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Examining the bidirectional nexus between financial development and green growth: International evidence through the roles of human capital and education expenditure

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ABSTRACT

In the context of the 2030 Agenda for Sustainable Development by the United Nations, the functionality of financial development is undeniable in the wider economy toward Sustainable Development Goals (SDGs). Using novel panel data of 36 countries over the last decades, the study sheds light on the bi-directional nexus between financial development and green growth where human capital and education expenditure present their central roles in sustainable development. The study provides critical findings to the existing literature on climate change, environment, and sustainability. Following the empirical findings, we provide important insights to regulators, policy makers, and organizations in investigating the substantial contributions of financial development including financial markets and financial institutions where their accessibility, depth, and efficiency need a thorough consideration toward SDGs and mitigating climate change impacts worldwide. Apart from using the multidimensional proxies, the empirical findings are validated by a set of econometric approaches.

1. Introduction

The global economy has been accelerating in the past decades resulting from human efforts in fulfilling their needs. In terms of gross domestic product (GDP), the global economy today has grown 28% than it was a decade ago, which was from $66,142 trillion in 2010 to $84,706 trillion in 2020. This growing output signals the expanding human needs and wider openness for trade among countries. However, apart from the expansion of human needs, the increasing trend of economic growth also indicates the development of human civilizations. One of the essential growing civilizations is the way human beings utilize financial instrument to support their life in the future. Financial sector development or more popularly known as financial development, plays a key essential role in economic development as it promotes growth through capital accumulation and technological progress, such as the accumulation of savings and investment, the increase in savings rate, and the management of foreign capital inflow (World Bank, 2021b).

Financial development is considered one of the crucial key economic drivers in emerging economies (Sadorsky, 2010). No consensus exists regarding the best indicator to approximate financial development. Some authors approximated financial development on the bases of stock market activities, such as stock market capitalization to GDP ratio, stock market turnover ratio, and stock market total value traded to GDP ratio, such as what was presented in Sadorsky (2010), Chang (2015), and Ibrahim and Sare (2018), among others. Others approximated using domestic credit to private sector relative to GDP, such as what was presented in Jalil and Feridun (2011); Ozturk and Acaravci (2013); and Ntow-Gyamfi et al. (2020), among others.

According to the International Monetary Fund (IMF)'s financial development index, financial development across countries is estimated to have twice increased during the period of 1980–2018, which is from 0.16 in 1980 to 0.33 in 2018. However, in the last decade, the index has not experienced substantial growth–it only increased from 0.32 in 2010 to 0.33 in 2018. On the other hand, green economic development (green growth thereafter), which is approximated based on carbon dioxide emission, remains stagnant during the period of 2010–2018, which was

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between 4483 metric ton per capita in 2010 to 4484 metric ton per capita in 2018. However, relative to 1980, green economy was quite diminishing, as seen from the increase in CO_2 emission relative to that of 1980 at 4315 metric ton per capita. Thus, from the perspective of carbon emission, the global green growth has not been achieved optimally.

The expansive financial development is not always beneficial for environmental quality. Some studies demonstrated that financial development has triggered energy consumption, hence followed by carbon emissions and reduced environmental quality (e.g., Jalil and Feridun, 2011; Mardani et al., 2019; Sadorsky, 2010). These findings argue that deeper and more sophisticated financial sector development can incentivize human beings to achieve more profit beyond normal, exploit the earth, and destroy the green economy (Pan et al., 2021). However, other scholars argue the opposite by presenting findings that financial development positively supports the green economy through the diminishing energy consumption and carbon emission (Al-Mulali et al., 2015; Ozturk and Acaravci, 2013; Tamazian et al., 2009).

Other views that lie in between positive and negative impacts were also given. For example, Chang (2015), extending the findings from Sadorsky (2010), argued that the negative impact of financial development on green economy only happened in low- and middle-income countries, whereas financial development was found to be beneficial for green growth in advanced economy. Ntow-Gyamfi et al. (2020) recently argued that the relationship between financial development and environmental degradation follows a U-shape curve, suggesting an initial deterioration, but the negative impact was diminishing until it turns positive. Overall, studies in the field of financial development and green economy thus deliver mixed findings, and the debate continues.

This study aims to contribute to the ongoing debate by investigating the causal association between financial development (FD) and green growth (GG) in the international sample of 36 countries for the period of 1996–2014. This study hypothesizes a bidirectional relationship between FD and GG. Specifically, financial development can influence green growth, either negatively when financial development creates further environmental degradation (e.g., Chang, 2015; Jalil and Feridun, 2011; Sadorsky, 2010) or when financial development can help reduce carbon emissions (Al-Mulali et al., 2015; Hasan et al., 2021; Sehrawat et al., 2015; Tamazian et al., 2009). By contrast, a cointegration occurs between green growth and financial development (Fernandes et al., 2021; W. Pan et al., 2019), in which green growth can promote economic growth and consequently boost financial development, according to finance-growth nexus theory (Herwartz and Walle, 2014; Law et al., 2013; Levine, 2005b). In the study, financial development is proxied by three indicators from IMF, namely, financial development index, financial institutions index, and financial market index (Gao et al., 2021). Meanwhile, green growth is approximated by multiple measures such as production-based CO_2 productivity, demand-based CO_2 productivity, non-energy material productivity, and mean population exposure to particulate matter (PM) 2.5 pollutant.

This study contributes originally to the literature of financial development and green economy in several important areas. First, to the best of our knowledge, this research is the first study investigating the bidirectional relationship between financial development (FD) and green growth (GG) by employing the multidimensional measures to overcome the limitation of single proxies used in the previous studies. This existing causal relationship strengthens the argument on the important role of green growth[1] (Capasso et al., 2019; Fernandes et al., 2021; World Bank, 2021b), thereby justifying sustainable development policy such as the sustainable development goals (United Nations, 2018; World Bank, 2021b). Second, from the methodological perspective, this study also contributes to the literature by presenting multiple estimation methods to produce robust findings regarding the above relationship, although extra emphasis was placed on the 2-step efficient GMM estimator. The model estimation includes the standard ordinary least squares (OLS) regression, the Seemingly Unrelated Regressions (SUR), three-stage least squares (3SLS), and the 2-step efficient Generalized Method of Moment (GMM). As such, the relevant discussions and suggestions drawn from those findings are reliable contributions for the global sustainable/green development.

Our study demonstrated a bidirectional relationship between financial development and green growth. That is, financial development was found to have positive significance in promoting green growth, while green growth helps promote financial development. In the first model, together with financial development, education and human development index were found to be statistically significant in positively affecting green economy, which recommended that more educated and developed human quality were essential to support the positive impact of financial development on economic growth. Conversely, in the second model, the study demonstrated that green economy positively affected financial development by holding the presence of stock market, foreign direct investment, and human development index unchanged. These findings were robust across different estimation methods highlighting a bidirectional relation between financial development and green growth in association with several instrumental factors in our global sample.

In the context of the United Nations' 2030 Agenda for Sustainable Development with the 17 Sustainable Development Goals (SDGs), the study contributes to the extant literature through the following critical findings and policy implications. First, the study sheds light on the bidirectional nexus among FD and GG toward SDGs using the newly developed multidimensional proxies introduced by IMF to overcome the limitations of using single proxies in modelling FD and GG in the recent studies (see Acheampong et al., 2020; C.-Q. Song, Chang and Gong, 2021) which may lead to the unidirectional relation detected between FD and its determinants. Similar to FD, the study employs a conceptual framework of Ahmed et al. (2022); Sohag et al. (2019) in determining the estimated function of GG instead of using the CO_2 to proxy green growth which is commonly employed in modelling environmental sustainability (Bibi et al., 2021; Umar et al., 2020), environmental quality (Avom et al., 2020; Zafar et al., 2021), and climate change as the challenge for economic growth (EG) (G. Li and Wei, 2021; Nordhaus, 2019; Sbia et al., 2014); therefore, the term "green growth (GG)" best suits our study.

Considering that the bi-directional nexus among FD and GG has been defined, the study's empirical findings further stress on the roles of human capital development (HDI) and education expenditure (EE) within the trajectory among GG, FD, and EG for the world's sustainable transition partially presented in the recent studies (see Z. Khan, Ali, Dong and Li, 2021; Shahbaz et al., 2022; Yao et al., 2019; Zaman et al., 2021). Our empirical findings are critical and highlight the roles of FD and sustainable economic activities toward GG and SDGs by the UNs in an international context for mitigating carbon emission and climate change risk in the recent literature (see M. K. Khan, Trinh et al., 2022; Trinh et al., 2022; Trinh et al., 2022).

The rest of this study is structured as follows. The following section presents the literature review. Section 3 explains the methodology. Section 4 provides the estimation result and analysis. Finally, Section 5 concludes the main findings with policy implications and future research agenda needed.

2. Literature review

Financial development is considered one of the crucial key economic drivers in emerging economies (Sadorsky, 2010). However, studies specifically investigating the impact of financial development on green economy are insufficient. Hence, most studies in this area approximate

[1] Previous studies on 'environmental sustainability', 'environmental quality' and 'environmental degradation' mainly employ the amount of carbon emission (CO2) risk as the main proxy; following the conceptual framework proposed by the UNEP (2011) and OECD (2011, 2012) to define and use the term 'green growth' which suits best in our study's purpose, represented in Equation (1).

green economy with environmental quality, carbon emission, or environmental degradation instead. Thus far, efforts that investigate the impact of financial development on green economy measures or vice versa remain unconnected to reach a consensus. Some studies demonstrate that financial development contributes to environmental degradation and is therefore detrimental for green economy (e.g., Chang, 2015; Jalil and Feridun, 2011; Sadorsky, 2010). Conversely, other studies argue that a higher degree of financial development promotes green economy by reducing carbon emission (Al-Mulali et al., 2015; Hasan et al., 2021; Sehrawat et al., 2015; Tamazian et al., 2009). These mixed findings signal that the relationship between the two measures is dependent on the research scope and considerations. The following sections review such literature, with their main findings presented in Table 1.

Overall, this study contains major gaps when compared with past literature. First, no earlier work approximates financial development using a single financial development index. Most of the studies since the 1970s proxy the financial development by using only two measures of the depth of financial systems which are private credit to GDP ratio and market capitalization to GDP ratio (J. L. Arcand, Berkes and Panizza, 2015; Dabla-Norris and Srivisal, 2013; Raghuram G. Rajan and Zingales, 1998), a process prone to conflicting results. Second, unlike the previous studies in the same area that estimate two separate equations in understanding the presence of bidirectional impact between financial development and green growth, this study offers a system of equation to estimate the vector of impact between green growth and financial development more accurately (illustrated in Fig. 1 below). Third, this study features the estimated models using some institutional control variables such as human capital index, R&D expenditure, and education expenditure, which are ignored by most past literature. Incorporating such institutional variables is considered important given that different countries must have different characteristics that make institutional variables influential in the relationship between green growth and financial development. For instance, Ntow-Gyamfi et al. (2020) argued that a strong institutional framework was found to reduce the negative impacts of financial development in environment in the long run.

2.1. Theoretical framework

The theory of financial development in relation to green economy is closely related to how the former affects environmental degradation. In most literature, environmental degradation is commonly measured by carbon dioxide emission. The ability of financial development to increase carbon emission is associated with a negative impact of the former on green economy, whereas a positive impact happens in the opposite relationship. Bui (2020) explained at least three transmission mechanisms through which financial development affects carbon emission and hence green economy, namely, through energy demand, income inequality, and growth channels.

The first transmission channel is obviously the energy demand. A higher degree of financial development is associated with greater loan given, which contributes to the purchase of new cars, vehicles, or machines that emit other carbon emissions. The second channel, which is mostly neglected in the literature, is how financial development affects carbon emission via income inequality. The higher credit access resulting from greater financial development narrows the gap between the rich and the poor as the latter now has better access to receive more loans. When income inequality is reduced, environmental degradation is worsening because income from low-marginal-propensity countries will be redistributed to those with a higher propensity (Ravallion et al., 2000). Finally, the transmission channel of financial development in affecting carbon emission occurs through growth channel. That is, a higher degree of financial development stimulates further growth, as people now receive more financial access to boost its economic activities. At the same time, more production activities produce more carbon emission. However, many studies demonstrate that the relationship

Table 1
Key findings of the previous literature on green growth and financial development.

Authors	Sample	Period	FD Indicator	Finding (FD => GG)
Tamazian et al. (2009)	BRIC countries	1992–2004	- Deposit money bank assets to GDP ratio	Positive
Sadorsky (2010)	22 emerging countries	1990–2006	- FDI to GDP ratio - Bank deposit to GDP ratio - Stock market capitalization to GDP ratio - Stock market turnover ratio - Stock market total value traded to GDP ratio	Negative
Tamazian and Bhaskara Rao (2010)	24 emerging economies	1993–2004	- Financial liberalization	Positive
Jalil and Feridun (2011)	China	1953–2006	- Private sector loans to GDP - Capital market index - Commercial bank assets ratio	Neutral
Zhang (2011)	China	1980–2009	- Loan to GDP ratio - Stock market capitalization to GDP ratio - Stock market turnover to GDP ratio	Negative
Ozturk and Acaravci (2013)	Turkey	1960–2007	- Private domestic credit to GDP ratio	Unidirectional negative
Shahbaz et al. (2013a)	Indonesia	1975–2011	- Domestic credit to private sector to GDP ratio	Positive
Shahbaz et al. (2013b)	South Africa	1965–2008	- Domestic credit to private sector to GDP ratio	Positive
Chang (2015)	53 low- and advanced-income countries	1999–2008	- Domestic credit to GDP ratio - Total value of traded stocks to GDP ratio - Total value of traded stocks to stock market capitalization - FDI net flow to GDP ratio	Indifferent
Al-Mulali et al. (2015)	129 countries	1980–2011	- World Bank financial development index	Positive
Sehrawat et al. (2015)	India	1971–2011	- Credit to private sector relative to GDP	Negative
Li et al. (2015)	102 countries	1980–2010	- Credit to GDP	Positive
Shahbaz et al. (2018)	France	1955–2016	- Credit to private sector relative to GDP	Positive

(continued on next page)

Table 1 (*continued*)

Authors	Sample	Period	FD Indicator	Finding (FD => GG)
De Haas and Popov (2019)	48 countries	1990–2013	- Private credit to GDP ratio - Stock Market capitalization to GDP ratio	Positive
Rajpurohit and Sharma (2020)	5 Asian countries	1980–2014	- Bank credit to bank deposit ratio	U-Shape
Song and Li (2020)	China	2008–2016	- Green credit - Green securities - Green insurance - Green investment	Positive
Ntow-Gyamfi et al. (2020)	African countries	1990–2016	- Domestic credit to private sector relative to GDP - Domestic credit provided by the financial sector relative to GDP	U-Shape
Bui (2020)	100 countries	1990–2012	- The share of domestic credit to GDP ratio	Negative
Shobande and Ogbeifun (2022)	24 OECD countries	1980–2019	- IMF Financial development index	Positive
Liu and Liu (2021)	China	2005–2018	- Total credit to GDP ratio	Positive
Jinquao et al. (2022)	Brazil, China, India, Mexico, Russia, and Turkey	1980–2020	- Credit to GDP ratio	Negative
Hasan et al. (2021)	Bahrain	1980–2018	- Credit to GDP ratio	Positive
Jianguo et al. (2022)	37 OECD countries	1998–2018	- IMF Financial development index	Positive
Sunday Adebayo et al. (2022)	Mexico, Indonesia, Nigeria and Turkey	1969–2019	- Credit and stock market development	Negative
Ehigiamusoe et al. (2022)	31 African countries	1990–2019	- Total credit to GDP ratio	U-Shape

through this channel follows the EKC hypothesis.

2.2. Negative impact of financial development on green economy

In some studies, financial development is found to trigger more pollution and thus detrimental for green economy. For example, Sadorsky (2010) explored the relationship between financial development and energy consumption in 22 emerging countries during the period of 1990–2006. In the study, financial development was proxied by some indicators, including foreign direct investment, bank deposit to GDP ratio, stock market capitalization to GDP ratio, stock market turnover ratio, and stock market total value traded to GDP ratio. The study hypothesized that energy consumption is dependent on past period consumption, income, price, and financial development. The study estimated the model using the system GMM approach following the Arellano and Bond method. Based on the estimated models, the study demonstrated that financial development, measured by stock market variables, positively affects the demand for energy consumption in emerging economies (Zhang et al., 2022). In other words, this finding

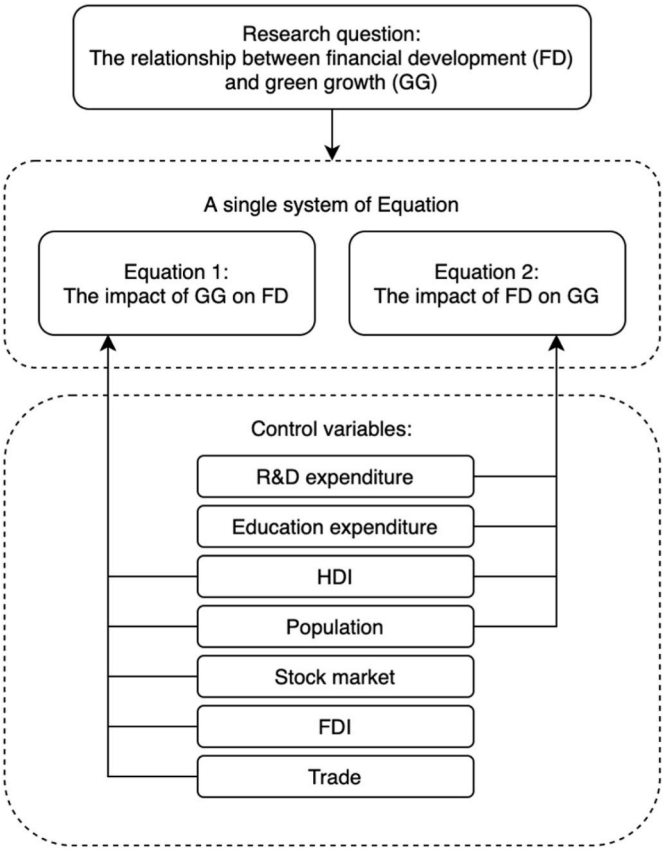

Fig. 1. The research framework conceptualized by the Authors based on the literature review.

suggests that financial development corresponds to low green growth. However, using multiple proxies for financial developments and separately estimating them can threaten the results to be less robust and inconsistent. Hence, we propose a different approach by estimating different equations as a single system and expect a more consistent result using a single proxy of financial development.

As demonstrated by Sadorsky (2010), the negative relationship found between financial development and green economy also resonates with those of other studies. For example, Hasan et al. (2021) explored the causal relationship between financial development and carbon emission. The study was taken in Bahrain during the period 1980–2018. Financial development was proxied by domestic credit and was hypothesized that it affected carbon emission, holding per capita GDP and population growth constant. The model was estimated by the vector error collection model and demonstrated a cointegration among carbon emission, financial development, per capita GDP, and population. The study also supported Sadorsky (2010) by demonstrating that financial development positively increased carbon emission and further found that being Granger caused the latter. However, we argue that a better result can be attained when financial development is approximated by a more comprehensive proxy, in which this study expects to deliver.

The detrimental impact of financial development is also revealed in a single country level and not only on a panel level. In China, Jalil and Feridun (2011) investigated the impact of financial development on environmental pollution by also incorporating the presence of economic growth and energy consumption. In the study, examining the period of 1953–2009, financial development was approximated by multiple indicators including the ratio of private sector loans to the nominal GDP, the capital market index, and the ratio of commercial bank assets to the sum of commercial bank and central bank assets. The study estimated the hypothesized model using Autoregressive Distributed Lag (ARDL)

bound testing procedure following Pesaran and Shin (1999). Based on the estimation method, the study demonstrated that financial development had no significant role in affecting environmental degradation in China, which implies that it had no impact on green growth as well. This finding is consistent with that from Zhang (2011) who investigated the link between financial development and carbon emission in China over the period of 1980–2009. Financial development in Zhang (2011) was proxied by multiple indicators including the ratio of loans to GDP, the ratio of stock market capitalization to GDP, and the ratio of stock market turnover to GDP. The study demonstrated that financial development had a significant impact in increasing carbon emission in China with the impact greater when financial development was proxied by lending than by stock. Unfortunately, using multiple proxies for financial developments and separately estimating them can threaten the results to be less robust and inconsistent. Hence, this study attempted a different approach by estimating different equations as a single system and expected a more consistent result using a single proxy of financial development.

In Turkey, Ozturk and Acaravci (2013) investigated the causal relationship between financial development and energy consumption by holding the presence of trade and economic growth. The study was taken during the period of 1960–2007 and approximated financial development using domestic credit to private sector as the share of GDP. By contrast, energy consumption was proxied by carbon dioxide emissions in terms of metric kg per capita. The model hypothesized that carbon emission should be significantly affected by financial development, together with the presence of trade openness and per capita GDP. Using the error correction-based Granger causality model, the study found that financial development significantly increased carbon emission in the short run but not the other way around, which signals the unidirectional negative impact of financial development on green economy. This finding is also shared by Sunday Adebayo, Saint Akadiri, Haouas, and Rjoub (2022) in the case of Mexico, Indonesia, Nigeria, and Turkey over the period of 1969–2019. Using credit and stock market development as the proxy of financial development, the study shows that financial development tends to increase carbon emission. Furthermore, our study is expected to improve the finding by presenting a different proxy of financial development using a new system of equation with human capital and R&D expenditure, which are not utilized in Ozturk and Acaravci (2013).

Chang (2015) extended the findings from Sadorsky (2010) by also incorporating the sample from low- and advanced-income countries, apart from emerging economies totaling 53 countries during 1999–2008. The sample countries were classified into three income levels. Financial development was proxied by similar indicators as in Sadorsky (2010), which include domestic credit to GDP ratio, total value of traded stocks to GDP ratio, total value of traded stocks to stock market capitalization, and the ratio of FDI net flow to GDP. Overall, the study revealed that financial development was positively associated with energy consumption when the former was proxied by private and domestic credit to GDP ratio in emerging economies. However, when financial development was proxied by stock market variables, financial development significantly reduced its growth, but it only happened in advanced economies. Similarly, the negative impact is also found in seven emerging economies, namely, Brazil, China, India, Russia, and Turkey, in the study from Jinqiao et al. (2022). Using the sample of countries over the period of 1980–2020 and utilizing credit to GDP ratio as the proxy of financial development, the study demonstrates that financial development increases carbon emission and is hence negative to green growth. However, using multiple proxies for financial developments and separately estimating them can threaten the results to be less robust and inconsistent. Accordingly, our study attempts improvement by presenting different equations under a single system to deliver a more consistent result using a single proxy of financial development.

Rajpurohit and Sharma (2020) also shared a similar finding related to a negative impact in financial development on green economy. The study was taken for five Asian emerging economies (Malaysia, Sri Lanka, Pakistan, India, and Bangladesh) over the period of 1980–2014. Similar to most past literature, financial development is also proxied by bank credit to bank deposit ratio. The study results suggest that financial development initially increases carbon emission and is hence negative for green economy but eventually decreases carbon emissions. This finding is also similar to that of Ehigiamusoe et al. (2022) in the case of African countries. This study utilizes domestic credit to GDP ratio as the proxy of financial development. However, we argue that the studies should also be focused on understanding the impact vector, whether it is unidirectional or bidirectional, which our study attempts to improve.

2.3. Positive impact of financial development on green economy

Some scholars supporting the positive impact of financial development on green economy are also noted. Al-Mulali et al. (2015) investigated the effect of financial development on carbon dioxide emission in 129 countries. The countries were classified into four groups on the basis of income groups set by World Bank and taken during the 1980–2011 period. Financial development was proxied by financial development index from World Bank, and carbon dioxide emission was derived from the Energy Information Administration (EIA). The model was estimated by the dynamic OLS and Granger causality tests and demonstrated that financial development was statistically significant in reducing carbon dioxide emission and hence environmental degradation across countries at all income levels which occurred in both the short and long term. This finding is also shared by Jianguo et al. (2022) who utilized the IMF financial development index as a proxy of financial development on 37 OECD countries over the period of 1998–2018. Using a two-step GMM methodology, the study demonstrates that financial development reduces carbon emission and hence negatively impacts the green economy, especially when considering the institutional quality and technology innovation. The IMF financial development index is also utilized in Shobande and Ogbeifun (2022) for 24 OECD countries over the period of 1980–2019 and results in a similar finding. These studies are closely related our study in terms of the single proxy used for financial development. Nonetheless, we propose different contributions by presenting two bidirectional equations under a single system and new control variables, which will be useful in understanding the presence of a reversible impact between financial development and green economy.

In support of Al-Mulali et al. (2015), M. Song and Li (2020) also demonstrated that financial development promoted green productivity in China. Specifically, M. Song and Li (2020) demonstrated that the impact of financial development on green growth should be bidirectional, as they found that green economy—proxied by green credit, green securities, green insurance, and green investment—also promoted financial development in China. This conclusion was taken on the basis of the Chinese data over the sample of 2008–2016. Liu and Liu (2021) also shared a similar finding by arguing that financial development positively reduces carbon emission and hence improves green economy. Liu and Liu (2021) utilized Chinese data over the period of 2005–2018 with total credit to GDP ratio as the proxy of financial development. These findings thus contradict the findings from Sadorsky (2010), Zhang (2011), Ozturk and Acaravci (2013), and Chang (2015), among others. Instead of using green productivity (M. Song and Li, 2020) or credit to GDP ratio (Liu and Liu, 2021), we propose a more straightforward approach by using green growth (as defined by UNEP, 2011) and financial development index as a multidimensional proxy of financial development. We also consider human capital and innovation in the equation, which is expected to deliver better results.

Similar to Al-Mulali et al. (2015), De Haas and Popov (2019) also investigated the impact of financial development on green growth across 16 industries in 48 countries during 1990–2013. In the study, financial development was proxied by the ratio of private credit and stock market capitalization over GDP, while green growth is presented by carbon

dioxide per capita. Apart from financial development, the study also incorporated financial structure, which was approximated by the ratio of stock market financing to the sum of total financing. The study implemented the standard OLS and 2SLS method to estimate the models and demonstrated that countries with higher financial development tend to be associated with a faster decline in carbon emissions per capita. It suggests a positive association between financial development and green growth because stock markets can trigger innovation to produce cleaner technology in the future. However, we argue that better results can be delivered by presenting the impact vector, whether unidirectional or bidirectional. Our study attempts to improve on this goal.

The mutual relationship between financial development and green economy is also found in the study of S. Li, Zhang, and Ma (2015) exploring the relationship between financial development and environmental quality by incorporating 102 countries as the sample countries. The study took the sample countries during the period of 1980–2010 and applied dynamic panel data analysis with GMM estimator. They revealed that financial development could strengthen the impact of environmental quality on economic growth and vice versa. Thus, the study showed a mutual relationship between financial development and environmental quality in that the former was helpful in increasing environmental quality and hence green growth. However, incorporating various countries at different development levels require institutional variables that can differentiate one country from the other. This study improves this weakness by incorporating institutional variables such as R&D expenditure, education, and human capital.

Ntow-Gyamfi et al. (2020) measured financial development by domestic credit to private sector and total domestic credit relative to GDP in Africa over the period of 1990–2016. The study demonstrated that the nexus between financial development and environmental degradation was affected by the quality of institutions. The relationship between financial development and environmental degradation also follows an inverted U-shape relationship. Strong institutional framework was found to reduce the negative impacts of financial development in environment in the long run. This finding is similar to Tamazian and Bhaskara Rao (2010) in their study across 24 transitioning economies demonstrating the positive association between financial development and green economy during 1993–2004. By contrast, in the case of the Brazil, Russia, India, China, and South Africa (BRIC) economies during 1992–2004, Tamazian et al. (2009) demonstrated that a higher level of financial development successfully reduced environmental degradation, particularly happening through the channel of foreign direct investment.

Shahbaz et al. (2013) investigated the nexus of economic growth, energy consumption, financial development, and trade openness in Indonesia during 1975–2011. Financial development was proxied by domestic credit to private sector to GDP. The study applied ARDL and demonstrated that financial development played a role in increasing carbon emission in Indonesia. In France, Shahbaz, Nasir, and Roubaud (2018) investigated the determinants of carbon emission with financial development as one of the key variables of interest. The study also approximated financial development using domestic credit to private sector to GDP. Using the ARDL estimation method, the study demonstrated that financial development unidirectionally reduced carbon emission and hence increased environmental quality. This negative impact of financial development on carbon emission is also similar to Shahbaz et al. (2013) with the sample country in South Africa. However, this finding was not found in India based on the study from Sehrawat et al. (2015) which demonstrated that financial development appeared to worsen environmental degradation. Accordingly, we propose a different approach by using a single comprehensive financial development index as a primary proxy. We also consider human capital and innovation in the equation, which other studies do not use.

3. Methodologies and data

3.1. Measuring green growth

This study follows the UNEP (2011) and OECD (2011, 2012) to define green growth as sustainable economic growth after accounting for the negative externalities of greenhouse gas emissions, extraction of natural resources, and other natural damages. In other words, green growth is determined as the indicator for environment-friendly economic development. According to Kazi Sohag, F. Dilvin Taşkın, and Muhammad Nasir Malik (2019) and Ahmed et al. (2021), the equation of green growth can be formulated as

$$GG_{i,t} = GDP_{i,t} - NRP_{i,t} - NFD_{i,t} - CO_{2i,t} \quad (1)$$

where *GG* is the green growth indicator as the function of *GDP* which is the annual growth rate of gross domestic product, *NRP* represents the level of mineral depletion (including crude oil, coal, and natural gas) and is proxied by the amount of fossil fuel consumption as percentage of total energy consumption, *NFD* represents the level of forest depletion and is proxied by the amount of forest rents as percentage of *GDP*, and CO_2 is the level of carbon-dioxide emissions from electricity and heat production as percentage of total fuel combustion. The characters of i and t indicate country i at year t in our international sample of 36 countries, respectively.

3.2. Measuring financial development

Previous literature has provided several indicators to evaluate the effects of financial development on a country's economic growth, stability, and inequality (Dabla-Norris and Srivisal, 2013; Demirgüç-Kunt and Levine, 2009; Levine, 2005a). Financial development considers the crucial functionality of a country's financial systems including (1) accumulating savings, (2) capital allocation, (3) efficiently allocating capital to investments, (3) keeping track of those investments, (4) diversifying associated risk factors, and (5) interchanging goods and services (Levine, 2005a). Hence, measuring a country's financial development is a multidimensional process; however, most of the studies since the 1970s proxy the financial development by using only two measures of the depth of financial systems which are private credit to GDP ratio and market capitalization to GDP ratio (J. Arcand, Berkes and Panizza, 2012; Dabla-Norris and Srivisal, 2013; Raghuram G Rajan and Zingales, 1996). In the modern fast-growing economy, financial sectors have global involvements, and the financial systems have evolved across different dimensions (Li et al., 2022). Hence, employing single and separate proxies might lead to biases and fail to fully capture a country's financial development.

Consequently, measuring a country's financial development is a multidimensional approach. We utilize the overall financial development index (FD) as the main proxy, as it is a multidimensional index composed of eight sub-proxies capturing how a country's financial institutions and financial markets have been developed including their depth, access, and efficiency.[2] The FD is estimated by employing a three-step standard procedure including (i) normalizing variables, (ii) aggregating normalized variables into the sub-proxies capturing specific functionality, and (iii) aggregating all the sub-proxies into the final multidimensional FD index. This multidimensional procedure conforms to the Handbook of Constructing Composite Indicators offered by the OECD (2008) which is a referencing source for detailed methodological

[2] This multi-dimensional procedure is offered by IMF following the coverage of financial system features described by Čihák et al. (2012).

description.[3] The financial indexes are constructed using the Financial Statistics (FinStats) as the more updated version of the World Bank's Global Financial Development Database (GFDD) preferred by Čihák et al. (2012) who complied with additional debt securities data offered by the Bank of International Settlements (BIS) and the IMF Financial Access Survey. The final and sub-indexes are apprehended together on the bases of 46 indicators in FinStats and 105 distinct indicators in GFDD that enable a comprehensive evaluation of the overall financial development and specific characteristics of financial systems.

3.3. Causal relationship between green growth and financial development

Previous literature has detected the positive relation between financial development and economic growth (Bist, 2018; F. Pan and Yang, 2019), between financial development and sustainable growth (Adams et al., 2018; Ahmed et al., 2021), and between financial development and environmental quality (Adams and Klobodu, 2018; Boutabba, 2014; Ozturk and Acaravci, 2013). Particularly, financial development can create opportunities for industries to access advanced/environment-friendly machinery and technologies and thus improve green growth (Adams et al., 2018; Ahmed et al., 2021; Ozturk and Acaravci, 2013). The recent review of Capasso et al. (2019) on the drivers and barriers of green growth also suggests that natural resources, human capital, research and development (R&D), market condition, and policy/institutions are key factors that can affect green growth. Considering that green growth concerns sustainable growth, the increases in productivity and efficiency, which are proxied by human capital and R&D, can obviously promote economic development while reducing the use of natural resources as well as minimizing negative externalities such as emissions and wastes (Hao et al., 2021; Tawiah et al., 2021). Additionally, larger markets tend to consume more and produce more, which in turn create larger impacts on nature (Hao et al., 2021; Samad and Manzoor, 2015). We consequently argue that the green growth of a country can be modelled as

$$GG = \alpha_0 + \alpha_1 FD + \alpha_2 RD + \alpha_3 EDU + \alpha_4 POP + \alpha_5 HDI + \varepsilon, \quad (2)$$

where GG stands for the country's green growth, FD stands for the country's financial development, RD stands for the country's expenditures on research and development, EDU stands for education expenditures of that country, POP stands for the country's population growth which represents its market size, and HDI stands for the country's human capital index which represents the country's human capital. Notably, the time and country subscripts are omitted for ease of expression.

Notably, financial development not only can affect economic development (and consequently sustainable development or green growth), evidence proves that economic development can also influence the development in the financial market. Specifically, the finance-growth nexus has undergone intensive examination in Levine (2005b), Law et al. (2013) and Herwartz and Walle (2014), among others. A recent study of Fernandes et al. (2021) using data from 32 countries between 1990 and 2013 has found that green growth can further promote economic growth. Additionally, evidence proves that the country's stock market, foreign direct investment, and trade are good IVs for its financial development, because a direct and strong relationship exists between them and the financial sector (Hadad et al., 2011; Herwartz and Walle, 2014; Ngo and Le, 2019; Odugbesan et al., 2020; Siddikee and Rahman, 2020; Suliman and Elian, 2014; Temiz Dinç, Gökmen, Nakip and Azari, 2017). Overall, market size and human capital are also considered important factors that can affect the financial sector, according to Hatemi-J and Shamsuddin (2016), Ibrahim and Sare (2018), and Zaidi et al. (2019), among others. We therefore hypothesize that for an examined country, green growth could also influence its financial development as in Equation (3) below.

$$FD = \beta_0 + \beta_1 GG + \beta_2 SMARKET + \beta_3 FDI + \beta_4 TRADE + \beta_5 POP + \beta_6 HDI + \varepsilon \quad (3)$$

where SMARKET is the size of the stock market, FDI is the foreign direct investment, and TRADE is the trade balance.

Instead of independently estimating equations (2) and (3) from each other using the OLS approach, we treat them as a system of equations. In this sense, the causal relationship between the two (dependent) variables GG and FD can be simultaneously accounted for, thus possibly treating the endogeneity issue. Apparently, Equation (3) has RD and EDU as instrument variables (IVs) for GG; while Equation (2) has SMARKET, FDI, and TRADE as instruments for FD. This over-identification assures that our system of equations can be estimated successfully (Wooldridge, 2016). Recent studies including Wooldridge (2016), Ngo and Le (2019), and Fernandes et al. (2021) further argued that the estimation methods such as the Seemingly Unrelated Regressions (SUR), two- and three-stage least squares (2SLS/3SLS), and the generalized methods of moment (GMM) are the efficient econometric tools for such simultaneous equation models. Notably, SUR will estimate the equations of interest under the assumption that only the errors of those equations are (likely to be) correlated (Ngo and Le, 2019). Thus, its results persistently suffer from endogeneity bias. By contrast, GMM estimates the two in parallel with the help from lagged values of the dependent variables as additional IVs and can therefore overcome the endogeneity problem. Notably, GMM is often seen as a generalized model of SUR and 2SLS/3SLS (Lee et al., 2016). Consequently, GMM has been used intensively to deal with the endogeneity issue, especially under a system of equation setting (Haouas et al., 2005; T. D. Le, Ho, Nguyen and Ngo, 2022; T. D. Q. Le, Ho, Nguyen and Ngo, 2021; Ngo and Le, 2019; Ullah et al., 2018). This study consequently employs the 2-step efficient GMM (Hayashi, 2000) for its estimations while considering the country and time fixed effect.

3.4. Data and variable selection

We collect data for this study from the three main databases as follows. First, FD was extracted from the financial development index database of the IMF (Sahay et al., 2015). Second, data for calculating GG (i.e., *GDP*, *NRP*, *NFD*, and CO_2) as well as for the other factors (e.g., *SMARKET* or *POP*) are collected from the World Bank's World Development Indicators (World Bank, 2021a). Finally, *HDI* was extracted from the Human Development Reports (United Nations, 2020). Beginning from 7059 (country-year) observations for FD, 13,237 observations from the WDI, and 5670 observations for HDI, after matching and removing for the missing ones, we ended up with an unbalanced panel dataset of 388 country-year observations covering 36 countries during the 1996–2014 periods (see Appendix 1 for a list of countries involved in this study). Considering that the data for *NRP* and CO_2 are only available up to 2014, we could not extend our dataset further to this point (see also Appendix 2). Table 2 below presents the statistics of those variables. Conversely, the average country of our sample had no sustainable growth (i.e., negative green growth)[4] although that country had a moderate level of financial development. The average country also spent approximately 1.5% and 5% of its GDP for R&D and education, respectively. The development of the stock market at this average

[3] Apart from the OECD Handbook for constructing financial indexes, please also see the other works of Amidžic et al. (2014); Cámara and Tuesta (2014); and Cardarelli et al. (2009).

[4] This negative figure of GG is similar to the statistic of Ahmed et al. (2021), although the latter only used data from several South Asian countries, such as Pakistan, India, Bangladesh, and Sri Lanka for the 2000–2018 periods.

country was still limited (valued at approximately 2.2% of GDP), but it has been an open economy with more than 10% FDI inflows and 100% trade balanced compared with its GDP. The average country also experienced a slight population growth of nearly 0.4% per annum. Its human development index was above the 0.8 mark, suggesting that most of our samples are developed countries. In fact, 283 observations in our dataset are from advanced markets (according to the IMF's definition), whereas only 105 observations are from emerging markets. Appendix 3 presents the details of the selected variables, definitions, and sources.

4. Results and discussions

4.1. Unit root testing

Given that our data cover a 19-year period (1996–2014), testing for the stationarity of the variables of interest is required. Among others, the Fisher-type unit root test is the simple, straightforward, and more efficient process than the Levin-Lin and Im-Pesaran-Shin unit-root tests and can handle unbalanced data (Maddala and Wu, 1999). Notably, our data contain gaps. Phillips and Perron (1988) proposed a Fisher-type unit root test (named after them as the PP test) that is nonparametric, allowing for a wide class of weakly dependent and even heterogeneous data. The PP test is therefore more powerful than the traditional (augmented) Dickey-Fuller unit root test. We consequently report the results of our PP unit root tests for our data as in Table 3 below. Accordingly, unit root exists in RD, TRADE, POP, and HDI. We therefore use their first differences in our analysis.

4.2. Robustness testing

As discussed earlier, more than one estimation method can be used to examine our research question. We therefore need to test if our chosen method (i.e., the 2-step efficient GMM estimator) is better than the others, and if our results are robust to the estimation method. Table 4 compares the estimation results for the relationship between the independent variables and the dependent one in terms of their signs and significance using OLS, 3SLS, SUR, and (2-step) GMM. We first observed that treating the two equations independently with OLS fails to investigate the (causal) relationship between FD and GG, because no significant relationship can be found between the two. Second, all the 3SLS, SUR, and GMM confirm the causality between GG and FD, with estimation results for other variables also consistent. We therefore argue that the treatment of Equations (2) and (3) as a system of equations is appropriate, and that the results of the 2-step efficient GMM are robust. Consequently, our discussions in the following section are based on those GMM results.

4.3. Results and discussions based on the 2-step GMM estimations

The 2-step system GMM is novel to traditional IV class estimation such as 2SLS and 3SLS in using a weighting matrix that considers temporal dependence, heteroscedasticity, or autocorrelation (for further details, please see Lee et al., 2016, etc.). Similar to 2SLS/3SLS, however, it still includes two stages in which the first stage estimates a reduced form of endogeneity variables (here are GG and FD), and the second stage used their fitted values (derived from the first stage) to estimate equations (2) and (3) instead of their original values. Table 4 presents the statistics of our first-stage estimations. First, SMARKET and EDU are good IVs for FD and GG, respectively (see Panel 5A of Table 5). Thus, the use of GMM estimators in estimating Equations (2) and (3) can overcome the endogeneity issue. Second, all the tests for under-identification, over-identification, and weak-identification for both equations using the Anderson and Rubin (1949), Anderson (1951), Sargan (1958), Cragg and Donald (1993), Stock and Wright (2000), and Sanderson and Windmeijer (2016) tests suggest that using those IVs in our system of equations is justified (see Panel 5B of Table 5).

The following details the second-stage results of the 2-stage system GMM estimation. In the first part of Table 6, we report the estimation results of Equation (2) where GG is the dependent variable, while FD and other factors are the independent variables. Evidence proves that financial development can positively influence green growth, whereas one percentage point increase in FD results in 21.397 percentage point increase in GG (although this association is weak at only 6.6% level of significance), further confirming the relationship between FD and GG (Adams et al., 2018; Ahmed et al., 2021; Ozturk and Acaravci, 2013). Human capital is also confirmed to be an important determinant of green growth, as evident through the positive and significant coefficients of EDU and HDI.

We also found a positive and significant impact from green growth to financial development, confirming our hypothesis on the causality between the two variables. Particularly, one percentage point increase in GG can lead to 0.008 percentage point increase in FD (see the second part of Table 6). This finding extends the argument of Fernandes et al. (2021) to not only confirm that green growth can help improve economic development but also has a positive impact on financial development (which is an important part of economic development). Given that the impact of GG on FD is larger than the one of FD on GG (i.e., 0.008 versus 21.397), we further argue that while both factors are important, countries should put extra efforts on the development of their financial sector. Table 6 also suggests that financial development positively associates with the development of the country' stock market (SMARKET) and foreign direct investment (FDI) but negatively associates with HDI. Therefore, the development of a country's financial market can be improved by increasing its capital flows and inflows.

The negative impact of HDI on FD surprisingly contradicts the literature (Ibrahim and Sare, 2018; Z. Khan, Hussain, Shahbaz, Yang and Jiao, 2020; Zaidi et al., 2019); however, it is explainable. Particularly, those previous studies examined developing countries where (i) their financial sectors are not well developed, (ii) their education systems and human capital remain low; thus, (iii) the contribution of HDI on FD is positive. In this study, we cover a wide range of countries with 283 observations for advanced markets and 105 observations for emerging markets (according to the IMF's definition), respectively, accounting for nearly 73% and 27% of our sample. While sustainable/green growth and financial development may be more apparent in the advanced markets, the role of HDI in this setting may not be that important. For example, Zaidi et al. (2019) found that human capital does not affect financial development in a sample of 31 OECD countries. In fact, when we run Equation (3) on those two groups of countries in our sample, the negative relationship between HDI and FD is only significant in advanced markets ($\beta_6 = -13.998$, $p-value = 0.001$) but not in emerging markets ($\beta_6 = -13.437$, $p-value = 0.725$).

When we further account for the country and time fixed effects in our models, we also find the bidirectional relationship between green growth and financial development, although the coefficients are now different. Nonetheless, they are still both positive and significant (see Table 7). Nonetheless, Table 7 also suggests that when the differences in time and country characteristics are included, they can explain for the relationship between GG and FD. Thus, most of the other factors become insignificant. The negative but insignificant coefficient of HDI on FD (see row 7 of the second part of Table 7) further supports our previous argument in the sense that by analyzing the differences between the examined countries (and over time), one may find that the role of HDI in this setting is not that important.

Overall, our empirical results show that the positive causal relationship between financial development and green growth does exist. Given that the impact of FD on GG is larger than that of GG on FD, continuing financial development is justified for countries, as it will foster green growth in the end. Our findings also support the sustainable development policy such as the SDGs (United Nations, 2018; World Bank, 2021b), as it could also help strengthen financial development. To develop the financial market, governments can put extra emphasis on

Table 2
Descriptive statistics of the variables of interest.

Variable	1996–2000		2001–2005		2006–2010		2011–2014		1996–2014	
	Obs	*Mean*	*Obs*	*Mean*	*Obs*	*Mean*	*Obs*	*Mean*	*Obs*	*Mean*
GG	74	−115.69	126	−121.24	106	−127.77	82	−124.25	388	−122.60
FD	74	0.51	126	0.51	106	0.58	82	0.55	388	0.54
RD	74	1.34	126	1.29	106	1.31	82	1.56	388	1.36
EDU	74	4.98	126	4.94	106	4.88	82	5.15	388	4.98
SMARKET	74	2.66	126	2.18	106	2.36	82	1.51	388	2.18
FDI	74	4.74	126	5.89	106	18.97	82	13.45	388	10.84
TRADE	74	81.57	126	88.91	106	106.70	82	127.26	388	100.47
POP	74	0.39	126	0.32	106	0.47	82	0.30	388	0.37
HDI	74	0.80	126	0.82	106	0.84	82	0.86	388	0.83

Notes: *Obs* stands for observations, *GG* stands for green growth, *FD* stands for the financial development index, *RD* stands for the expenditures on research and development (% of GDP), *EDU* stands for education expenditures (% of GDP), *POP* stands for population growth (in %), *HDI* stands for the human development index; *SMARKET* is the traded value of the stock market (% of GDP), *FDI* is the net inflows of foreign direct investment (% of GDP), and *TRADE* is the trade balance (% of GDP).

Table 3
The PP unit root tests for the variables of interest.

Variables	Tests at levels				Tests at first differences			
	No trend		Trend		No trend		Trend	
GG	−1.65	**	−1.91	**	−14.29	***	−10.62	***
FD	−2.16	**	−1.29	*	−11.92	***	−11.50	***
RD	3.15		0.94		−8.89	***	−7.96	***
EDU	−2.45	***	−2.65	***	−13.20	***	−8.16	***
SMARKET	−8.77	***	−2.92	***	−11.64	***	−9.50	***
FDI	−5.47	***	−5.49	***	−18.62	***	−15.39	***
TRADE	0.86		1.98		−9.24	***	−7.38	***
POP	3.22		2.89		−6.41	***	−4.03	***
HDI	1.28		1.19		−6.48	***	−10.16	***

Notes: *GG* stands for green growth, *FD* stands for the country's financial development, *RD* stands for the country's expenditures on research and development, *EDU* stands for education expenditures of that country, *POP* stands for the country's population growth which represents its market size, *HDI* stands for the country's human capital index which presents the country's human capital; *SMARKET* is the size of the stock market, *FDI* is the foreign direct investment, and *TRADE* is the trade balance. ***, ** and * denote the rejection of the null of a unit root for the significance levels at 1%, 5% and 10%, respectively.

Table 4
Regression results derived from different estimation methods.

	OLS		3SLS		SUR		GMM	
	Sign	Significance	Sign	Significance	Sign	Significance	Sign	Significance
Equation (2): GG as dependent variable								
FD	+		+	*	+	**	+	*
RD	+		+		+		+	
EDU	+	***	+	**	+	***	+	**
POP	–		–		–		–	
HDI	+	*	+	**	+	**	+	**
Constant	–	***	–	***	–	***	–	***
Equation (3): FD as dependent variable								
GG	+		+	***	+	***	+	***
SMARKET	+	***	+	***	+	***	+	***
FDI	+	**	+		+	**	+	***
TRADE	–		–		–		–	
POP	–		+		–		+	
HDI	–	***	–	***	–	***	–	***
Constant	+	***	+	***	+	***	+	***

Notes: "+" represents a positive relationship; "-"represents a negative relationship; ***, ** and * denote 1%, 5% and 10% level of significance, respectively.

the stock market and foreign direct investment. To attain a green economy, efforts need to be focused on education and human capital, especially for developing countries.

5. Conclusions

The previous literature has investigated the relation and importance of green growth and financial development to several different aspects of the real economy. However, in the context of a multinational perspective and the nature of both specific advanced and emerging economics, revisiting the effects of financial development and green growth is critical to generate well-balanced outputs for not only economic outcomes but also SDGs in the long run. Consequently, those research questions have become one of the top priorities for researchers, regulators, policy makers, and economists from public and private agencies.

Using the most comprehensive global sample of 36 emerging and developed countries around the globe during the 1996–2014 period (a

Table 5
Results from the GMM's first-stage regression 5A. Regression results.

Dependent variable	FD			GG		
	Coef.		Std. Err.	Coef.		Std. Err.
Instrumental variables						
RD	0.0793		0.083	7.2203		13.778
EDU	0.0452	***	0.007	5.4420	***	1.188
SMARKET	0.003	***	0.000	0.0698	**	0.034
FDI	0.0003		0.000	−0.2387	***	0.053
TRADE	−0.0005		0.001	0.2846		0.180
POP	−0.008		0.026	−2.1101		4.239
HDI	−8.9185	***	2.052	576.5970	*	338.859
Constant	0.2704	***	0.039	−154.2421	***	6.474

5B. Estimated statistics

Identifications tests	FD			GG		
	Statistic	p-value	Conclusion	Statistic	p-value	Conclusion
Under-identification (H_0: The equation is under-identified)						
SW	219.53	0.001	Reject H_0	22.75	0.001	Reject H_0
ALM	128.86	0.001	Reject H_0	21.2	0.001	Reject H_0
Weak-identification (H_0: The instruments are weak instruments)						
CD	71.3	0.001	Reject H_0	11.08	0.001	Reject H_0
ARF	8.58	0.001	Reject H_0	21.18	0.001	Reject H_0
ARW	26.4	0.001	Reject H_0	43.47	0.001	Reject H_0
SWLM	24.34	0.001	Reject H_0	38.15	0.001	Reject H_0
Over-identification (H_0: The instruments are valid)						
SG	0.072	0.788	Accept H_0	0.018	0.893	Accept H_0

Notes: FD stands for financial development; GG stands for green growth; Coef. stands for coefficient; Std. Err. stands for standard error; SW stands for the Sanderson-Windmeijer χ^2 statistic; CD stands for Craig-Donald Wald F statistic; ALM stands for the Anderson LM statistic; ARF stands for the Anderson-Rubin Wald F statistic; AFW stands for the Anderson-Rubin Wald χ^2 statistic; SWLM stands for the Stock-Wright LM statistic; SG stands for the Sargan χ^2 statistic; ***, ** and * denote 1%, 5% and 10% level of significance, respectively.

Table 6
Results from the GMM' second-stage regression.

Equation (2): GG as dependent variable			
Independent variable	**Coef.**	**Std. Err.**	**p-value**
FD	21.397	11.651	0.066
RD	10.403	14.142	0.462
EDU	3.175	1.312	0.016
POP	−2.595	4.324	0.548
HDI	842.443	374.874	0.025
Constant	−155.915	7.690	0.001
Equation (3)**: FD as dependent variable**			
Independent variable	***Coef.***	***Std. Err.***	***p-value***
GG	0.008	0.002	0.001
SMARKET	0.002	0.000	0.001
FDI	0.002	0.000	0.001
TRADE	−0.003	0.002	0.117
POP	0.010	0.044	0.827
HDI	−13.762	3.573	0.001
Constant	1.560	0.277	0.001

Notes: FD stands for financial development; GG stands for green growth; Coef. stands for coefficient; Std. Err. stands for standard error.

Table 7
Results from the GMM regression with country and year fixed effects.

Equation (2): GG as dependent variable			
Independent variable	**Coef.**	**Std. Err.**	**p-value**
FD	71.772	23.897	0.003
RD	−1.165	2.705	0.667
EDU	−0.396	0.818	0.629
POP	−0.075	0.797	0.925
HDI	195.924	75.949	0.010
Constant	−152.702	17.502	0.001
Equation (3)**: FD as dependent variable**			
Independent variable	***Coef.***	***Std. Err.***	***p-value***
GG	0.010	0.005	0.042
SMARKET	0.000	0.000	0.426
FDI	0.000	0.000	0.945
TRADE	−0.000	0.000	0.945
POP	0.002	0.009	0.851
HDI	−1.848	1.379	0.180
Constant	1.704	0.558	0.002

Notes: FD stands for financial development; GG stands for green growth; Coef. stands for coefficient; Std. Err. stands for standard error.

total of 388 country-year observations), our study first reaffirms the nexus presented between green growth and financial development across the whole sample over the recent decades. Second, we contribute further to the ongoing literature by providing a bidirectional relation between green growth and a country's financial development. In other words, green growth can affect a country's financial development and vice versa. This finding is critical not only to the existing theoretical background but also to future empirical works, while most previous studies focus mainly on their one-way relation. We also produce robustness checks for this important finding via a combination of several economic approaches and techniques as exhibited in Sections 3 and 4, respectively. Finally, our findings release a negative impact of human capital (HDI) on financial development which is somehow contradictory to the previous literature. This finding is controversial but provides a strong rationale to a sub-group of emerging economies in our sample where their human capital remains relatively low, negatively affecting the financial development index compared with the advanced economies.

Our findings provide important insights to regulators, policy makers,

and related parties in simultaneously understanding and suggesting strategically long-term plans for a country's financial development and green growth toward the SDGs.[5] Additionally, the bidirectional relation between green growth and financial development as well as the inverse impact of human capital on financial development once again reflect an important perspective in terms of both international cooperation as well as the nature of each country when researchers, regulators, and related agencies carry out empirical works and policy briefs. Consequently, a strong need arises for further research, particularly by the sub-groups of sample countries considering a range of their social and economic features in the short, medium, and long terms. As such, seeing future studies employing advanced techniques such as ARDL, forecasting, and machine learning on this topic would be interesting. Future studies should also work on the impacts of global events (e.g., the 2007 global financial crisis or the Coronavirus disease COVID-19) on financial development and green growth.

Considering that the bidirectional nexus between FD and GG is presented in our study through an international context of 36 countries across regions worldwide, it provides critical implications to policymakers, scholars, and related parties in future studies on the roles of FD toward GG in the context of the 2030 Agenda for Sustainable Development adopted by the United Nations to consider other critical factors that may change across countries and regions for climate change adaptation and mitigation toward the world's sustainable development. Apart from the central roles of human capital and education expenditure, the other critical determinants such as financing sustainable infrastructure (Global Infrastructure Initiative, 2017; Thacker et al., 2019; Trinh et al., 2022) and smart energy systems and energy efficiency (Trinh, 2021; Trinh et al., 2022), play undeniable roles in the trajectory between FD and GG toward SDGs.

Based on our empirical findings and the extant literature on sustainable development, energy and climate change; policymakers may need to consider the escalating needs and gaps in financing sustainable infrastructure development along with the presence of the bi-directional nexus between FD and GG which are particularly critical to high-polluting countries[6] such as Bangladesh, India, Pakistan, etc. This is also important to the world's leading economies whose primary energy consumption is heavily dependent on fossil fuel energy (nonrenewable) sources for economic growth (EG) such as China, the US, Russia and India.[7] As documented by the Global Infrastructure Initiative, 2017; Thacker et al. (2019); Trinh (2021); policymakers need to thoroughly evaluate the trajectories between GG, FD, EG and infrastructure investments for addressing the long-run climate change impacts and achieving the UN Sustainable Development Goals where human capital development and education expenditure show their central roles worldwide.

Author statement

Thanh Ngo: Conceptualization, Ideas, Methodology, Formal Econometric Analysis, Software Data Curation, Writing, Editing. **Hai Hong Trinh:** Ideas, Data Curation, Review & Editing, Polishing Writing, Final Revision, Story Formation and Project Management. **Ilham Haouas:** Literature Review, Writing, Introduction, Proofreading, Resources and Editing. **Subhan Ullah**: Validation, Investigation, Resources, Review, Directions and Project Management.

Data availability

Data will be made available on request.

Appendix 1. List of sample countries in this study

No.	Country	Country Code	Region	Income Group
01	Austria	AUT	Europe	Advanced
02	Belgium	BEL	Europe	Advanced
03	Canada	CAN	Western Hemisphere	Advanced
04	China	CHN	Asia and Pacific	Emerging
05	Croatia	HRV	Europe	Emerging
06	Cyprus	CYP	Europe	Advanced
07	Czech Republic	CZE	Europe	Advanced
08	Denmark	DNK	Europe	Advanced
09	Estonia	EST	Europe	Advanced
10	Finland	FIN	Europe	Advanced
11	France	FRA	Europe	Advanced
12	Germany	DEU	Europe	Advanced
13	Hong Kong SAR, China	HKG	Asia and Pacific	Advanced
14	Iceland	ISL	Europe	Advanced
15	Ireland	IRL	Europe	Advanced
16	Israel	ISR	Europe	Advanced
17	Italy	ITA	Europe	Advanced
18	Japan	JPN	Asia and Pacific	Advanced
19	Kazakhstan	KAZ	Middle East and Central Asia	Emerging
20	Korea, Rep.	KOR	Asia and Pacific	Advanced
21	Lithuania	LTU	Europe	Advanced
22	Luxembourg	LUX	Europe	Advanced
23	Netherlands	NLD	Europe	Advanced
24	New Zealand	NZL	Asia and Pacific	Advanced
25	Norway	NOR	Europe	Advanced
26	Portugal	PRT	Europe	Advanced
27	Qatar	QAT	Middle East and Central Asia	Emerging
28	Russian Federation	RUS	Europe	Emerging
29	Singapore	SGP	Asia and Pacific	Advanced

(*continued on next page*)

[5] For other details of SDGs, please see: https://sdgs.un.org/goals.

[6] Please visit Most Polluted Countries 2022 (worldpopulationreview.com).

[7] Please see the world map of primary energy consumption measured in terawatt-hours (TWh) by country at Energy Data Explorer - Our World in Data.

(*continued*)

No.	Country	Country Code	Region	Income Group
30	South Africa	ZAF	Africa	Emerging
31	Spain	ESP	Europe	Advanced
32	Sweden	SWE	Europe	Advanced
33	Switzerland	CHE	Europe	Advanced
34	Thailand	THA	Asia and Pacific	Emerging
35	United Kingdom	GBR	Europe	Advanced
36	United States	USA	Western Hemisphere	Advanced

Appendix 2. Green growth (GG) and Financial Development (FD) by country

Appendix 3. Variables, definitions and sources

Variable	Brief description	Source
GG	Green growth index is estimated by the authors using Eq. (1) where GG = GDP + EE – NRP – NFD – CO_2	WDIs-WB
GDP	Annual growth rate of gross domestic product (%)	WDIs-WB
EE	Education expenditure for each of 36 sample countries – EDU.	WDIs-WB
NRP	Level of minerals depletion (including crude oil, coal and natural gas) and is proxied by the amount of fossil fuel consumption as percentage of total energy consumption	WDIs-WB
CO_2	Level of carbon-dioxide emissions from electricity and heat production as percentage of total fuel combustion.	WDIs-WB
FD	The composite financial development index introduced by IMF which covers the development of financial markets (FM) and financial institutions (FI) including their accessibility, depth and efficiency for each of 36 sample countries.	FD-IMF
RD	Expenditures on research and development (% of GDP)	WDIs-WB

(*continued on next page*)

(*continued*)

Variable	Brief description	Source
HDI	Human capital index (HCI) (scale 0–1)	WDIs-WB
SMARKET	Traded value of the stock market (% of GDP)	WDIs-WB
TRADE	Trade balance (% of GDP).	WDIs-WB
FDI	Net inflows of foreign direct investment (% of GDP)	WDIs-WB

Note: World Development Indicators database by the World Bank (WDIs-WB) can be accessed via https://datatopics.worldbank.org/world-development-indicators/. Financial Development Index Database by International Monetary Fund (FD-IMF) can be accessed via https://bit.ly/3PziG6T.

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