (0.18)	0.70*** (0.182)	0.55*** (0.178)
GB_{it}	−0.005 (−0.003)		0.0003 (0.013)	−0.24*** (0.042)	−0.09*** (0.031)	−0.35*** (0.082)
EC_{it}	0.74*** (−0.089)	0.74*** (0.09)	−0.21 (0.149)	−2.05*** (0.320	0.26 (0.189)	0.312* (0.165)
HC_{it}	0.31** (−0.135)	0.30** (0.135)	−0.66*** (0.175)	−0.23 (0.18)	−2.89*** (0.711)	−0.57*** (0.169)
GDP_{it}	0.11*** (−0.033)	0.106*** (0.033)	−0.301*** (0.135)	−0.41*** (0.116)	−0.54*** (0.142)	−1.103*** (0.22)
FD_{it}*GB			0.004 (0.021)			
EC_{it}*GB_{it}				0.029*** (0.005)		
HC_{it}*GB_{it}					0.030*** (0.009)	
GDP_{it}*GB_{it}						0.012*** (0.002)
R^2	0.861	0.86	0.86	0.87	0.86	0.87
Adjusted R^2	0.85	0.85	0.85	0.87	0.85	0.86
S.E. of regression	0.22	0.22	0.22	0.2	0.21	0.21
F-statistic	135.4	147.15	125.3	143.1	130.7	135.1
Prob (*F*-statistic)	0	0	0	0	0	0
Durbin w.stat	0.36	0.31	0.39	0.30	0.32	0.33

Note. The *t* value is in parentheses; ***1%, **, 5%, and *10%—significant levels. Moreover, CO_2, FD, GB, EC, HC, and GDP represent carbon dioxide emission, financial development, globalization, energy consumption, human capital, and gross domestic product

(Table 7; column 4), the impact of the interaction between EC and GB (EC_{it}*Gb_{it}) on CO_2 emission is negatively correlated as a combined effect, as it reduces −0.007% of CO_2 emission at a 1% significance level (which is converse to panels A and C). However, the findings for panel B and C (column 5) in Tables 7 and 8 indicate GB moderates the positive impact of HC and GB (HC_{it}*GB_{it}) on CO_2 emission, which is in line with the results of panel A. Lastly, in Tables 7 and 8 (column 6), the interaction between GDP and GB, that is, GDP_{it}*GB_{it} for panels B and C is positive and significantly correlated with CO_2 emissions, indicating growth in the economy leads to environmental degradation. Developing and developed countries of the G20 block encourage global businesses to boost the economy, which also causes CO_2 emission (Table 9).

This empirical study uses the panel Granger causality test to explore the causal relationship between CO_2, FD, GB, EC, HC, and GDP. Table 10 presents the interesting findings of the Granger causality test from G20 countries. Results indicate that there is a unidirectional causality running from CO_2 and FD. We also identify a unidirectional causality relationship between ECP and CO_2. Similarly, there is a unidirectional causality relationship between CO_2 and GDP and GB and FD. Furthermore, ECP, HC, and GDP cause FD and have a unidirectional relationship. Our findings indicate GB causes an increase in ECP and also shows the unidirectional causality relationship. Likewise, HC causes GB and GDP, but GB also causes GDP, though all causality is unidirectional. Finally, our reported results for the relationship between GDP and ECP and ECP and GDP demonstrate the existence of a bidirectional causality relationship in G20 countries.

Conclusion and policy recommendations

This empirical study formulated a newly developed model to explore the moderating role of GB between all independent variables (FD, EC, HC, and GDP) and CO_2 emission. This study employed Pesaran's (2004) proposed FE-OLS and the D–K (Driscoll and Kraay 1998) standard error technique to estimate the results. Moreover, to check the causal relationship between variables, we used a panel Granger causality test proposed by Dumitrescu and Hurlin (2012). The panel data comprised the full sample of G20 countries (panel A) and subsamples (panels B and C for developing and developed countries) from the period from 1986 to 2018.

Our findings for the full sample are diverse, as FD and GB improve the environmental quality, while conversely, EC and GDP cause environmental degradation (panels A, B, and C). Further, HC remained insignificant in the case of the full sample of G20 countries. This suggests that FD and GB are key drivers for the improvement of environmental quality in G20 countries. This is because GB helps developing countries to import advanced technology from developed countries, and FD helps to invest in environmentally friendly and green projects. Moreover, G20 countries put financial restrictions in the form of taxes and penalties to discourage anti-environmental projects and promote the concept of green finance. However, countries that are in the developing phase looking for growth also raise the energy demand, and it leads to environmental degradation.

Similarly, GB is the key driver of environmental quality, as it moderates with all the explanatory variables on CO_2

Table 9 Granger causality results (G20 countries)

Null hypothesis	*F*-statistic	*F*-prob
FD → CO_2	1.53	0.2164
CO_2 → FD	4.41	0.0126**
GB → CO_2	1.95	0.1431
CO_2 → GB	0.86	0.4227
ECP → CO_2	5.06	0.0066***
CO_2 → ECP	1.01	0.3658
HC → CO_2	1.21	0.2995
CO_2 → HC	0.21	0.8123
GDP → CO_2	1.74	0.1763
CO_2 → GDP	10.04	5.E−05***
GB → FD	8.26	0.0003***
FD → GB	1.09	0.3351
ECP → FD	7	0.0010***
FD → ECP	0.41	0.6621
HC → FD	8.25	0.0003***
FD → HC	1.21	0.2961
GDP → FD	3.52	0.0301**
FD → GDP	0.52	0.5907
ECP → GB	1.76	0.1715
GB → ECP	2.9	0.0557*
HC → GB	4.62	0.0101**
GB → HC	0.02	0.9726
GDP → GB	0.12	0.8865
GB → GDP	5.89	0.0029***
HC → ECP	1.33	0.264
ECP → HC	1.34	0.2623
GDP → ECP	8.12	0.0003***
ECP → GDP	15.75	2.E−07***
GDP → HC	0.01	0.9891
HC → GDP	8.29	0.0003***

Note. The table represents the linear Granger causality test results for CO_2, FD, GB, ECP, HC, and GDP. "→" does not Granger cause; ***1%, **, 5%, and *10%—significant levels

emission. Our findings demonstrate that GB moderates the positive effects of FD on CO_2 in panels A and B. It is likely that in G20 countries, due to GB, the import of advanced technology and investments in green projects improve the quality of the environment. However, panel C has a negative but statistically insignificant impact. Moreover, HC, which is vital in improving the environmental quality, moderates positively with the environment in the case of panels A, B, and C. This suggests people in the G20 block countries have technical education and knowledge, which encourage pro-environmental activities and promote a healthy lifestyle.

Further, we observed GB moderates the adverse effects of EC and GDP on environmental quality, as EC and GDP are positively correlated with CO_2 in panels A and C. In other words, GB boosts economic activities; thus, the production of goods and services increases, subsequently increasing the demand for energy, which leads to environmental degradation. Lastly, we also reported the bidirectional causality relationship between GDP and ECP.

Based on our findings, this empirical study also recommends the following policy implications for the policymakers or and key stakeholders of G20 countries:

- As a policy implication, sustainable development in economic growth while protecting the environmental quality can be achieved by encouraging green finance. The developing countries of the G20 block need to change the financial system, as financial institutions make environment-friendly investments, create mechanisms to eliminate the level of risk while mobilizing funds from private sources, and correct valuations of environment-related risks. Moreover, the particular development banks must also play a role in it by developing green finance in allied countries by providing support in making policies and building capacity.
- For the energy sector, the policymakers must create a mechanism to control the oil crises for sustainable development. Therefore, for efficient consumption of energy, governments must provide R&D facilities, invest in experimental development, and industrialize the renewable energy sector. Moreover, the government should encourage research institutions, universities, and firms to promote green energy by removing the barriers to innovation and opt for low carbon technologies and infrastructure.
- The development of HC is crucial for sustainable growth while protecting the environment. Especially in developing countries of the G20 block, it is critical to provide education and skills to the workforce to convert the fossil-intensive firms into environment-friendly firms. Moreover, it is essential to launch awareness campaigns about climate change at the government level, promote green policies, and strictly impose environmental laws.
- Lastly, it is vital to formulate country-specific climate policies, such as increasing the carbon emission industries' taxes and replacing inefficient fossil technologies. Further, it is important to have public procure support to invest in environment-friendly infrastructure, as it will stimulate the industrial model innovation by creating leading markets.

This empirical study has some limitations. Our study used county-level data. Based on the firm's data level, we can more closely understand how FD promotes efficient technology that can be environment-friendly if we conduct in-depth analyses. Moreover, our study used a single indicator of GB. Future studies can use the multi-dimensional regional integration index as an alternative proxy and institutional quality or environmental tax as the moderators.

Appendix 1

Table 10 Data description and source

Variables	Description	Symbols	Sources
CO_2 emissions	CO_2 metric tons per capita	CO_2	World Bank (2019)
Financial development	Financial development index	FD	The Financial Development Index by Syirydzenk (2016) and International Monetary Fund (2019)
Globalization	Globalization index	GB	Kof (2019)
Energy consumption	ECP per capita	ECP	World Bank (2019)
Human capital	Average year of education	HC	Penn World Table (PWT) 9.0
Gross domestic product	GDP constant of 2010 million dollars	GDP	World Bank (2019)

Appendix 2

Table 11 Pesaran CIPS unit root test and cross-sectional dependence test

Variables	CPIS			CADF		
	Level	**1st difference**	Order	**Level**	**1st difference**	Order
CO_2	−2.329**	–	I(0)	−1.561	−3.966***	I(1)
FM	−2.754***	–	I(0)	−2.500***	–	I(0)
GB	−3.007***	–	I(0)	−2.629***	–	I(0)
EC	−2.451***	–	I(0)	−2.089*	–	I(0)
HC	−2.326**	–	I(0)	−2.385***	–	I(0)
GDP	−2.346**	–	I(0)	−2.490***	–	I(0)

Note. C and CT represent the constant and constant trend; ***1%, **, 5%, and *10%—significance levels

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Declarations

Ethical approval Study did not use any data which need approval.

Consent to participate All authors participated in the process of draft completion. All authors have read and agreed to the published version of the manuscript.

Consent to publish All authors agree to publish.

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