The effect of digital financial inclusion on the green economy: the case of Egypt

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Abstract

Purpose – This paper aims to assess whether digital financial inclusion (DFI) supports Egypt's CO_2 reduction efforts. More specifically, this paper examines the dynamics between digital finance, traditional financial inclusion (TFI) and renewable energy on carbon emission in Egypt.

Design/methodology/approach – The study employed the autoregressive distributive lag (ARDL) model for Egypt over the period 1990–2020 to estimate an extended STIRPAT model for long-run linkages of DFI, traditional bank-based financial inclusion and renewable energy on carbon emissions, along with other control variables.

Findings – The results showed that using digital financial services limits carbon emissions in the long run but not in the short run, indicating that Egypt is still in its early stage of digitalization (DFI < 0.5). Moreover, renewable energy proved to have a significant negative impact on carbon emissions in the long run, implying that more investments in renewable energy projects will improve environmental quality.

Practical implications – The findings from this study help policymakers incorporate DFI policies into climate change adaptation strategies and execute better green growth policies that integrate DFI with energy-efficient technologies investments for a better environment.

Social implications – Foster economic growth and sustinabaility.

Originality/value – This study contributes to the literature by quantifying the DFI in Egypt using a two-stage principal component analysis and then examines its impact on carbon emission reduction efforts. In addition, this paper extends the research on the environment from the perspective of digital finance, making it possible to excavate more deeply into the relationship between financial inclusion and carbon emission and draw more explicit policy implications for sustainable economic growth.

Keywords CO_2 emissions, Digital financial inclusion, Traditional financial inclusion, Climate change, Sustainability

Paper type Research paper

1. Introduction

Egypt is facing dual challenges: to maintain a sustainable economic growth rate and improve environmental quality by reducing CO_2 emissions. Thus, to face these challenges, Egypt Vision 2030 focuses on achieving higher digital financial inclusion (DFI) and reducing carbon emissions as the main goals to achieve environmental sustainability. Financial inclusion policies are designed to provide easier access to and use of all financial services, which foster

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economic activities and thereby raise the demand for energy-intensive durable goods whose uses contribute heavily to carbon emissions and environmental pollution. Frankel and Romer (1999) and Zaidi et al. (2021) show that Egypt's rapid economic growth, along with high consumption rates of polluting fossil fuel energy, is increasing carbon emissions and leading to climate change.

In this context, an important question was raised on how traditional financial inclusion (TFI) and DFI affect carbon emissions, especially in developing and emerging countries that set high economic growth rates as their primary goal regardless of their effect on environmental quality. Renzhi and Baek (2020) and Salman and Hosny (2021) discuss the impact of reducing carbon emissions and achieving sustainable economic growth as the most critical challenges faced by countries worldwide. Other scholars expect that DFI is expected to limit carbon emissions where more funds are provided for green technology initiatives that significantly limit fossil fuel energy consumption and reduce carbon emissions (Love, 2003; Lin et al., 2017; Wan et al., 2021). Therefore, DFI, economic development and climate change policies can be coordinated to create a synergy.

Although the effect of financial development on carbon emissions has been studied heavily in the literature (Shahbaz et al., 2013; Charfeddine and Kahia, 2019), only a few studies examined the link between financial inclusion and CO_2. Most previous studies were more concerned with financial inclusion's influence on economic growth, poverty and gender equality, ignoring its effect on climate change. Furthermore, only a few studies discuss the impact of DFI on environmental degradation. Thus, the literature on how financial inclusion impacts the environment is still in its infancy, and the research regarding the impact of DFI on the environment is still blank and thus currently is receiving extensive attention from researchers (Wan et al., 2021).

Against this background, this paper aims to examine the effect of DFI, renewable energy, foreign direct investment (FDI) and other control variables on carbon emissions in Egypt. The contribution of the paper to the literature is three-fold: first, to the best of our knowledge, this paper is the first attempt to study the effect of DFI on CO_2 emissions in Egypt at the country level. Second, we decompose the financial inclusion index into two separate indices: DFI and TFI, using two-stage principal component analysis (PCA). By doing so, the effect of both TFI and DFI on CO_2 emissions is captured separately. Thus, the empirical results can help policymakers and researchers better understand why and how DFI limits CO_2 emissions and draw more explicit policy implications for Egypt's climate change policies.

The rest of the paper is organized as follows. Section 2 summarizes the related literature; section 3 introduces the data sources and methodologies. Subsequently, section 4 presents research empirical findings and discussion. Section 5 concludes the study and provides managerial and academic implications, and finally, section 6 discusses research limitation and future research.

2. Literature review
2.1 Traditional financial inclusion and CO_2 emissions nexus
Financial inclusion is a broad term that has no single definition. Researchers analyze the weak capacity to access the formal financial system (i.e. financial exclusion) as a massive weakness to the bank-based financial institutions and the country's economic development. Thus, inclusive digital finance engages those involuntarily excluded from using traditional financial services, increasing the level of the inclusiveness of the financial system and boosting the country's economic growth (Sun, 2018; Ozili, 2018; Singh and Stakic, 2021). However, the gains from the superior level of financial inclusion are not only limited to the country's economic development process but also reflected in its financial stability, poverty reduction and better environmental quality.

Even though financial inclusion has become a critical issue on the global policy agenda for sustainable development, economic research is still in its preliminary stages. Only the impact of financial inclusion on economic growth, poverty alleviation and gender inequality has been discussed heavily in the literature, with only a few studies examining the nexus between financial inclusion and CO_2 emissions (Beck *et al.*, 2007). Therefore, reducing carbon emissions is a top priority at the national and regional levels since it is considered a cornerstone to achieving sustainable development goals. The researchers' primary interest is identifying the factors needed to achieve better environmental quality.

The literature available concerning the impact of financial inclusion on CO_2 produced equivocal results; financial inclusion increases environmental pollution, where easier access to credit increases domestic production and investments, thus boosting economic growth and increasing CO_2 emissions. Lin *et al.* (2017) show that higher financial inclusion induces people to increase their demand for durable goods, increasing energy consumption and producing more carbon emissions.

On the other hand, Renzhi and Baek (2020) confirmed a negative relationship between financial inclusion and CO_2. They found that the relationship between financial inclusion and CO_2 is an inverted U-shape; thus, achieving a high level of financial inclusion will force investors to accept stricter measures that improve environmental quality, resulting in lower carbon emissions. Zaidi *et al.* (2021) also confirmed that financial inclusion reduces CO_2 in the Organisation for Economic Cooperation and Development countries in the short and long run. Moreover, Zhao *et al.* (2021) found that with an inclusive financial system, firms can quickly get loans and invest in green technologies which limit CO_2.

2.2 Digital financial inclusion and CO_2 emissions nexus
Inclusive digital finance has evolved as an innovative indispensable part of the financial system, where financial services are delivered through a reliable digital payment system. Thus, inclusive digital finance provides financial services through the full use of the Internet and thus engages those who are involuntarily excluded from the use and access to traditional financial services (Ozili, 2018).

Although the relationship between financial inclusion and environmental pollution had been examined recently, the research regarding the impact of DFI on the environment is still blank. Lin *et al.* (2017) produced equivocal results, and the conclusions were not uniform. The ultimate effect of digital finance on pollutant emissions is expected to be negative. Inclusive digital finance limits carbon emissions by providing investors with diversified financial products, significantly increasing the funds available for green technology initiatives and limiting CO_2 (Le *et al.*, 2016). On the contrary, traditional finance cannot provide the necessary funds for green technological investments due to its considerable risk, high cost and lengthy research period (Love, 2003; Zhao *et al.*, 2021).

Moreover, with the help of information technologies, inclusive digital finance reduces operational costs caused by asymmetric information, disperses risk and expands the investors' group and service scope, providing a basis for diversifying innovation risks in the broader community. Therefore, compared to traditional finance, digital finance is more capable of entering the high-risk innovation fields; financing technological investments promotes green technological innovations, which significantly limits fossil fuel energy consumption and reduces carbon emissions. In addition, FDIs are currently directed toward digital finance "Fintech," which supports technological developments, especially environmentally friendly technologies.

Similarly, high DFI can change the overall industrial structure in a more environmentally friendly direction since digital financial services rely on the user's behavior as the primary data to assess the user's credibility and make credit decisions. Thus, the service sector that relies heavily on information technologies is more likely to benefit from digital finance, and by

directing more funds to this sector, its development will significantly impact carbon emission reduction (Li *et al.*, 2021; Wan *et al.*, 2021). Finally, inclusive digital finance induces consumer engagement in environmental protection activities since it raises consumers' awareness about the importance of going green by eliminating paperwork and encouraging people to move toward cashless societies by using online digital payment gateways (Zhao *et al.*, 2021).

3. Data and methodology

3.1 Data sources
This study examines the role of DFI in reducing CO_2 emissions in Egypt. The data for CO_2, energy intensity, renewable energy, trade openness, economic growth and FDI were extracted from World Bank Development Indicators (WDI). The data used to construct digital and financial inclusion indices are based on the Ministry of Communication and Information Technology (MCIT), Financial Access Survey (FAS – IMF) and International Technology Unit (ITU) over the period 1990–2020.

3.2 Econometric model
The impact of technological development on environmental pollution had been examined for the first time by Ehrlich and Holdren (1971). They proposed the population (P), affluence (A), and technology (T) impact (I) the environment (IPAT) model, which took the form of a linear equation that examines the impact of population growth, technology and affluence on environmental pollution. However, their equation was criticized heavily for being a static equation where no additional variables that might impact the environment are added. In addition, it does not encounter factor or variable elasticities. Due to these limitations, Dietz and Rosa (1997) extend the IPAT equation into a stochastic form known as the "STIRPAT model."

$$I = \alpha_{it} P^{\beta 1} A_{it}^{\beta 2} T_{it}^{\beta 3} \varepsilon_{it}$$

where the impact of human activities on environmental pollution is captured by I, while P.A.T is the driving force of CO_2 emissions defined earlier by Ehrlich and Holdren (1971), and finally, $\beta 1$, $\beta 2$ and $\beta 3$ represent variable elasticities. The STIRPAT model was extended several times to include other crucial factors that impact the environment. Ren *et al.* (2021) add energy structure to the model, and Zaidi *et al.* (2021) add infrastructure, corruption and energy use on the environment. This study extends the STIRPAT model to include the effect of DFI and TFI on environmental pollution (proxied by CO_2). In addition, this study adds other control variables found to have different effects on consumption of energy (CE) in the literature, namely FDI (Zhang and Zhou, 2016), energy intensity, renewable energy, the share of manufacturing and trade openness. Thus, the basic model is as follows:

$$CO_2 = \beta + \beta_1 FI + \beta_2 ENI + \beta_3 REN + \beta_4 FDI + \beta_5 GDP + \beta_6 MAN + \beta_7 TR \quad (1)$$

The dependent variable is CO_2 emissions which capture environmental pollution. The independent variables are energy intensity (ENI), renewable energy (REN), FDI, economic growth proxied by GDP, the value of manufacturing value added (MAN) and trade openness (TR). The most crucial regressor is the DFI index. Since there is no standard way to evaluate the extent of DFI in a country, we developed a multidimensional index that follows the approach proposed by Ismael and Ali (2021). Another index was constructed to examine whether DFI can limit CO_2 emissions in Egypt compared to traditional financial

services, which is the TFI index. By doing so, the effect of both DFI and TFI on CO_2 emissions is captured separately. Thus, the empirical results can help policymakers and researchers better understand why and how DFI limits CO_2 emissions. Both indices were constructed using a two-stage PCA where the process is outlined in Ismael and Ali (2021) (see Table 1).

Therefore, we divide the basic equation into two equations: equation (2) captures the effect of DFI on CO_2, while equation (3) examines the impact of TFI on CO_2.

$$CO_2 = \beta + \beta_1 DFI + \beta_2 ENI + \beta_3 REN + \beta_4 FDI + \beta_5 GDP + \beta_6 MAN + \beta_7 TR \quad (2)$$

$$CO_2 = \beta + \beta_1 TFI + \beta_2 ENI + \beta_3 REN + \beta_4 FDI + \beta_5 GDP + \beta_6 MAN + \beta_7 TR \quad (3)$$

Thus, the impact of both DFI and TFI on CO_2 was estimated using the autoregressive distributive lag (ARDL) model. In this context, two models were used to investigate the impact of financial inclusion on CO_2 in Egypt. The first model examines whether DFI has a significant negative impact on CO_2 emissions and hence its effectiveness in reducing carbon emissions, while the second model examines whether TFI has a positive or negative significant impact on CO_2. The ARDL model and the error correction specification were given in equations (4) and (5) for Model 1 and Model 2, respectively. The first model examines whether DFI has a significant negative impact on CO_2 emissions and hence is effective in reducing carbon emissions. The ARDL model and the error correction specification are given in equations (2) and (3).

Model 1: ARDL and error correction model (ECM) specification

$$\Delta Co2_t = \alpha_0 + \alpha_1 t + \sum_{i=1}^{n} \alpha_1 \Delta DFI_{t-i} + \sum_{i=0}^{n} \alpha_2 \Delta FDI_{t-i} + \sum_{i=0}^{n} \alpha_3 \Delta ENI_{t-i} + \sum_{i=0}^{n} \alpha_4 \Delta REN_{t-i}$$
$$+ \sum_{i=0}^{n} \alpha_5 \Delta GDP + \sum_{i=0}^{n} \alpha_6 \Delta TR_{t-i} + \sum_{i=0}^{n} \alpha_7 \Delta MAN_{t-1} + \vartheta_1 DFI_{t-1} + \vartheta_2 FDI_{t-1}$$
$$+ \vartheta_3 ENI_{t-1} + \vartheta_4 REN_{t-1} + \vartheta_5 GDP_{t-1} + \vartheta_6 TR_{t-1} + \vartheta_7 MAN_{t-1} + \mu_{1t}$$
$$(4)$$

where $\alpha_1 - \alpha_7$ and $\vartheta_1 - \vartheta_7$ are regression coefficients, α_0 is a constant and μ_{1t} is a white noise error term.

Traditional financial inclusion index	Digital financial inclusion index
Access	*Access*
No. of automated teller machines per 100,000 adults	Mobile cellular subscription per 100 people
No. of branches per 100,000 adults	A number of registered mobile money accounts
	% of mobile Internet users
Usage	*Usage*
No. of deposit accounts with commercial banks per 1,000 adults	Mobile payments accounts
No. of borrowers from commercial banks per 1,000 adults	No. of mobile money transactions per 1,000 adults
No. of debit cards per 1,000 adults	Makes online purchases or pays an online bill
No. of credit cards per 1,000 adults	Made an online purchase via mobile

Table 1.
The summary of measurement variables and data sources

$$\Delta co2_t = \alpha_0 + \alpha_1 t + \sum_{i=1}^{n} \alpha_1 \Delta DFI_{t-i} + \sum_{i=0}^{n} \alpha_2 \Delta FDI_{t-i} + \sum_{i=0}^{n} \alpha_3 \Delta ENI_{t-i} + \sum_{i=0}^{n} \alpha_4 \Delta REN_{t-i}$$
$$+ \sum_{i=0}^{n} \alpha_5 \Delta GDP_{t-i} + \sum_{i=0}^{n} \alpha_6 \Delta TR_{t-i} + \sum_{i=0}^{n} \alpha_7 \Delta MAN_{t-1} + \gamma_1 ECM_{t-1} + \mu_{1t}$$

(4a)

where $\alpha_1 - \alpha_7$ and γ_1 are coefficients, α_0 is a constant, ECM_{t-1} is lagged error term and μ_{1t} is a white noise error term

Model 2: ARDL and ECM specification

$$\Delta Co2_t = \alpha_0 + \alpha_1 t + \sum_{i=1}^{n} \alpha_1 \Delta TFI_{t-i} + \sum_{i=0}^{n} \alpha_2 \Delta FDI_{t-i} + \sum_{i=0}^{n} \alpha_3 \Delta ENI_{t-i} + \sum_{i=0}^{n} \alpha_4 \Delta REN_{t-i}$$
$$+ \sum_{i=0}^{n} \alpha_5 \Delta GDP + \sum_{i=0}^{n} \alpha_6 \Delta TR_{t-i} + \sum_{i=0}^{n} \alpha_7 \Delta MAN_{t-1} + \vartheta_1 DFI_{t-1} + \vartheta_2 FDI_{t-1}$$
$$+ \vartheta_3 ENI_{t-1} + \vartheta_4 REN_{t-1} + \vartheta_5 GDP_{t-1} + \vartheta_6 TR_{t-1} + \vartheta_7 MAN_{t-1} + \mu_{1t}$$

(5)

where $\alpha_1 - \alpha_7$ and $\vartheta_1 - \vartheta_7$ are regression coefficients, α_0 is a constant and μ_{1t} is a white noise error term.

$$\Delta co2_t = \alpha_0 + \alpha_1 t + \sum_{i=1}^{n} \alpha_1 \Delta TFI_{t-i} + \sum_{i=0}^{n} \alpha_2 \Delta FDI_{t-i} + \sum_{i=0}^{n} \alpha_3 \Delta ENI_{t-i} + \sum_{i=0}^{n} \alpha_4 \Delta REN_{t-i}$$
$$+ \sum_{i=0}^{n} \alpha_5 \Delta GDP_{t-i} + \sum_{i=0}^{n} \alpha_6 \Delta TR_{t-i} + \sum_{i=0}^{n} \alpha_7 \Delta MAN_{t-1} + \gamma_1 ECM_{t-1} + \mu_{1t}$$

(5a)

where $\alpha_1 - \alpha_7$ and γ_1 are coefficients, α_0 is a constant, ECM_{t-1} is lagged error term and μ_{1t} is a white noise error term

3.2.1 Unit root tests. Before applying ARDL bound test, we need to test for the order of stationarity of the time-series data to ensure that all variables are stationary at a level I (0), the first difference I (1) or mixed integrating order to avoid spurious results that lead to type 1 error and thus biased results (Engle and Granger, 1987; Pesaran *et al.*, 2001; Narayan, 2005). We used augmented Dickey–Fuller (ADF) and Phillips Perron (PP) tests to test for the order of the stationarity of all variables under study. Table 2 confirmed that ARDL bound test can be applied in this study since no variable is integrated at the second difference I (2), where all variables under study are integrated at a level I (0)k, the first difference I (1) or both.

3.2.2 Cointegration testing. Applying ARDL bound requires selecting the optimal lag length to avoid biases in the model's reliability (Baloch, 2018). The Akaike information criterion (AIC) chooses the optimal lag length since it produces more accurate and consistent results than the Schwartz Bayesian criterion. The results show that the optimal lag length selected for Model 1 is ARDL (1, 2, 2, 2, 0, 0, 1, 1) and for Model 2 is ARDL (2,1,2,2,1,0,1,2). After selecting the optimal lag length, we test the existence of a cointegration relation between the dependent and independent variables by performing an "$F-test$" on the null hypothesis that the coefficients on the level variables are jointly equal to zero (Pesaran *et al.*, 2001). The rejection of the null hypothesis indicates a cointegrating long-run relationship between the

Variables	ADF test (at level)	ADF test (at first difference)	PP test (at level)	PP test (at first difference)
CO_2 emissions	−0.269	−4.408***	−0.381	−4.435***
GDP	−3.013**	−7.621***	−3.184	−7.237***
Energy intensity	−1.997	−6.078***	−2.095	−6.064***
Renewable energy	−0.395	−6.560***	−0.185	−7.253***
FDI	−1.817	−3.543**	−2.202	−3.517**
Manufacturing	−1.674	−4.050***	−2.098	−4.041***
Trade	−1.421	−4.197***	−1.690	−4.204***
DFI	−1.162	−6.065***	−0.755	−6.325***
TFI	3.387	−3.793**	1.450	−4.041**

Note(s): *, ** and *** indicate that the null hypothesis is rejected at the 10, 5 and 1% levels of significance, respectively
Source(s): The author's computation using Stata 14

Table 2.
Unit root tests results

variables. According to Pesaran *et al*. (2001), if the *F*-statistic calculated is less than I (0), we accept the null hypothesis that no cointegration relationship among variables exists. On the other hand, if the *F*-statistic exceeds I (1), we confirm the long-run cointegrating relationship between variables. The results of the ARDL bounds tests confirm the existence of a cointegrated long-run relationship between CO_2 and other independent variables in models (1) and (2), where the *F*-statistic lies above the upper bound critical value of 4.26 at a 1% significance level.

3.2.3 Diagnostic tests. The statistical results indicate that the model is a good fit with a high R^2. In addition, diagnostic tests were performed to ensure the accuracy of our results. Table 3 indicates no evidence for serial correlation where the residuals are normally distributed and serially uncorrelated to order two. Moreover, we found no evidence for heteroscedasticity. The Ramsey RESET (Regression Equation Specification Error Test) test indicates that the model is correctly specified for model specification. The CUSUM (cumulative sum control chart) and CUSUMQ (the cumulative sum of squares test) statistics fluctuate within the 5% critical bounds, implying that the estimate parameters are accurate and stable over time. Therefore, the model is stable and provides reliable results.

4. Results and discussions
The long-run results for model 1 showed that five out of seven variables are statistically significant. Our primary key variable, DFI, came significantly with a negative coefficient. This result indicates that digital financial services can limit CO_2 in the long run, where a 1% increase in DFI will reduce CO_2 by 1.466% in the long run. In other words, higher DFI using Internet banking and other digital payment gateways decreases the demand for fossil fuel energy and

LM test statistic	Model 1	Model 2
R^2	0.998	0.938
Adjusted R^2	0.996	0.814
F-statistics	463.59 (0.000)	236.20 (0.000)
Serial correlation	2.82 (0.0209)	2.7682 (0.0003)
Heteroscedasticity	29.00 (0.4125)	29.00 (0.4125)
Normalit	28.09 (0.0000)	28.09 (0.0000)
Ramsey RESET test	1.37 (0.3129)	1.14 (0.3978)

Source(s): The author's computation using Stata 14

Table 3.
The diagnostic tests

thus limits CO_2. Another possible explanation is that inclusive digital financial services have a superior advantage over traditional bank-based financial services as it promotes easy access to green credit and can provide more funds for green technologies initiatives aimed at improving the green economy (Love, 2003; Zhao et al., 2021; Wan et al., 2021). As discussed earlier, financing technological investments promotes green technological innovations which significantly limits fossil fuel energy consumption and reduces CE. The results came in line with previous literature (Wan et al., 2021; Elheddad et al., 2021; Li et al., 2021).

The negative link between renewable energy (REN) and CO_2 emissions in both the long and short run supports the previous result. As more credit facilities are available for green technologies, more investments in renewable energy projects take place, which will improve the environmental quality by limiting CO_2. Our result indicates that increasing the share of renewable energy from total energy output will significantly reduce CO_2 in Egypt. In 2014, the Egyptian government launched a feed-in tariff support system for solar photovoltaic and wind projects to boost renewable energy production. Also, in 2015, Egypt adopted incentive investment measures to attract further investments in the energy sector, especially in the field of renewable energy. In addition, this result might suggest that DFI may affect the energy structure through its moderating role between renewable energy and CO_2 emissions and thus could be an essential policy tool to improve environmental quality in Egypt. Our findings are consistent with the literature (Mehmood, 2021; Ren et al., 2021; Li et al., 2021).

Surprisingly, FDI has an unfavorable impact on CO_2 in Egypt in the long run. This result indicates that foreign investments in Egypt do not consider any environmental regulations. Thus, more FDI inflows will increase CO_2, negatively impacting Egypt's sustainability goals. This result aligns with the pollution haven hypothesis (HPP) that the low environmental regulations in developing countries attract all polluting industries that developed countries refuse to host due to their strict environmental standards (Le et al., 2016). Another proposed explanation is that although FDI inflows are attracted to "Fintech" and the information and communication technology (ICT) sector, which supports technological developments, especially environmentally friendly technologies; however, Egypt is still in its early stage in this field and thus FDI must attract more ICT sector investments for its digital transformation program (Laeven et al., 2015; Yi et al., 2020; Zhang et al., 2020; Wan et al., 2021; Zhao et al., 2021).

Interestingly, openness to trade seems to reduce CO_2 emissions in Egypt in the long run. Trade agreements can promote a cleaner environment by encouraging government officials to tackle environmental issues during signing the agreements (Le et al., 2016). Eliminating trade barriers on environmental goods and services through trade agreements can encourage investors to shift into less polluting industries and facilitate the adoption of eco-friendly technologies at a lower cost (Meltzer, 2014).

Economic growth shows a significant positive impact on CO_2 in both the long and short run, where a 1% increase in GDP will increase CO_2 emissions by 0.056% in the long run and by 0.028% in the short run. This result was expected as Egypt is an emerging country with a high economic growth rate. Thus, as Egypt accelerates its growth rate, it also consumes high energy levels, increasing CO_2. This result indicates that Egypt's economic growth is one of the main pillars of environmental pollution. Moreover, heavy industries that produce higher emissions usually lead to higher economic growth. In addition, as GDP per capita increases, the demand for high energy-consuming products increases and thus leads to more CO_2. Our result suggests that economic growth policies in Egypt are not aligned with its sustainable development goals toward a green economy. This result was supported heavily in the literature (Farhani and Shahbaz, 2014; Sinha and Shahbaz, 2018; Zafar et al., 2020).

Following the research papers of Odhiambo (2009) and Narayan and Smyth (2008), we obtain the short-run dynamic parameters by estimating an ECM associated with the long-run estimates. The short-run estimates of the CO_2 model provide surprising results where DFI and REN significantly impact CO_2 emissions in the short run. This result might suggest that

the extensive credit facilities provided by commercial banks for people applying for online loans result in increased spending on domestic goods, accelerating domestic fossil fuel energy use and leading to higher CO_2. Thus, countries with low DFI, like Egypt (DFI < 0.5), must pay attention to CO_2 emissions in the short run if it needs to achieve their sustainable development goals. Another proposed explanation is that the impact of DFI on environmental quality differs according to the country's development stage. Specifically, DFI might increase CO_2 in the short and medium run and then restrain the emissions in the long run, which suggests an inverted N-shaped relationship between DFI and CO_2 (Wan *et al.*, 2021).

In addition, it is evident that energy use associated with rapid economic growth increases pollution and hence CO_2 in the short run, whereas a 1% increase in energy use increases CO_2 emissions by 0.115% in the short run. This result implies that the consumption of fossil fuel energy is still the main pollutant factor in Egypt. This result is consistent with previous studies (Antonakakis *et al.*, 2017; Wan *et al.*, 2021).

Finally, the ECM (−1) shows the short-run adjustment process. If the coefficient of ECM lies between 0 and −1, the correction to CO_2 emissions in period t is a fraction of the error in period $t-1$. In this case, the ECM causes CO_2 emissions to converge monotonically to its long-run equilibrium path in response to the changes in the exogenous variables. The error correction coefficient is −0.7928 and significant at 1%. This finding implies that the equilibrium adjustment rate is approximately 79% in case of shock. Also, the results indicate that it takes less than one year to adjust any shock in CO_2 emissions in Egypt.

The results of model two came in line with our expectations. The long-run results proved that all independent variables are statistically significant except manufacturing. GDP, energy intensity and TFI significantly impact CO_2, while FDI and renewable energy significantly impact emissions. The results reveal that our primary variable, TFI, increases CO_2 in Egypt, where a 1% increase in TFI leads to a 0.9162% increase in CO_2 in the long run and 1.6686% in the short run (see Table 4). This finding indicates that Egypt is still in its early stage of development, where it allocates its financial resources toward people's needs regardless of how the rise in domestic demand and fossil fuel energy usage will impact the environment. Another reason for the positive link between TFI and CO_2 is that a higher inclusive financial system usually provides huge credit facilities to accelerate the growth rate and thus generate more pollutant industries. This result means that financial inclusion policies are designed without considering the impact on the environment in Egypt. This result came to align with previous literature (Zaidi *et al.*, 2021; Mehmood, 2021).

As in the case of Model 1, the finding of economic growth showed a significant positive impact on CO_2 in both the long run and short run, where a 1% increase in GDP will increase CO_2 emissions by 0.0656% in the long run and by 0.0259% in the short run. This result indicates that Egypt's economic growth is one of the primary sources of environmental pollution (Salman and Atya, 2014; Sinha and Shahbaz, 2018; Zafar *et al.*, 2020). However, the result did not match other literature that found a negative relationship between economic growth and CO_2 emissions.

The coefficient of energy intensity is positive and significant in both the long run and short run, which indicates that a 1% increase in energy use will lead to an increase in CO_2 by 0.0489% in the long run and by 0.031% in the short run. This result indicates that Egypt's economy still depends heavily on fossil fuel energy, which proves that Egypt's economic growth process is dominated by traditional fossil energy. This finding suggests Egypt's policymakers need to reconsider the use of renewable energy instead of fossil fuel energy to be able to achieve its sustainable development goals. Although renewable energy has no significant effect in the short run, the coefficient is negative and statistically significant in the long run. This result supports the positive link between energy use and CO_2 emissions, where Egypt's economic development policies focus on accelerating economic growth regardless of its impact on the environment.

	Model 1: Digital financial inclusion				Model 2: Traditional financial inclusion			
Variable	Coefficient	Standard error	t – stat	Prob.	Coefficient	Standard error	t – stat	Prob.
Long run								
GDP	0.0556	0.0126	4.41	0.001	0.1252	0.0656	1.91	0.089
Energy intensity	0.0169	0.1014	0.17	0.870	0.2794	0.0489	5.70	0.000
Renewable energy	−0.2769	0.0095	−29.09	0.000	−0.2772	0.0260	−10.63	0.000
FDI	0.0175	0.0084	2.08	0.060	−0.0143	0.0044	−3.19	0.011
Manufacturing	−0.0066	0.0160	−0.41	0.689	−0.0153	0.0112	−1.37	0.205
Trade	−0.0031	0.0017	−1.75	0.106	−0.0042	0.0011	−3.83	0.004
DFI	−1.4766	0.3604	−4.10	0.001	–	–	–	–
TFI	–	–	–	–	0.9162	0.2183	4.20	0.002
Short run								
ΔGDP	0.0281	0.0077	3.62	0.003	0.0259	0.0101	2.56	0.031
ΔGDP (1)	0.0103	0.0050	2.05	0.063	–	–	–	–
ΔEnergy intensity	0.2119	0.0759	2.79	0.016	0.2267	0.1152	1.97	0.081
ΔEnergy intensity (1)	0.0979	0.0577	1.70	0.115	0.2324	0.1015	2.29	0.048
ΔRenewable energy	0.1957	0.0464	4.22	0.001	0.0344	0.0349	0.99	0.349
ΔRenewable energy (1)	0.1115	0.0238	4.67	0.001	0.0360	0.0257	1.40	0.195
ΔFDI	–	–	–	–	0.0326	0.0108	3.01	0.015
ΔTrade	−0.0022	0.0014	−1.54	0.150	0.0076	0.0023	3.25	0.010
ΔTrade (1)	–	–	–	–	0.0035	0.0018	1.95	0.083
ΔDFI	1.0860	0.3083	3.52	0.004	–	–	–	–
ΔTFI	–	–	–	–	1.6686	0.8583	1.94	0.084
ΔTFI (1)	–	–.	–	–	0.6317	0.4953	1.28	0.234
ECM (−1)	−0.7928	0.1717	−4.62	0.001	−0.3561	0.1734	−2.05	0.070
R^2 = 0.998		Adjusted R2 = 0.996			R^2 = 0.938		Adjusted R^2 = 0.814	
DW statistic = 2.82		Sum-squared residuals = 0.0073			DW statistic = 2.76		Sum-squared residuals = 0.0106	
F-statistic = 463.59		Prob.(F-statistic) = 0.000			F-statistic = 236.20		Prob. (F-statistic) = 0.000	
Schwartz Bayesian criterion = −100.6734		Akaike information criterion = −123.9174			Schwartz Bayesian criterion = −83.10827		Akaike information criterion = −109.0869	

Table 4.
ARDL statistical
results

As expected, FDI has a negative impact on CO_2 emissions in Egypt in the long run due to the polluting activities but not in the short run. This result indicates that a 1% increase in FDI will decrease CO_2 by 0.0143% in the long run but will increase CO_2 by 0.0259% in the short run. One possible explanation is that moving toward digitalization captures the attention of foreign investors toward "Fintech" and information technology, which supports technological developments, especially environmentally friendly technologies. Thus, FDI has a favorable impact on the environment by transferring green technologies to Egypt. This result was confirmed in the long run where high levels of development are reached, and more FDI inflows reduce CE through transferring green technologies to the host countries.

Interestingly, the coefficient of openness to trade is negative and statistically significant in the long run although positive in the short run. This result indicates that openness to trade seems to reduce CO_2 emissions in Egypt in the long run but not in the short run. The positive coefficient in the short run implies that more trade openness and the resulting inflow of capital increase economic activity and, thus, CO_2. Therefore, policymakers and government officials should consider signing different trade agreements that eliminate trade barriers on environmental goods

and services. Moreover, the ECM (-1) shows the short-run adjustment process. In Model 2, the error correction coefficient is -0.3561 and significant at 10%. This finding implies that the equilibrium adjustment rate is approximately 36% in case of shock. Also, the results imply that it takes less than two years to adjust for any shock in CO_2 emissions in Egypt.

5. Conclusion and policy implications

The main objective of this study is to examine the role of DFI in limiting carbon emissions in Egypt from 1990 to 2020. The role of FDI, energy intensity, economic growth and trade openness were also studied as control variables that play a significant role in achieving sustainability goals. Although few studies examined the impact of DFI on CO_2, no study constructed a separate index that measures DFI. We thus fill in this gap. Two separate indices were built, DFI and TFI, to examine the mechanisms through which DFI can limit CO_2 compared to TFI. The ARDL method was employed for empirical investigation, and long-run panel cointegration exists between the study variables.

Our novel findings reveal that DFI contributes to CO_2 reduction in the long run but not in the short run. This finding shed light on the link between inclusive digital finance and the level of economic development, where an emerging country like Egypt with low DFI (<0.5) and digital financial services play a supplementary role to traditional finance. Thus, since the level of financial inclusion might differ severely among Egypt's governorates, especially the governorates located in upper Egypt – the poorest governorates, awareness of the importance of moving toward digitalization and the use of digital financial services is necessary. Moreover, our empirical results reveal that more FDI inflow worsens the environmental quality by increasing carbon emissions which aligns with the pollution haven hypothesis (HPP). In addition, economic growth and energy intensity have proved to be the main contributors to CO_2, which suggests that economic growth policies in Egypt based on high fossil fuel energy consumption are not aligned with its sustainable development goals. On the positive side, renewable energy can limit CO_2, implying that more investments in renewable energy projects will improve the environmental quality. More specifically, adopting renewable energies can reduce the risk of climate change. Finally, openness to trade seems to reduce carbon emissions in Egypt in the long run, suggesting that eliminating trade barriers on environmental goods and services through trade agreements can encourage investors to shift into less polluting industries and facilitate the adoption of eco-friendly technologies at a lower cost.

Hence, we conclude that inclusive digital finance and environmental sustainability are complementary policies, "two sides for one coin," where digitalization improves environmental quality, while limiting CO_2 cannot be achieved without a digitalized financial system. This has a critical financial policy implication as the financial sector in Egypt can play a vital role in tackling environmental challenges. Nonetheless, renewable energy can also complement the financial sector's positive role and endeavor to improve environmental quality.

The findings of this study give rise to several important policy implications on academic, managerial and governmental levels:

First, inclusive digital financial policies designed by policymakers are essential to achieve a higher inclusive financial system to grab the full benefits of digital financial services to achieve better environmental quality.

Second, strengthening the ICT infrastructure is necessary for Egypt's digital transformation program.

Third, FDI investments in Egypt must shift from heavy industries to Fintech and the ICT sector to limit carbon emissions.

Fourth, achieving a cleaner environment and promoting sustainable economic growth requires policymakers to deal with DFI as both a development and a climate change policy measure. In this context, new policies integrating digital finance and the real economy

must be designed rather than implementing separate economic growth and financial inclusion policies.

Fifth, encouraging investors to use renewable energy is necessary for a better environment since heavy industrial activities and fossil fuel energy consumption are Egypt's main contributors to carbon emissions. Thus, policymakers should adjust all policies and regulations and introduce green growth policies to encourage investors to switch to green energies and use energy more efficiently.

Sixth, achieving the 2030 Agenda for Sustainable Development, particularly SDG7 and SDG13, which focus on climate change and higher inclusive economic growth rate, requires more efforts to be exerted by the government to add new renewable energy sources to the energy mix and increase investments in renewable energy projects. This implies using the financial sector, more specifically, digital finance, as an economic tool to direct financial resources toward more research and development activity in the energy sector.

Seventh, articulating rules for financial institutions to provide more funds with more accessible procedures through digital financial channels for firms, businesses and individuals involved in green innovations and environmentally friendly projects.

Finally, raising people's awareness about climate change and limiting carbon emissions is necessary to achieve environmental sustainability. Thus, it is the government's responsibility to improve the financial literacy of consumers and raise their awareness about environmental problems. Thus, the link between digital finance, renewable energy and a better environment should be used extensively in massive campaigns that target the public.

6. Limitations and future research

The paper's novelty is based on examining the effect of DFI on CO_2 in Egypt using the DFI index and comparing the results with a TFI index to prove whether DFI in Egypt helps reduce CO_2 emissions. Three limitations dictate an agenda for future research. First, there is a considerable data limitation on digital finance in Egypt; thus, the DFI index is unavailable until earlier than 2000. Second, the analysis is based on a country level where a similar study on the level of Egypt's governorates is highly recommended for a better picture of the effect of digital finance on CO_2. Finally, the DFI index is constructed based on data from the Egyptian MCIT. Thus, the index is more inclined to capture digital finance from the consumer side only. In addition, this index cannot be used while performing any comparative study with Egypt as the data are extracted from local databases and not from international databases.

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