CHARLES UNIVERSITY IN PRAGUE

FACULTY OF SOCIAL SCIENCES

Institute of International Studies

UNIVERSITY COLLEGE LONDON

SCHOOL OF SLAVONIC AND EAST EUROPEAN STUDIES

IMESS: Economics & Business

Master thesis

2022 **YUANHAO LIU**

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The Impact of Financial Development on Carbon Dioxide Emissions: Evidence from CEEs

Master thesis

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Abstract

A sample of 13 CEE countries from 2000 to 2019 is used to investigate the total, direct, and indirect effects of financial development on carbon dioxide emissions. This study introduces four mediating effects of financial development on carbon dioxide emissions, i.e. economic growth, industrial structure, technology innovation, and the combined effect. To assess mediating effects and decompose total effect, GMM-SYS methods and bootstrap are employed. The empirical results entail that the total effect of financial development on CO_2 emissions is inverted U-shaped. The mediating effects of economic growth, technology innovation, and the combined effect are enhancing mediating effects, with contributions to the total effect of 7.12%, 1.74%, and 3.29%, respectively. On the contrary, the mediating effect of industrial structure is a suppressing effect, with a 44.42% contribution rate. Therefore, industrial structure turns out to be the primary mediators through which financial development influences CO2 emissions in CEE countries. These findings give additional empirical evidence for the mediational model and Environment Kuznets Curve hypothesis from the perspective of financial development, and also provide new ideas for CEE policy makers to reach carbon neutrality objective by 2050.

Keywords

Financial Development, Carbon Dioxide Emissions, Economic Growth, Industrial Structure, Technology Innovation, Mediating Effect, GMM-SYS

Range of thesis: [122 301 Symbols, 80 Pages]

Declaration of Authorship

1. The author hereby declares that he compiled this thesis independently, using only the listed resources and literature.

2. The author hereby declares that all the sources and literature used have been properly cited.

3. The author hereby declares that the thesis has not been used to obtain a different or the same degree.

Prague 31.07.2022 **YUANHAO LIU**

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Proposed Topic:

The Impact of Financial Development on Carbon Dioxide Emissions: Evidence from CEEs

Motivation:

Achieving carbon neutrality by 2050 is a formidable challenge for the CEE countries. Since they cannot replicate the strategies used by the more developed countries of Western Europe, CEE countries must instead find a road to carbon neutrality that suits them.

Many studies have shown that economic development will affect carbon dioxide emissions. In contrast, financial development has received less attention, and the findings about the relationship between financial development and carbon dioxide emissions are inconsistent. There was a significant drop in global per capita CO2 emissions between 2007 and 2009, which implies a subtle correlation with the global financial crisis of 2007-2008. This paper focuses on the influence of financial development on carbon dioxide emissions among CEE countries. This paper also intends to investigate if financial development can influence CO2 emissions via other transimission channels.

Hypotheses:

Hypothesis 1: Financial development causes an increase of carbon dioxide emissions and then a reduction.
Hypothesis 2: Financial development causes an increase in carbon dioxide emissions and then a reduction through economic growth.
Hypothesis 3: Financial development causes an increase in carbon dioxide emissions and then a reduction through the industrial structure.
Hypothesis 4: Financial development causes an increase in carbon dioxide emissions and then a reduction through technological innovation.
Hypothesis 5: Financial development causes an increase in carbon dioxide emissions and then a reduction through a combined effect of economic growth, industrial structure, and technology innovation.

Methodology:

This paper employs SYS-GMM and bootstrap approaches in dynamic panel data models to test the effect of financial development on carbon dioxide emissions in 13 CEE countries from 2000 to 2019. To assess mediating effects, this paper constructs an innovative mediational test model based on the traditional causal steps approach proposed by Baron & Kenny (1986) and Zhonglin et al. (2022). In the mediational model, economic growth, industrial structure, technology innovation, and the combined effect are mediating variables.

Expected Contribution:

This paper will be the first empirical study to explore the transmission channels in FD-CO2 in the CEE regions and the first to apply the mediational model to the context of CEE carbon finance. It will give additional empirical evidence for the mediational model and EKC hypothesis from the perspective of financial development. The findings will provide experience and implications for the future pathway towards CEE carbon neutrality.

Outline:

1. Introduction
2. Literature Review

Core Bibliography:

Bui, D. T. (2020). *Transmission channels between financial development and CO2 emissions: A global perspective.* Heliyon, 6(11), e05509.

Chen, F. W., Tan, Y., Chen, F., & Wu, Y. Q. (2021). *Enhancing or suppressing: The effect of labor costs on energy intensity in emerging economies.* Energy, 214, 118964.

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Shoaib, H. M., Rafique, M. Z., Nadeem, A. M., & Huang, S. (2020). *Impact of financial development on CO2 emissions: a comparative analysis of developing countries (D8) and developed countries (G8).* Environmental Science and Pollution Research, 27(11), 12461-12475.

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1 Introduction

Achieving carbon neutrality by 2050 is a formidable challenge for the Central and Eastern European countries (CEEs). Since they cannot replicate the strategies used by the more developed countries of Western Europe, CEE countries must instead find a road to carbon neutrality that suits them.

In the existing literature, most studies have concentrated on the effect of economic growth on carbon dioxide emissions in the CEEs. In contrast, financial development has received less attention, and the findings about the relationship between financial development and carbon dioxide emissions are inconsistent. Achieving emission reduction goals and transitioning to a low-carbon economy in the CEEs are inseparable from financial system assistance. For instance, the large investment institutions steer the flow of economic resources to greener projects and promote economic transformation and sustainability through green credits and green funds. As shown by Appendix 1, there was a significant drop in global per capita CO_2 emissions between 2007 and 2009, which implies a subtle correlation with the global financial crisis of 2007-2008. By doing so, this paper focuses on the influence of financial development on carbon dioxide emissions among CEE countries.

This research also explores three transmission channels through which financial development indirectly affects carbon dioxide emissions: economic growth, industrial structure, and technology innovation. As there are currently no empirical studies on the indirect effects of financial development on CO_2 emissions for CEE economies, our study will significantly contribute to the literature in this area. The methodology of this research, which includes a mediational model, is another innovative component of the work. The paper will be the first empirical study of the CEE countries to incorporate a mediational model.

The remaining part of the paper is as follows: this chapter continues with a description of carbon dioxide emissions and the background of financial development in CEE countries. Chapter 2 is a review of the pertinent literature. Chapter 3 comprises the theoretical foundation of the three transmission channels and five underlying assumptions. Chapter 4 provides an overview of panel data collection and measurement of financial development. The emphasis of Chapter 5 is on the dynamic panel model, the specification of mediational models, and the GMM-SYS estimation technique. The empirical results are shown and discussed in Chapter 6. The concluding chapter summarizes the paper and suggests feasible mitigation strategies.

1.1 Carbon dioxide emissions

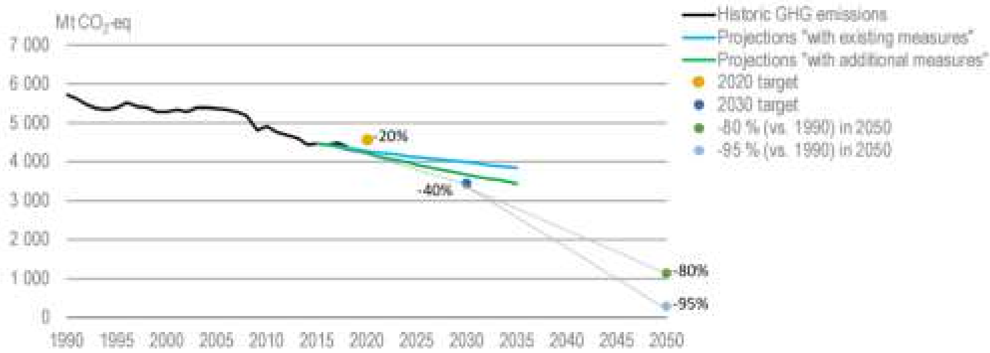
Climate change is the defining challenge of our era, occurring even faster than anticipated. Carbon dioxide emissions are a critical component in the climate system and play a significant influence on climate change. In 2020, the concentration of carbon dioxide in the atmosphere reached 150 percent of its pre-industrial level[1]. A new study by American Geophysical Union (2019) pointed out that rising atmospheric carbon dioxide concentrations are nine to ten times higher than during the Paleocene-Eocene Thermal Maximum (PETM), which scientists frequently use as a comparison for modern climate change[2]. According to estimates, if atmospheric carbon dioxide continues to rise at its current rate, the globe is predicted to reach a level of carbon dioxide concentrations that has not been seen since PETM in just 140 years. In doing so, countries and organizations worldwide have advocated the reduction of carbon dioxide emissions to prevent the perpetual consequences of climate warming, mainly caused by the increase in atmospheric carbon dioxide concentrations.

[1] “The State of the Global Climate 2021,” World Meteorological Organization, access date: 01.08.2022. URL: https://public.wmo.int/en/our-mandate/climate/wmo-statement-state-of-global-climate.

[2] American Geophysical Union, “Earth may be 140 years away from reaching carbon levels not seen in 56 million years,” Phys.org, publication date: 20.02.2019, access date: 15.07.2022. URL: https://phys.org/news/2019-02-earth-years-carbon-million.html

The European Union (EU) is a staunch proponent of global action to combat climate change and reduce carbon dioxide emissions. Since adopting the 2016 Paris Agreement, the EU has steadfastly met its commitments to cut greenhouse gas emissions (GHG). The EU's total GHG emissions in 2018 declined by 17% compared with 2005 and 23% compared with 1990 (IEA, 2020), indicating that the EU has thus already reached its 2020 target of reduction by 20% from 1990 levels. Figure 1.1 depicts the trajectory of GHG emissions in the EU from 1990, as well as the projections and targets. According to forecasts, EU GHG emissions are far from achieving the 40% reduction target by 2030 from 1990 levels, and further efforts are required. Even still, the European Commission stated an ambitious plan (i.e. European Green Deal) aimed at reducing GHG emissions by 50%-55% by 2030. The European Green Deal (EGD) specifies a goal of carbon neutrality by 2050, which means that net carbon dioxide emissions will be zero.

Figure 1.1 Trends, predictions, and objectives for EU GHG emissions, 1990-2050



Source: IEA, 2020.

Upon the EU's climate ambitions, a few countries of Central and Eastern Europe (CEE) held disapproving attitude. CEE argued that such climate pledges threaten their energy security and hurt their economies (Bocquillon & Maltby, 2017). The EGD would cost billions of euros yet provide citizens with little tangible benefits. In relation to the more developed countries of Western Europe, CEE countries showed an inevitable "delay" since they developed capitalist market economies considerably later than their Western European counterparts (Pakulska, 2021). During the period of being a part of the ex-socialist bloc, CEE economies established a highly concentrated industry that targeted high-emissions economic sectors, including coal, steel, and chemicals (Asadnabizadeh, 2019). Among them, Poland and the Czech Republic are the primary opponents: Poland continuously resisted the commission’s proposal, arguing that these policies are too stringent; the Czech Republic voiced concerns and was among the prominent critics but did not vote against the proposal. Poland is an especially dependent state on coal and other fossil fuels. Instead of paying enormous economic expenditure to reduce emissions, the Polish elites would rather maintain the status quo of coal reliance. Since the EGD was proposed, Poland has vehemently opposed it. Initially, it had the support of Estonia, Hungary, and the Czech Republic (both endorsed the EGD after being allowed to substantially replace coal with nuclear energy). Undoubtedly, opposition from a minority of member states is unlikely to prevent the implementation of EGD.

Due to the “delayed” and specific nature of the economies of the CEE countries, the approaches to reducing carbon dioxide emissions advocated by the more developed countries of Western Europe are not always applicable to the CEE region. Coupled with the fact that the CEE countries have different climatic and geographical circumstances, as well as varying economic growth, industrial structures, and technological innovation strength, CEEs urgently need to explore a path that suits them.

1.2 Financial development in CEE Countries

Before analysing the effect of financial development on carbon dioxide emissions, it is essential to comprehend the current level of financial development in CEE nations. Financial development is defined as the development of financial institutions, financial markets, and financial instruments (Yurtkur, 2019). The paper focuses on the financial development of the CEE region before and after the financial transition from the perspective of financial institutions and markets and does not cover financial instruments.

1.2.1 Financial institutions

Financial liberalization reforms in CEE countries mostly started after 1989 and were substantially concluded by the turn of the 21st century. Hungary is a partial exception.

Due to the planned economic system of government directives, the countries' financial sectors were incompletely developed and inefficient prior to the reform. The primary role of the financial sector was that of an accounting system for implementing the economic plan (Cojocaru et al., 2016). The single bank system was composed of a central bank and a few specialized banks with a single business and a high degree of monopoly. These specialized banks were responsible for household deposits, business loans, and import or export transactions. Non-bank financial institutions were scarce, and only a few state-owned insurance companies existed. Besides, securities markets had not yet been established (Weili, 2010). Setting a vibrant financial sector and a market-oriented financial system was thus a tough endeavour. For transition countries undergoing financial reform, once the new financial system fails to function correctly, the existing large domestic firms would be left in limbo due to the funding gaps, which would definitely worsen the economy of the entire country (Cojocaru et al., 2016).

Instead of rebuilding capital markets with stock markets as the core component, the financial transformation in CEE countries has primarily concentrated on bank privatization and bank restructuring. During the transition period, CEE nations experienced the transition from a one-tier to a two-tier banking system, the reconstruction of the banking sector, privatization reforms, and the entry of foreign banks.

The reform of the bank industry was kicked off by the creation of a two-tier banking system in the late 1980s to early 1990s. The two-tier system was one in which private commercial and investment banks and other financial institutions made up the bottom tier, with central banking serving as its representative at the top (Lieberman &

Kennett, 1992). Under the new banking system, the central bank was responsible for the issuance of currency, the formulation and implementation of monetary policy, as well as the regulation and supervision of commercial banks; commercial banks expanded their business beyond accepting deposits and making various loans to investments, guarantees, and settlements (Weili, 2010). Among the CEE countries, Hungary, Poland, and the Czech Republic were the first to implement a two-tier banking system. Hungary divested the lending operations of the central bank in 1987 and established three commercial and two specialized banks. In Poland, the Banking Act and the Act on the National of Bank of Poland were enacted in 1988. The following year, the commercial functions of the monobank were separated and assumed by nine regional commercial banks. Poland had eighteen state-owned commercial banks as of the end of 1989. In former Czechoslovakia, with the establishment of two state-owned commercial banks in 1990, the monobank system was transformed into a two-tier banking system. When the Czech-Slovak Federal Republic was dissolved in 1993, all of these banks, with the exception of Obchodni, were split up into their respective nations (Borish, Ding, & Noel, 1997). However, since commercial banks evolved from national banks in the previous planned economy, they inherited an extensive portfolio of historically nonperforming assets and lacked operational autonomy. Affected by macroeconomic fluctuations in the early 1990s, the banking sectors deteriorated, bad and nonperforming loans increased, and descended into crisis. Consequently, the government had got to implement additional reforms, which included cleaning up or rebuilding nonperforming loans, reorganizing the shareholding structure of state-owned commercial banks, and bringing in foreign investors. Ultimately, the banking sectors were privatized (Kun, 2012). Among the CEE countries with a more successful transition are the Czech Republic, Poland, and Hungary. The privatization of Czech, Polish, and Hungarian banks are shown in Table 1.1. The voucher refers to a book of coupons that represents potential shares of the state-owned firms and is provided to citizens for free or at a low cost; IPOs mean initial public offerings; SFFI is strategic foreign financial investors. They are three methods through which banks can be privatized. Table 1.1 shows that countries' banking sectors had different privatization strategies during the early stages of reform, with the Czech Republic primarily selling the vouchers and Poland and Hungary mainly using IPOs and SFFI. As the transmission moves into its later stages, countries accumulated experience and adopted similar privatization strategies, opting to implement SFFI. Another feature of the transmission of financial institutions in CEE countries has been the entry of foreign banks. A regulated bank industry was converted into a highly competitive one when foreign banks were allowed into the market.

Table 1.1 Privatization process of Czech, Hungarian and Polish banks (1992-2001)

	Czech Republic	**Poland**	**Hungary**
1992	KB (Voucher) CS (Voucher) IPB (Voucher)		
1993		WBK (SFFI/IPOs)	
1994		BSK (SFFI/IPOs)	MKB (SFFI/IPOs)
1995		BPH (IPOs) BG (IPOs)	OTP (IPOs) BB (SFFI/IPOs) Mezobank (SFFI)
1996		BSK (SFFI)	MHB (SFFI) MKB (SFFI)
1997		PBK (IPOs) BH (IPOs) WBK (SFFI)	K&H(SFFI) Takarékbank (SFFI)
1998	Agrobanka (SFFI) IPB (SFFI)	BPH (SFFI)	
1999	CSOB (SFFI)	PeKao (SFFI) BZ (SFFI)	
2000	CS (SFFI)	PBK (SFFI)	
2001	KB (SFFI)		

Source: Tiangong, 2006.

1.2.2 Financial markets

Financial markets in CEE are widely believed to be reliant on debt securities and domestic credit rather than equity markets with lower liquidity (Yemelyanova, 2021). Indeed, financial market reforms were ongoing during the transition but proceeded rather slowly (John Bonin, Iftekhar Hasan, & Wachtel, 2008). Until the 1990s, many CEE countries did not have stock exchanges, as seen from the timeline in Table 1.2. In contrast to those in developed economies, the financial markets in CEE regions are underdeveloped, unstable, and pretty small.

Table 1.2 Chronology of the development of stock markets in CEE countries

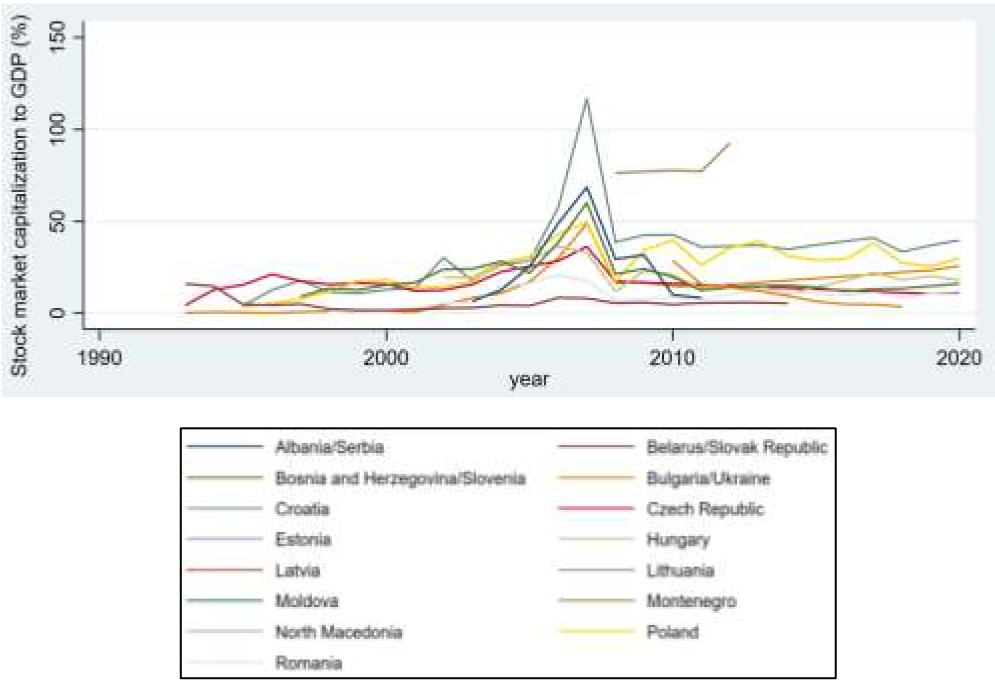
Country	Timeline
Belarus	In 1998, Belarusian Currency and Stock Exchange (BCSE) was founded.
Bosnia and Herzegovina	In 2001, Sarajevo Stock Exchange (SASE) and Banja Luka Stock Exchange (BLSE) was founded; In 2002, SASE commenced trading.
Bulgaria	In 1991, Bulgarian Stock Exchange (BSE) was established as a joint stock company.
Croatia	In 1991, Zagreb Stock Exchange (ZSE) was founded; In 2007, ZSE created a single Croatian capital market by incorporating Varaždin Stock Exchange (VSE).
The Czech Republic	In 1871, Prague Stock Exchange (PSE) was founded; In 1993, PSE was reopened.
Estonia	In 1995, Tallinn Stock Exchange was founded; In 1996, Tallinn Stock Exchange began operations with the listing of 11 securities.
Hungary	In 1864, Hungarian Stock Exchange was established; In 1990, Budapest Stock Exchange (BSE) was re-established.
Latvia	In 1993, Nasdaq Riga was established.
Lithuania	In 1992, National Stock Exchange of Lithuania was established.
North Macedonia	In 1995, Macedonian Stock Exchange (MSE) was founded; In 1996, first trading occurred in MSE.
Poland	In 1817, Warsaw Mercantile Exchange (WSE) was founded; In 1991, Warsaw stock exchange was re-established.
Serbia	In 1992, Belgrade Stock Exchange replaced the Yugoslav Capital Market as its name. In 2002, Trading in bonds of the Republic of Serbia started.
Slovenia	In 1989, Ljubljana stock exchange (LJSE) was founded.

Note: Alphabetized by country

Source: Compiled by the author.

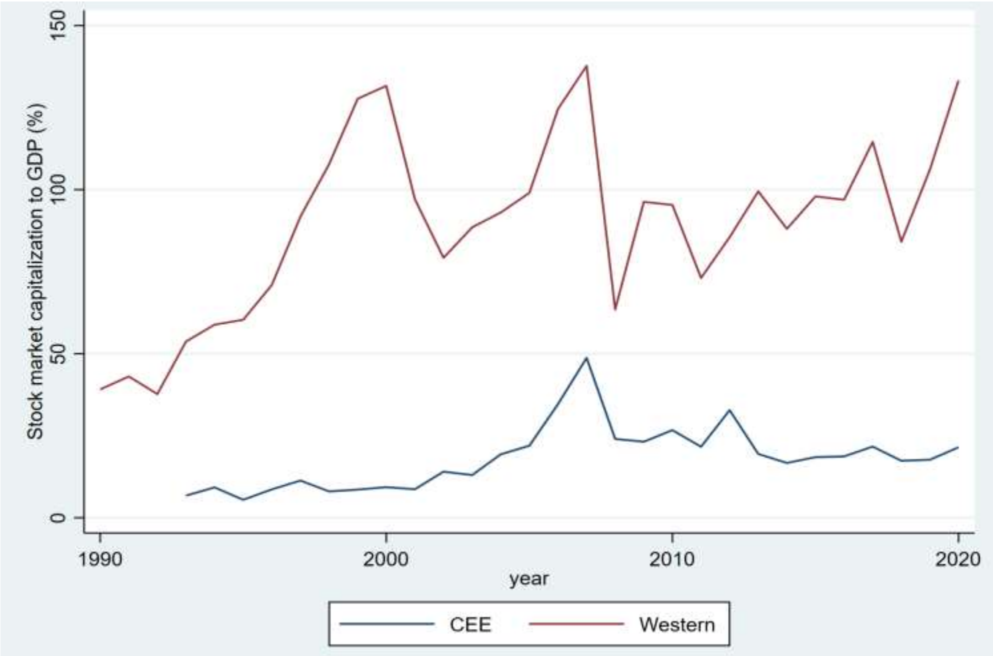
Using the ratio of stock market capitalization to GDP as a measure of financial market size, it is evident that the stock markets of the majority of CEE nations have grown rapidly since 2000, which can be seen in Figure 1.2. Among these CEE countries, the Czech Republic, Poland, and Hungary had the most developed capital markets in terms of size, liquidity, and diversity of products (Kun, 2012). Croatia became the fastest-growing of these nations. A nationwide stock market boom occurred in Croatia because of the sale of shares by several Croatian state-owned enterprises to the public and the simultaneous IPO of shares in circulation on the Croatian stock market. Some countries, like Bulgaria and Romania, benefited from joining the EU. However, compared with Western European countries' financial markets, CEE countries' financial markets are much smaller (see Figure 1.3). The CEE region was unstable for financial market stability, as demonstrated by the degree of curve volatility in Figure 1.4.

Figure 1.2 Stock market capitalization to GDP in CEE countries (1990-2020)



Source: Author's construction, using data from Global Financial Development Database (World Bank).

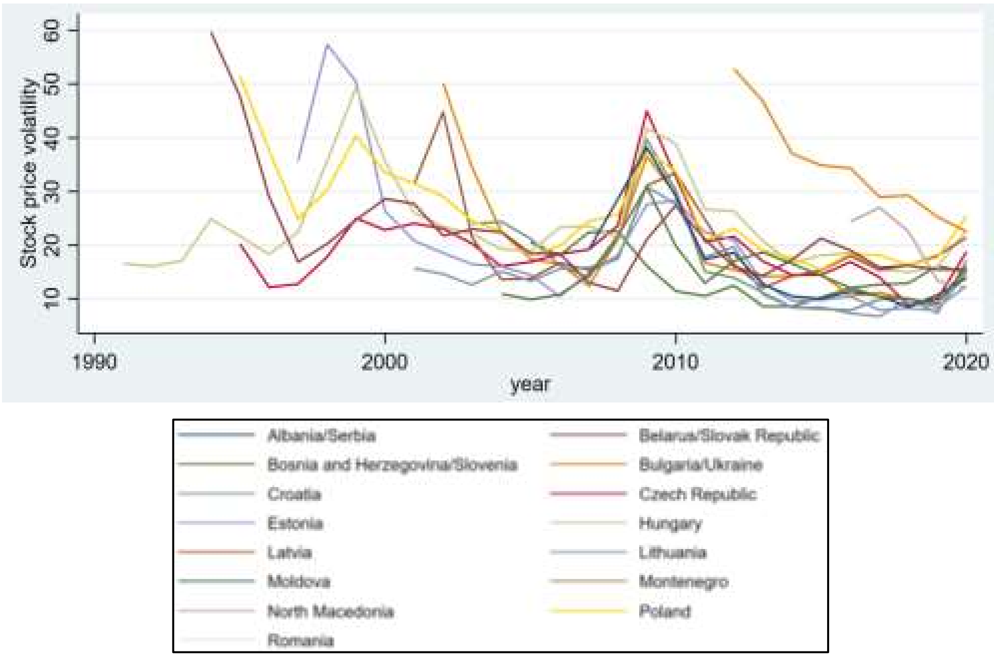
Figure 1.3 Stock market capitalization to GDP on average in CEE and Western countries (1990-2020)



Note: The mean value of Stock market capitalization to GDP is taken for the countries under different years.

Source: Author's construction, using data from Global Financial Development Database (World Bank).

Figure 1.4 Stock price volatility in CEE countries (1990-2020)



Source: Author's construction, using data from Global Financial Development Database (World Bank).

2 Literature Review

This section is comprised of previous studies on the impact of financial development, economic growth, industrial structure, and technology innovation on carbon dioxide emissions. The author breaks down the literature review into seven sub-summaries in order to better understand the effects of financial development and the three potential transmission channels (i.e. economic growth, industrial structure, and technological innovation) on carbon dioxide emissions.

2.1 Financial development and carbon dioxide emissions

The theoretical and empirical studies have proposed and demonstrated a meaningful relationship between financial development and carbon dioxide emissions. However, there is a lack of consensus on how financial development affects carbon dioxide emissions. The current mainstream perspective can be divided into three divisions: one believes that financial development encourages carbon dioxide emissions, another that it decreases carbon dioxide emissions, and the third that the influence of financial development on carbon dioxide emissions is inverted U-shaped.

One perspective is that financial development enhances carbon dioxide emissions. In other words, environmental degradation has been sacrificed for financial development. An empirical study of 30 Asian countries conducted by Le et al. (2020) confirmed that financial inclusion results in an increase in carbon dioxide emissions and contributes to the deterioration of the environment between 2004 and 2014. The studies of Boutabba (2014), Sethi et al. (2020), Tamazian and Rao (2010), and Acheampong (2019) came to similar conclusions. The study of India presented a long-run positive and causal relationship between financial development and carbon dioxide emissions (Boutabba, 2014). Further evidence for the conclusion that financial development is detrimental to environmental sustainability in India is provided by Sethi et al. (2020). They evaluated ecological sustainability using a single framework that takes the effects of growth, globalization, and financial development into account over the period 1980–2015.

Tamazian and Rao (2010) discovered that financial liberalization does harm environmental quality in transition economies if it is not carried out in a solid institutional framework. Furthermore, a consistent conclusion that financial development raises CO2 emissions can draw using various indicators to gauge financial development. For instance, the empirical outputs of Acheampong (2019) demonstrate that using domestic private sector credit, broad money, and domestic private sector credit from banks as proxies for financial development can also raise carbon dioxide emissions.

Some hold the reverse view that financial development aids in mitigating carbon dioxide emissions and plays a significant part in combating excessive carbon dioxide emissions and environmental deterioration. A sound financial system reduces transaction and information costs, speeds up transactions, and ensures transaction security. According to Claessens and Feijen (2007), the development of the financial sector and the provision of financial services impact the stability of the environment because a well-developed financial system facilitates lending and investment, including investment in environmentally friendly projects. Tamazian, Chousa, & Vadlamannati (2009) investigated the relationship between financial development, economic development, and carbon emissions. The findings indicate that financial development, particularly in the banking and capital markets, is crucial for lowering CO2 emissions. Jalil and Feridun (2011) tested the long-term equilibrium relationship between financial development and carbon dioxide emissions in the case of China. The analysis shows a negative sign for the financial development coefficient, indicating that finance can curb carbon dioxide emission by improving energy use efficiency. Similarly, Shahbaz et al. (2013) examined the Malaysian economy from 1971 to 2011 and discovered that financial development lowers carbon dioxide emissions. When commercial banks dominate a nation’s financial institutions, the public and private sectors can access loans for a variety of projects, especially for environmental projects, at a lower cost and through a more streamlined process. In another study, Saidi and Mbarek (2017) proposed using financial development to prevent the environment from deteriorating further by implementing financial reforms since the empirical findings for 19 emerging economies show that financial development appears to minimize carbon dioxide emissions. Further findings were revealed by Zaidi et al. (2019) in the case of APEC countries. From the perspective of globalization, Zaidi et al. (2019) explored the dynamic links between financial development and carbon emissions and concluded that financial development and globalization both diminish carbon dioxide emissions in the short and long term. Another case study for China also shows that financial deepening facilitates the reduction of carbon dioxide emissions and the increase of carbon productivity (Linhai & Huiwen, 2016). In a recent study on financial development in Jamaica related to carbon dioxide emissions, Brown et al. (2022) employed the NARDL bounds tests and Granger causality tests. They found that greater domestic economic activity and trade openness positively impacted carbon dioxide emissions while negatively impacted by financial growth. Slightly different from the above arguments, Abbasi and Riaz (2016) contended that certain financial factors only matter in emissions reduction if more remarkable financial sector development and liberalization are accomplished.

Some researchers are of the opinion that the relationship between financial development and carbon dioxide emissions is in an inverted U-shape. Rising levels of financial prosperity lead to an initial rise in carbon dioxide emissions, followed by a subsequent decline in those levels. This inverted U-shaped curve can be approximated by the Environmental Kuznets Curve (EKC), which presupposes that per capita income and environmental quality have an inverted U-shaped relationship. The specific explanation of the EKC hypothesis is explicitly given in chapter 2.5 and Chapter 3.2. Since the pioneering study about EKC from Grossman and Krueger (1995), a growing number of academic researchers are concentrating on the EKC hypothesis and testing it in various nations and regions. Shahbaz et al. (2013) researched Indonesia between 1975 and 2011 to investigate the dynamic relationship between financial development and carbon dioxide emissions. Even though there are structural breaks in the series, the empirical results of financial development and carbon dioxide emissions have been found to be cointegrated over the long run. Based on the work of Shahbaz et al. (2013), Charfeddine and Khediri (2016) explored the application of the EKC hypothesis in the UAE. They further confirmed that carbon dioxide emissions positively correlate with financial development, and when the financial industry reaches maturity, the relationship weakens and then turns negative. As a response, they give recommendations for strengthening the financial sector to fund energy-efficient technologies. In the case of China, similar outcomes were discovered: in developed provinces, financial development reduces carbon dioxide emissions, while in less developed provinces, it increases them (Xiong, Tu, & Ju, 2017). Table 2.1 summarizes previous studies on the relationship between financial development and carbon dioxide emissions. Other factors affecting CO2 are also listed in Table 2.1, which facilitates the selection of control variables in the empirical model of Chapter 4.

Table 2.1 A summary of previous research examining the relationship between financial development and carbon dioxide emissions

Author(s)	**Time period**	**Country/region**	**Other determinants of CO_2**	**Methodology**	**Impact of financial development on CO_2 emissions**		
					Increase	**Decrease**	**Inverted U-shape**
Tamazian & Rao (2010)	1993-2004	24 Transition economies	Economic development, Institutional quality	GMM approach	X		
Zhang (2011)	1980-2009	China	Economic growth, FDI	Cointegration test, Granger causality test, Variance decomposition	X		
Al-Mulali & Sab (2012)	1980-2008	30 Sub Saharan Africa	Energy consumption	Pedroni Cointegration, VECM Causality	X		
Boutabba (2014)	1971-2008	India	Economic growth, Energy consumption, and Trade openness	ARDL, VECM, Granger Causality	X		
Acheampong (2019)	2000-2015	46 Sub-Saharan Africa countries	Economic growth, Energy consumption, Trade openness, Urbanization and Population size	GMM-SYS approach	X		
Shoaib et al. (2020)	1999-2013	16 Developing and Developed countries	Economic growth, Energy consumption, and Trade openness	PMG-panel ARDL	X		
Le et al. (2020)	2004-2014	31 Asian countries	Income, Urbanization, Trade openness, FDI, Energy consumption, and Industrialization	Driscoll-Kraay standard errors	X		
Sethi et al. (2020)	1980-2015	India	Globalization, Economic growth, and Energy consumption	ARDL, VECM, Granger Causality	X		

Tamazian, Chousa, & Vadlamannati (2009)	1992-2004	BRIC countries	Economic development	Random-effect model		X	
Jalil & Feridun (2011)	1953-2006	China	Economic growth, Energy consumption	ARDL		X	
Shahbaz et al. (2013)	1971-2011	Malaysia	Economic growth, Energy consumption	ARDL bounds testing error correction method		X	
Abbasi & Riaz (2016)	1971-2011, 1988-2011	Pakistan	Economic development, Foreign direct Investment (FDI)	ARDL, Augmented VAR, ECM		X	
Linhai & Huiwen (2016)	1998-2012	China	Urbanization, Industrial structure, Energy consumption structure, R&D intensity, and Openness	GMM approach		X	
Saidi & Mbarek (2017)	1990-2013	19 Emerging countries	Income, Trade, and Urbanization	GMM-SYS approach		X	
Zaidi et al. (2019)	1990-2016	APEC countries	Globalization	Westerlund Cointegration approach, CUP-FM, and CUP-BC		X	
Brown et al. (2022)	1980-2018	Jamaica	Real domestic economic activity, Trade openness	NARDL bounds testing, VECM Granger causality test		X	

Shahbaz et al. (2013)	1975-2011	Indonesia	Economic growth, Energy consumption, and International trade	Zivot–Andrews unit root test, ARDL, VECM, Innovative accounting approach (IAA)			X
Xiong, Tu, & Ju (2017).	1997-2011	China	Market force, Institutional constraints	Dynamic panel data model			X
Charfeddine & Khediri (2016)	1975-2011	UAE	Electricity consumption, Economic growth, Trade openness, and Urbanization	Multiple structural breaks, Regime-switching cointegration techniques			X

Source: Constructed by the author.

2.2 Financial development and economic growth

It is widely recognized and acknowledged that the financial market plays a crucial role in fostering robust economic growth (Goldsmith, 1969; McKinnon, 1973; Shaw, 1973; etc.). This section summarizes the extant literature from financial institutions' and financial markets' perspectives.

The development of financial institutions, especially banking institutions, is a critical element in economic growth because of its role in allocating savings, encouraging innovation, and financing productive investments (Schumpeter, 1911). A well-developed banking system has a sizable positive impact on the accumulation of capital, and it contributes to economic efficiency by redirecting funds from unproductive to productive uses (Rioja and Valev, 2014; Durusu-CIftci, Ispir, & Yetkiner, 2017); the general economy may be exposed to excessive risks if loose financial institutions persist (Liang & Reichert, 2012). Some advocates provide extensive empirical evidence of a positive relationship between financial institutions and economic growth. Levine (1997) considers bank deposits and credit as an indicator of financial development, and the exploratory research discovers a favourable correlation between financial development and economic growth. Similar work includes the study of Hassan et al. (2011). The study examines the link between financial development and economic growth in 168 nations, utilizing domestic credit to the private sector as a measure of financial development. The findings in East Asia, the Pacific, Latin America, and the Caribbean revealed a significant positive association between financial development and economic growth in those nations. Another study by Cetorelli and Gambera (2001) finds a statistically positive correlation between the concentration of the banking segment and economic growth. They point out that the more concentrated the distribution of banks, the more they can satisfy the credit needs of those enterprises that rely on external sources of funds, particularly start-up enterprises.

Economic growth is influenced by financial market prosperity as well. Early works, such as Levine (1991), and Greenwood and Smith (1997) believed that the development of the financial market promotes economic expansion. Theoretically, the prevailing view can be divided into two parts to analyze the impact of the financial market on economic growth: Firstly, financial markets give companies more tools for risk management, enabling them to diversify their holdings and reduce risk aversion, thereby stimulating economic growth (Levine, 1991; Saint-Paul, 1992). In general, banks favour conservative investments and their propensity to invest in large-size, comprehensive, and well-rounded firms; for many start-up and technology-based companies, banks are not the optimal source of funding (Hellwig, 1991). By contrast, the financial markets allow investors to take advantage of portfolios to diversify risks and reduce liquidity risks by trading on the secondary market, thereby providing these businesses with access to capital (Weinstein and Yafeh, 1998). Secondly, financial markets influence economic growth by altering corporate control incentives (Durusu-CIftci, Ispir, & Yetkiner, 2017). Jensen and Murphy (1990) and Demirgüç-Kunt and Levine (1996) state that a stock market that truly mirrors a company's actual value instead of the book value makes it easier to tie a manager's compensation to its stock. Managers are incentivized to use their entrepreneurial skills to maximize the company's value because rising stock prices benefit both owners and managers. Empirically, the study of Caporale et al. (2004) confirmed that a well-functioning financial market promotes economic growth. They tested the causal linkage between the stock market and economic growth within seven countries and discovered that a healthy and robust capital market could stimulate economic expansion by accelerating capital accumulation and refining it through more efficient resource allocation. Ake (2010) provided similar evidence from five Euronext countries, using the market cap, overall trade value, and turnover ratio as stock market proxies. For those nations with a liquid and vibrant stock market, there is a positive relationship between the stock market and economic growth.

Nevertheless, there are exceptions. Pagano (1993) put forward that the introduction of financial instruments into the household credit market is likely to reduce precautionary savings and, consequently, the long-term growth rate. Besides, in the empirical study by Ake in 2010, the causal relationship between financial development and economic growth is disproven for nations with small and illiquid stock markets. Consistent with Ake (2010), Hassan et al. (2011) found that domestic credit to the private sector is adversely linked with economic growth in high-income nations.

2.3 Financial development and industrial structure

Recent emphasis has shifted to the impact of financial development in shaping industrial structure. In studies of global economic history, every industrial transition has been intimately connected with financial development, and the financial revolution triggered the outbreak of the industrial revolution (Hicks, 1969; Sylla, 2002). The financial system sponsored large projects during the transformation from an agrarian to an industrial society, which contributed to the first industrial revolution (Bagehot, 1873). The subsequent second and third industrial revolutions also occurred in the most financially developed countries or regions (Xin & Fengliang, 2018).

Thus far, many studies have explained how financial development affects the industrial structure. Financial development aids in lowering financial frictions, hastening the industrial structure transformation (Rajan & Zingales 1998; Xin & Fengliang, 2015). They explained that by reducing the additional costs arising from information asymmetries across industries, financial development makes it possible to reduce the cost of external financing for enterprises, thereby supporting the optimization and transformation of the industrial structure. Fisman and Love (2003) reevaluate how the development of the financial market affects the intersectoral allocation of resources and come to the conclusion that as the level of financial development increases in a country, the sectoral interdependence between the growth rates of its various industries rises, thus helping these industries thrive. Moreover, Yunxin et al. (2020) investigated the impact of financial structure on industrial structure and concluded that industrial structure differs under various financial systems. Financial institutions, such as banks, are more beneficial than financial markets in fostering the development of traditional, mature industries. In contrast, financial markets such as the stock and bond markets are more advantageous in strengthening the expansion of emerging sectors, especially for start-ups (Allen & Gale,2000; Yunxin et al., 2020). Thus, a market-oriented financial structure rather than a bank-oriented financial structure is better suited to industrial upgrading.

With the advent of the idea of "too much finance"[3], academics have started investigating the negative and non-linear correlation between financial development and industrial structure. Kabango (2009) states that financial development does not eliminate financing restraints on enterprises, particularly small and medium-sized ones, even while it increases the availability of credit and the number of lending institutions relative to the pre-reform period. Conversely, a more flexible and well-developed financial system is advantageous to large corporations, which may impede industrial transformation. In the case of China, Aiping and Junchao (2015) examine the variations in how financial development in the East, Central, and West affects industrial restructuring using the Hansen threshold model. The empirical findings demonstrate an inverted U-shaped relationship between financial development and industrial structure; the contribution of financial development to the industrial structure is less noticeable in the East, where the degree of financial development is high and more pronounced in the middle and western provinces, where the level of financial development is low.

2.4 Financial development and technology innovation

There are two different viewpoints in the extant literature about the role of financial development in promoting technology innovation.

Some researchers maintain that financial development is a driving force behind technology innovation. The literature summary is carried out under two distinct financing approaches: financial institutions and financial markets. From the standpoint of financial institutions, banks, as financial institutions consuming public funds, have a large-scale

[3] "Too much finance" was introduced by Berkes, Panizza, and Arcand (2012). The meaning is that when financial development is above a certain threshold, it loses its beneficial effects on economic growth and even starts to hurt the economy.

capital and can constantly offer financial services suitable for various businesses. These particular financial services will positively affect enterprises' innovation (Gerschenkron, 1962; Gnezditskaia, 2003). A study by Tadesse (2005) concludes that there is a significant positive correlation between industries' realized technological progress and the level of development of their supporting financial sector using a sample of 38 nations. Specifically, industries where younger companies are more reliant on external financing, see a higher speed of technological improvement in countries with more mature banking sectors. Additionally, healthy competition within the banking sector is a catalyst for firm-level innovation (Liu & Li, 2020). Competition among banks diminishes the market dominance of banks; to attract financing-needing enterprises, banks with weak market power are likely to reduce the price of credit. The lower cost of funding for firms spurs intensive innovation activity (Lian, 2018). The empirical results of Liu and Li (2020) suggest that the effect of bank competition in fostering companies' innovation is stronger in small or private firms. Regarding for the intimate connection between financial markets and technology progress, it was firstly emphasized by Hicks (1969). Hicks contended that the adoption of new technologies necessitates sizable and illiquid capital investments, which risk-sharing financial markets can provide. According to Hellwig (1991), banks have the drawback of conservative lending and small credit limits, while financial markets are well-positioned to make up for the weakness of banks and can afford risker technological investments.

Conversely, some argue that the role of financial development in technology innovation is limited. Law, Lee, and Singh (2018) revisit the finance-innovation nexus with a sample of 75 developing and developed nations. In their study, the outcomes show an inverted U curve of the link between financial development and technology innovation. Financial development only encourages creativity to a specific extent, and additional financial development beyond this level would have a detrimental effect on innovation. Some analysts (e.g. Hsu, Tian, & Xu, 2014) assume that the effectiveness of financial development on technological progress is contingent on the financial structure. In a bank-dominated financial system, banks have the initiative in lending and consequently may reap the benefits of corporate innovation, which diminishes the incentives for corporations and is not conducive to motivating them to innovate (Boot & Thakor, 1997). To prove the conjecture, Hsu, Tian, & Xu (2014) compared the impact of the credit market and stock market on technology innovation among 32 developed and emerging countries. Unsurprisingly, in nations with highly established stock markets, sectors that rely on external finance and are technology-intensive show a disproportionately greater degree of innovation, whereas the innovation performance of these related industries is less promising in countries where the credit markets are dominant.

2.5 Economic growth and carbon dioxide emissions

The linkage between economic growth and carbon dioxide emissions can be traced back to the introduction of the Environmental Kuznets Curve (EKC). Grossman and Krueger (1995) were the ones who initially implemented the EKC hypothesis to analyze the association between GDP per capita and pollutant emissions. They noted that pollution rises along with per capita GDP, but after a threshold point, higher per capita GDP is linked to lower pollution levels. Since then, numerous studies have evaluated the EKC hypothesis for its veracity. For instance, Moomaw and Unruh (1997) confirm the hypothesis of EKC in 16 OECD countries. After applying the cubic model specification to samples, they found out that the correlation of per capita CO2 and GDP is reconciled with the EKC hypothesis, and all the 16 countries went through the transition point swiftly as a result of a temporary historical event (i.e. oil price shock) in the 1970s. Supplementary was made by Panayotou, Peterson, and Sachs (2000). Their study adds structural change and trade as the representative factors in the income aspect, finding out that developed and developing countries are on the two sides of the EKC curve.

However, experts have questioned the EKC hypothesis on the basis of empirical studies. In the example of China, Hong (2000) employs a state-space representation technique and finds a complicated interaction between the current and prior values of GDP per capita and CO2 emissions per capita, rather than an inverted U-shape. Subsequently, a subgroup study of 165 countries was conducted by Yujun & Yang (2009).

The study discovers that countries with high income but low industrialization exhibit an N-shape structure and do not conform to the EKC hypothesis; for the countries with low income but high industrialization, carbon dioxide emissions grow with income increases (Yujun & Yang, 2009). Aye and Edoja (2017) analyze the relationship between economic growth and CO2 emission in developing countries by an innovative method--a dynamic panel threshold framework. The empirical findings were presented as a violation (i.e. U-shape) of the EKC hypothesis in the sense that a negative relationship between carbon dioxide emissions and economic growth in the economic low growing regime and vice versa.

Alternatively, some researchers have attempted to establish causality as the explanation for the connection between economic growth and carbon dioxide emissions. Coondoo & Dinda (2002) investigates the relationship between per capita income and the corresponding per capita CO2 emissions in various regions based on the traditional Granger causality test. The results indicate unidirectional causality from carbon emissions to economic growth for developed countries and regions in North America and Western Europe and from economic growth to carbon emissions for countries such as South America, Oceania, and Japan. For the country groups such as Asia and Africa, there is bi-directional causality between carbon emissions and economic growth. In the case of Iran, there appears to be a unidirectional Granger causality running from economic growth to carbon dioxide emissions (Acheampong, 2018).

2.6 Industrial structure and carbon dioxide emissions

To better understand the relationship between industrial structure and carbon dioxide emissions, researchers have analyzed the impact of different sectors on carbon dioxide emissions. The primary sector, especially agriculture, generates environmental externalities and is currently a contributor to the rise in CO2 levels as it exploits native ecosystems in the tropics for agricultural purposes (Paustian et al., 1998). Jorgensonl and Kuykendall (2008) conducted a statistical analysis of 35 developing countries and found that the level of agricultural output supported by foreign investment and the use of agricultural machinery increased carbon emissions. In a comparable study by Panayotou et al. (2000), researchers examined the assumption of whether the industrial structural changes encouraged the environmental transition by clarifying economic activity according to the three industries in 17 OECD countries. The study showed that the development of all three industries has a negative impact on the environment, with the secondary industry having the most incredible intensity of pollution on the environment. In the same vein, Zhang (2011) supports that carbon dioxide emissions from the secondary industry were significantly higher than the other two industries (i.e. the primary industry and the tertiary industry). During the period from 1978 to 2012 in China, the percentage of carbon dioxide emissions from primary, secondary, and tertiary industries were 0.65%-1.866%, 84.03%-91.98%, and 4.49%-5.84% (Sun and Liu, 2016), which unequivocally demonstrates that the secondary sector is the primary contributor to atmospheric CO2 emissions. Liu and Chen (2010) manipulated panel data of seven representative countries to construct a variable coefficient constant intercept model of industrial restructuring and carbon dioxide emissions by using Cross-section SUR. The findings suggest that the development of the tertiary sector will result in lower CO2 emissions than the expansion of the primary and secondary sectors.

There are significant prospects for the mitigation of carbon dioxide emissions through industrial restructuring. As pointed out by Chang (2015), there is a trade-off between GDP volume and CO2 emissions; in order to balance these two indicators, it is optimal to focus on industrial groups' adjustment. According to Paustian et al. (1998), altering the use and management of agricultural lands can reduce carbon dioxide emissions. Zhu et al. (2019) found that the rationalization and advancement of the national industrial structure play a key role in promoting green development in China, with advanced industrialization being more effective than the former. Thus, they suggest accelerating the advanced industrial structure. Li et al.(2019) also proposed and deliberated the hypothesis between manufactured upgradation and rationalization and emissions in China. They stated that collaboration within the industry is required to achieve emissions reduction.

2.7 Technology innovation and carbon dioxide emissions

Much of the literature agrees on the role of technology innovation in reducing carbon dioxide emissions. According to Fei et al. (2016), there are three green innovation types: technological, institutional, and business-model innovation. Of these, technological innovation is the key to generating renewable energy and achieving the objective of an eco-city. As noted by Garrone and Grilli (2010) and Weina et al. (2016), technology innovation is far more cost-effective in lowering carbon dioxide emissions. In a study that set out the relationship between technology innovation, globalization, and carbon dioxide emissions among Belt and Road countries with a period of 1991-2019, Bial et al. (2021) found that there is a negative relationship between information and communication technology (ICT) and carbon dioxide emissions. In addition, Jianguo et al. (2022) linked technology innovation and CO2 emission to financial development and economic growth and proposed a long-term conductive mechanism for mitigating CO2 emissions without doing harm to economic prosperity. They illustrated that financial development attracts more foreign direct investment (FDI), which can further encourage the improvement of the R&D sector and then contribute to a lower level of CO2.

On which technology is best for mitigating carbon dioxide emissions, some researchers have conducted studies (Gnansounou, Dong & Bedniaguine, 2004; Chen et al., 2011). Comparing the contribution of various low-carbon technologies to the reduction of carbon dioxide emissions, Chen et al. (2011) discovered that carbon dioxide emissions can be reduced more effectively with the use of carbon-free energy technologies (such as nuclear and wind) than with fossil-fuel technologies (such as coal-fired and gas-fired).

Based on the significance of energy R&D and energy technology innovation in CO_2 reduction, Sagar and Van der Zwaan(2006) proposed that energy R&D and learning-by-doing should collaborate to update energy technologies required for sustainable energy supply and environment improvement. Gilli et al. (2014) also advocate for increased investment in environmental and technological innovation, as innovation is essential to complementing the remanufacturing agenda and enhancing environmental performance at the EU level.

Nonetheless, some researchers doubt the efficacy of technology innovation in lowering carbon dioxide emissions. Newell (2009) explained that the marginal contribution of new technologies in improving resource use efficiency is declining, and a fast expanding economic scale may nevertheless necessitate additional investments in natural resources. In a study conducted by Weina et al. (2016), it was shown that the technological changes in Italy did not bring a profound effect on cutting the CO2 emissions, especially in the high-emitting northern regions. Meanwhile, Braungardt et al. (2016) looked into the long-term debate on the impact of technology innovation and diffusion on CO2 emissions through the lens of EU-27 residential electricity demand. This study highlighted the limitation resulting from the direct rebound effects and indirect re-spending and macroeconomic effects, which means eco-innovation is not enough for solving carbon dioxide emissions problems. Furthermore, Du et al. (2019) identified a single threshold connected to the income level, and technology innovation had no significant effect on carbon dioxide emissions when a country's income level was below the threshold. In a follow-up study, Chen and Lee (2020) performed spatial econometric models in 96 countries from 1996 to 2018 and found that global carbon dioxide emissions are not significantly reduced by technological advancement. The group-based studies indicated that R&D intensity even could raise carbon dioxide emissions in some economies.

2.8 Limitations of the existing literature

Collectively, these studies outline the critical roles of financial development, economic growth, industrial structure, and technology innovation on carbon dioxide emissions. Nevertheless, researchers have not yet achieved a consensus on how financial development directly influences carbon dioxide emissions and whether intermediary variables are involved. Differences in sample selection, measurement indicators, and methodological discrepancies all contribute to the ambiguity around the ultimate impact of financial development on carbon dioxide emissions. In addition, the majority of the study focuses on the BRIC countries, Western European countries, and emerging economies; there is limited research on how the financial development of CEE countries influences carbon dioxide emissions.

3 Theoretical foundation and hypothesis

This chapter illustrates the theoretical underpinnings of how financial development affects carbon dioxide emissions directly and indirectly through economic growth, industrial structure, and technology innovation. Along with these theoretical mechanisms, the corresponding hypotheses are presented at the end of each section.

3.1 Financial Development - CO_2 nexus

Financial development directly affects the release of carbon dioxide. Shahbaz (2013) pointed out that a lack of environmental concern in the financial sector was responsible for the initial increase in carbon dioxide emissions during the early stages of financial development. As the financial system evolves, financial development hinders carbon dioxide emissions. Financial development facilitates the accessibility of low-carbon financing. The developed financial sector prefers to make investments in low-carbon projects to minimize the amount of carbon dioxide emissions as capital markets expanding. Diversified direct financial instruments, such as stocks and bonds, can help broaden the financing channels for environmentally friendly projects and contribute to the economy's transition into a decarbonized economy that produces low carbon dioxide emissions. Besides, consumers have shown preference for low-carbon products with practical influences and personal benefits. The popularity of eco-friendly consumer credit[4] has contributed to an increase in both the awareness of environmental issues and the demand for environmentally responsible products. In doing so, consumers are willing and able to afford to pay more for eco-friendly goods. In response, vendors are seeking more low-carbon merchandise that benefits the release of carbon dioxide (Yong et al., 2021). On the basis of the theoretical analysis, the paper assumes the following:

Hypothesis 1: Financial development causes an increase of carbon dioxide emissions and then a reduction.

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[4] Consumer credit refers to debt incurred by an individual to pay for goods and services.

3.2 Financial Development - Economic Growth - CO_2 nexus

Financial development is critical in the process of generating robust economic growth because financial markets make a significant contribution to economic efficiency by redirecting financial resources from less productive uses to more productive uses (Durusu-Ciftci et al., 2017). For example, one of the components of the financial markets and the banking system has a role in the distribution of savings, fostering innovation, and providing capital for productive investment, which substantially spurs economic growth (Schumpeter, 1911). Also, financial markets enable firms to boost the liquidity of their assets by holding a diversified portfolio, hence hedging risk and promoting economic growth (Saint Paul, 1992).

Endogenous growth theory suggests that economic growth is the consequence of internal forces, which can be achieved irrespective of external forces. These internal forces primarily refer to investments in human capital, innovation, and knowledge (Aghion et al., 1998). The theory claims a positive relationship between financial development and economic growth. Financial development enhances economic growth in two ways. Firstly, a well-developed financial system offers the education sector loans and increases investment. More investments in the relevant sector will raise human capital in the economy. Since human capital has a spillover effect, it leads to the higher efficiency of production factors, enables more rational allocation of resources, and enhances economic expansion (Yunnan, 2012). Secondly, with financial instruments, specialized resources such as capital and labour can be utilized in more specialized fields without incurring risks. Saint Paul (1992) states that a broader division of labour is required to increase productivity. Economic growth is a forward process that begins with the division of labour[5]. As the division of labour becomes more refined, economic output increases, which results in rising wages and per capita income. However, this more granular division

[5] Adam Smith, "Division of Labour and Specialization," Econlib, access date: 05.07.2022. URL: https://www.econlib.org/library/topics/highschool/divisionoflaborspecialization.html#:~:text=The%20main%20cause%20of%20prosperity,pins%20per%20worker%20per%20day.

of labour will expose specialized resources (i.e. capital, labour) to greater risk. Financial derivatives can help to eliminate risk exposure.

The Environmental Kuznets Curve (EKC) is the primary theoretical foundation for explaining how economic growth affects carbon dioxide emissions. Grossman and Krueger (1995) identified an inverted U-shaped relationship between income and environmental evolvement. To be more specific, environmental quality worsens along with the economic expansion, but this trend reverses once a predetermined benchmark has been crossed. As carbon dioxide emissions are considered one of the parameters for measuring the quality of the environment, the EKC theory predicts that the relationship between economic growth and carbon dioxide emissions is likewise inverted U-shaped.

In conjunction with Maslow's hierarchy of needs theory (Maslow & Lewis, 1987), this paper further explains how economic growth causes the carbon dioxide emissions curve to assume an inverted U-shape. In the initial phase of economic growth, the primary needs of humans were physiological, including food supply, water, as well as clothing. The only concern for human beings was how to ensure their survival; thus, they disregarded environmental issues. People relied on or even plundered natural resources such as land and fossil fuel to address the problem of necessities, improve living standards, and pursue rapid economic development. This has led to the overexploitation of resources and dramatic growth in waste production, most importantly, carbon dioxide emissions. Fortunately, when economic growth exceeds a certain threshold, and the individual's survival needs have been met, human beings' spiritual needs would outweigh their physiological needs. People consciously consider their daily behaviors, their awareness of environmental protection increases, and they modify their behavior spontaneously in accordance with their consciousness, leading to a decrease in carbon dioxide emissions. For instance, people who previously commuted by car now spontaneously choose low carbon means of transportation such as bicycles and buses. For enterprises, they would independently modify their production methods and products in a more eco-friendly way, which is undoubtedly beneficial to reducing carbon dioxide emissions and augmenting the ecological environment.

The paper makes the following hypothesis based on the aforementioned theoretical mechanisms by which financial development influences the economy and, consequently, carbon dioxide emissions:

Hypothesis 2: Financial development causes an increase in carbon dioxide emissions and then a reduction through economic growth.

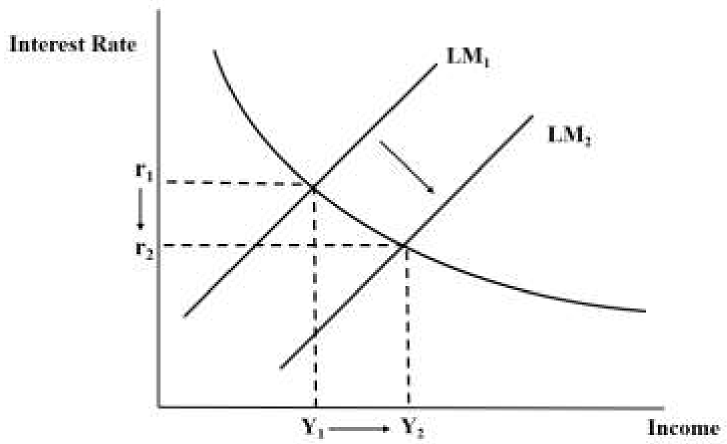
3.3 Financial Development - Industrial Structure - CO_2 nexus

The changes in industrial structure are a response to the pressure of mass consumption and investment and are either imposed or initiated to adapt to social changes (Pollard, 1958; Kongsamut et al., 2001). This section combines the quantity theory of money (QTM) and the IS-LM model to illustrate how financial development affects consumption and investment. The QTM theory was first proposed by Milton Friedman, and the related modern form was later given by Irwing Fischer.

$$M \cdot V_t = \sum_i (p_i \cdot q_i) = p^t q$$

M represents the total money in circulation. Transaction velocity (V_t) denotes the average frequency with which a unit of money gets spent across all payments. p_i is the transaction price, and q_i measures the number of transactions. A sophisticated financial industry permits a variety of flexible settlement methods that shorten the time demanded cash and speed up the circulation of money (V_t). The value of V_t is growing, indicating that the number of transactions (q_i) that take place over a specific period will also increase, and the price (p_i) will fall proportionately (Shoaib et al., 2020). In addition, the IS-LM model illustrates the interaction between the markets for economical products (IS) and loanable funds (LM), as established by economists John Richard Hicks and Alvin Hansen based on Keynesian macroeconomic theory (Hicks, 1980). Considering that the level of financial growth rises, the rate at which money circulates grows as well, while the price level of commodities falls; this increases the real money balance (M/P). Referring to the liquidity preference theory, reduced interest rates result from a rise in the real money balance. As depicted in Figure 3.1, the LM curve drops downward, and the equilibrium point shifts from point A to point B. Likewise, the income level (Y) associated with the new equilibrium point B rises to the right. The rise in income indicates an increase in demand for consumption and investment. It follows that there will be increased demand for both consumption and investment if there is an increase in the level of income.

Figure 3.1 The IS-LM model



Source: constructed by the author.

Changes in consumer demand will not only induce the emergence of new business models and sectors but also hinder or replace outmoded traditional industries. When mass consumption varies, enterprises will adapt accordingly to serve the market, thus influencing the factor market and altering the industry's structure (Hailan et al., 2022). Moreover, Maslow's hierarchy of needs theory mentioned in Section 3.2 is also applicable to explain the relationship between consumption and industrial structure. This paper divides it into the following three phases. In the low-income phase, food expenses account for the bulk of household expenditures, and the demand structure is based on meeting people's physiological demands. Society invests its resources in agriculture and extraction (i.e. the primary sector). In the middle-income phase, because of the accumulation of wealth, basic needs are satisfied. Further consumption of the masses is at the stage of pursuing the convenience and functionality of life. The supply of durable goods rises, and the secondary sector (i.e. manufacturing) dominates the national economy. In the high-income phase, people gradually seek the spiritual component of consumption, and their needs become more individualized and diversified. The relevant service sectors have flourished, and society has transformed from the secondary industry to the tertiary industry (Alam, 2015; Hailan et al., 2022).

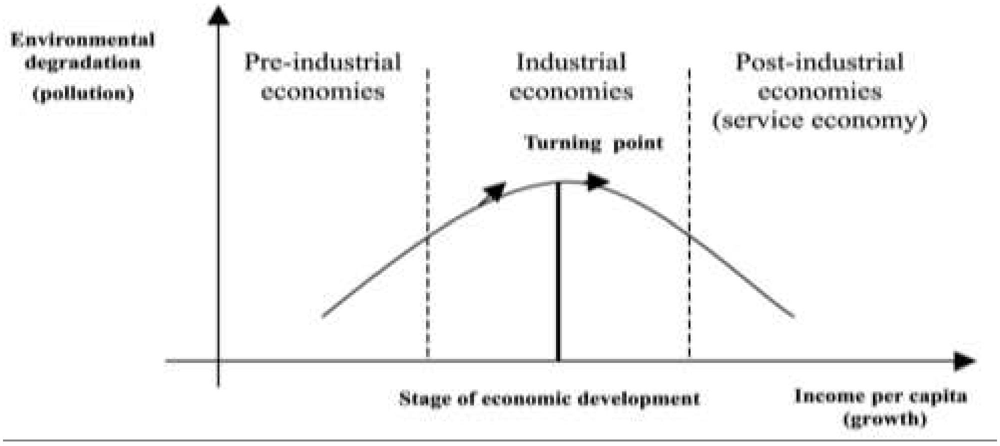
Alterations in investment patterns are another way in which financial development can impact industrial structure. The distribution and movement of capital between different fields are made possible by investment. Financial institutions have a propensity to invest their capital in industrial initiatives with promising growth prospects, which speeds up the process of industrial restructuring.

Changes in carbon dioxide emissions are caused by industrial restructuring. As shown in Figure 3.2, the EKC theory states that transitioning from an agrarian to an industrial economy leads to more significant environmental degradation and carbon dioxide emissions due to the exploitation of natural resources. In comparison, it is believed that the transition from an industrial to a service-based economy results in a plateau and sustained decline in environmental degradation and carbon dioxide emissions because of the demand from human needs for ecological quality (Alam, 2015).

Based on the preceding analysis of the theoretical mechanism, the article makes the following assumption:

Hypothesis 3: Financial development causes an increase in carbon dioxide emissions and then a reduction through the industrial structure.

Figure 3.2 Three stages of environmental degradation



Source: Panayotou, 1993.

3.4 Financial Development - Technology Innovation - CO_2 nexus

Financial development is an important driving force for technology innovation. The two characteristics of technology innovation are high cost and high risk. Initially, research and development (R&D) are capital-intensive, necessitating large sums of money. Especially in those cutting-edge areas of science and technology, colossal capital investments are required, and such investments are frequently fraught with high uncertainty. They may not generate returns in the short term. Financial development finances technology innovation in enterprises or industries and alleviates their financing challenges, thereby enhancing technology innovation output and efficiency. As Hicks (1969) pointed out in his research, there is a direct correlation between technology innovation and the maturity of national financial systems in terms of capital mobilization. Also, to make long gestation productive technologies more appealing to investors, developed capital markets and institutions lower the risks associated with investing in such projects while still providing the necessary funding to keep them moving forward (Tadesse, 2005).

Financial development has three primary effects on carbon dioxide emissions via technology innovation. First, the more stable the financial market environment, the lower price and the more diverse the access to finance available to companies. Hence, the lower and less risky cost of capital invested in R&D encourages businesses to further technological advancement. Technological progress drives up the productivity of firms and industries and decreases carbon dioxide emissions per unit of production. Second, technological advancement develops new low-carbon energy sources. With the promotion of low-carbon energy, the original high-carbon energy sources are phased out, which reduces carbon dioxide emissions intensity. Furthermore, a robust and open financial market attracts direct investment from technologically equipped international investors. As a result, local enterprises have more substantial incentives and opportunities to modernize and adapt their technologies, ultimately improving energy usage efficiency and diminishing carbon dioxide emissions per unit of energy consumed.

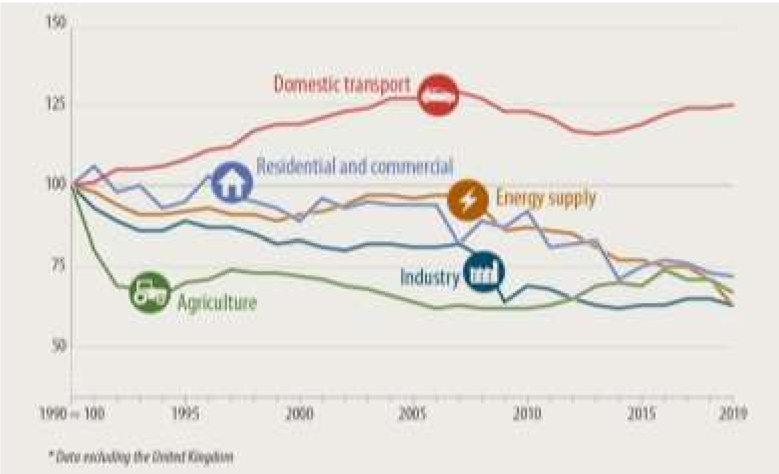
Technological breakthroughs do not help mitigate carbon dioxide emissions in the initial stages of developing technology. Potential carbon dioxide reductions related to technical advances in energy usage may be offset by the "take-back" or "rebound" effect (Wigley, 1997). The rebound effect refers to a rise in the supply of energy services accompanied by a decline in their effective price. In turn, this may contribute to an increase in demand because of these price reductions. Thus, an increase in demand for energy without a corresponding rise in fuel prices can offset gains from technical efficiency (Greening, 2000). Even if technology innovation enhances the efficiency of energy usage, the drop in the effective price of energy stimulates an unexpected increase in energy demand and consumption in the market. Instead, the carbon dioxide emissions from increased energy consumption far outweigh the carbon dioxide reductions due to the advancement of energy usage efficiency, resulting in a continued increase in carbon dioxide emissions. According to Figure 3.3 below, the main sources of carbon dioxide emissions in the EU are domestic transport, residential and commercial, energy supply, and industry. The rebound effect has detrimental effects in three ways: First, for domestic vehicle, which emits the majority of carbon dioxide emissions, lower petrol prices making driving a car more affordable, leading to an increase in car usage and carbon dioxide emissions. Second, cheaper electricity encourages residential and commercial energy consumption. Third, for industries, especially the steel industry, the giant of energy consumption, when the cost of energy consumption falls, the output of steel keeps rising. Overall, carbon dioxide emissions are increasing intensively.

However, as technology innovation rises, the rebound effect becomes progressively less powerful. The rebound effect ceases to work when technological innovation reaches a particular level and may contribute to carbon dioxide reductions. For example, new technologies (e.g. decarbonization tech) convert carbon dioxide into fuel or solid carbon, directly eliminating carbon dioxide emissions.

Therefore, financial development may be held responsible for stimulating the increase of carbon emissions as well as promoting its reduction (Ziaei 2015). The article makes the following assumption based on the above theoretical mechanisms:

Hypothesis 4: Financial development causes an increase in carbon dioxide emissions and then a reduction through technological innovation.

Figure 3.3 Change in carbon dioxide emissions levels by sector within the EU, 1990-2019.



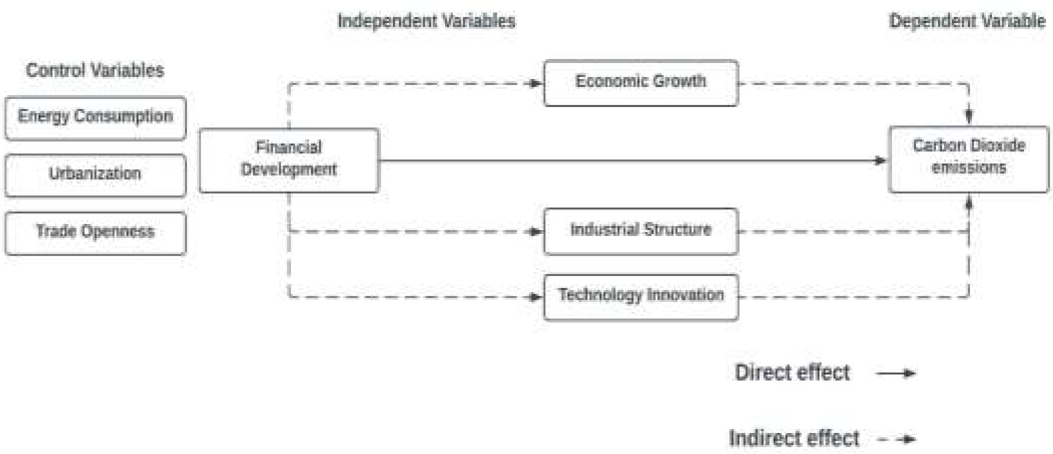
Source: European Environment Agency, 2022[6].

[6] News European Parliament, "CO2 emissions from cars: facts and figures (infographics)", access date: 06,07,2022. https://www.europarl.europa.eu/news/en/headlines/society/20190313STO31218/co2-emissions-from-cars-facts-and-figures-infographics

3.5 Financial Development - Economic Growth & Industrial Structure & Technology Innovation - CO_2 nexus

The previous three sections illustrate the theories and hypotheses regarding how financial development influences carbon dioxide emissions via economic growth, industrial structure, and technology innovation. To visualize these three transmission channels between financial development and carbon dioxide emissions, the author constructs Figure 3.4 below.

Figure 3.4 Insight into the transmission channels between financial development and carbon dioxide emissions.



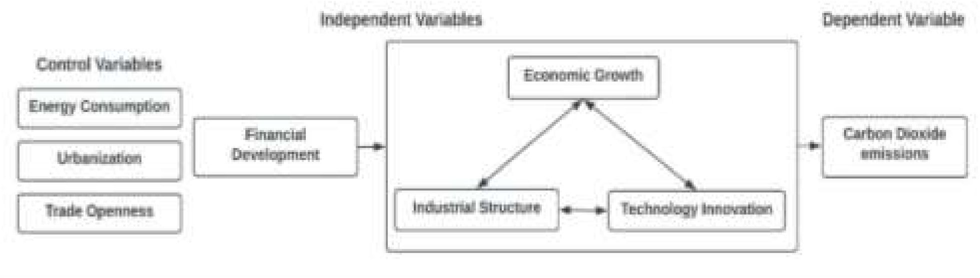
Source: Constructed by the author.

None of these three economic factors (i.e. economic growth, industrial structure, and technology innovation) can be considered independent of the others. The expansion of the economy is accompanied by technological evolution and industrial structure modification. Not only does economic growth provide monetary support for technological innovation, but it also provides a pool of human resources for it since a portion of the social wealth would be allocated to education, entertainment, and other activities, fostering the improvement of population quality. Also, the alteration in industrial structure enables labor and capital to concentrate in high-productivity industries rather than low-productivity ones, advancing technological progress and driving economic growth. Under the pressure of market competition, those low-productivity departments are compelled to engage in technology innovation lest the market eliminates them. At the same time, sectors with high production efficiency naturally have higher profit margins. They will use the remaining funds to advance technological innovation and actively maintain market competitiveness. In turn, technology innovation also affects economic growth and industrial structure. In the "Theories of Surplus Value" (1963), Karl Marx proposed that the accumulation of technological innovation raises the productive efficiency of labor, shortens the socially necessary labor time, and increases surplus value (i.e. economic aggregates). In his 2008 book, "Capitalism, Socialism, and Democracy," Schumpeter coined the term 'creative destruction' and defined technological innovation as an ongoing process of devastation. In this process, obsolete techniques are abolished, and new industrial structures gradually replace existing ones. In other words, creative destruction of technology is the autonomous removal of outdated elements in the current industrial system and the continuous construction of new industrial structures through ongoing refinement, which ultimately achieves the original technological development trajectory's breakthrough. During the first Industrial Revolution, for instance, the widespread use of steam engines led to the substitution of handicrafts by large-scale machine manufacturing and fostered industrial revolutions in a wide range of labor sectors, such as mining, metallurgy, and manufacturing. Therefore, an interaction effect is produced by the joint action of economic growth, industrial structure, and technology innovation. Figure 3.5 depicts their interaction.

To better comprehend how financial development influences carbon dioxide emissions through this interaction effect of three indicators, the paper proposes a hypothesis and examines it in the following analysis.

Hypothesis 5: Financial development causes an increase in carbon dioxide emissions and then a reduction through a combined effect of economic growth, industrial structure, and technology innovation.

Figure 3.5 The interaction effect of economic growth, industrial structure, and technology innovation.



Source: Constructed by the author.

4 Data description and measurement of financial development index

For the purpose of conducting empirical research, the paper makes use of a panel data set obtained from the World Bank, Global Change Data Lab (Our World in Data), and International Monetary Fund (IMF) data for thirteen selected Central and Eastern Europe (CEE) countries during the course of the years 2000 to 2019 due to the restrictions on the availability of data.

The countries studied in this paper include Belarus (BLR), Bosnia and Herzegovina (BIH), Bulgaria (BGR), Croatia (HRV), Czech (CZE), Estonia (EST), Hungary (HUN), Latvia (LVA), Lithuania (LTU), North Macedonia (MKD), Poland (POL), Serbia (SRB), and Slovenia (SVN) are considered for this panel analysis. Despite the fact that each of these countries is from different European territories and has a unique history and economic blast – some are former Soviet Union republics, some of them are former Yugoslavia – they all have one thing in common, that is, they are all ex-socialist economies. This is the economic rationale for utilizing these nations. Several CEE countries are excluded due to the lack of comprehensive data.

In this article, the dependent variable is CO_2 emissions, defined as the country's total annual CO_2 emissions divided by its total population. Financial Development (FD), Economic Growth (Growth), Industrial Structure (Industry), and Technology Innovation (Tech) are independent variables. At the same time, energy consumption (Energy), urbanization (Urban), and trade openness (Trade) are all considered to be control variables (Saidi & Mbarek, 2017; Saud et al, 2019; Shao et al., 2022). The variables are summarized in Table 4.1. For a few missing values in this panel data, even if they do not hinder the manipulability of the regressions, they can introduce some bias into the results. The author employs the linear interpolation technique to construct new data points to tackle missing values in the dataset.

The most crucial independent variable is Financial Development (FD). In the existing empirical studies, the majority have adopted various individual proxies for measuring financial development. Specifically, single proxy measures of financial development such as the percentage of real domestic credit to private sector per capita, stock market turnover ratio, stock market capitalization to GDP ratio, and Bank z-score rule the empirical literature (Shahbaz et al., 2013; Shoaib et al., 2020; Younsi & Bechtini, 2020). Nevertheless, financial development is a multidimensional idea rather than a single concept (Svirydzenka, 2016; Ito, 2018). Using various individual proxies for financial development may not adequately reflect the actual degree of financial development and may even result in contradicting findings (Acheampong et al., 2020). For instance, the empirical evidence presented in Acheampong (2019) demonstrates that an increase in carbon dioxide emissions is associated with financial development, as measured by broad money, domestic credit to the private sector, and domestic credit to the private sector by banks. However, financial development has a negligible effect on carbon dioxide emissions when financial development is approximated using current liabilities, foreign direct investment, and domestic credit provided by the financial sector to the private sector. In order to reflect the complex and multidimensional nature of financial development, some researchers have derived a comprehensive index from relevant indicators indicating the degree of financial development by using the Principal Component Analysis (PCA) technique. The Global Financial Development Database of the World Bank has designed a simple but thorough conceptual 4x2 framework to approximate global financial development. As a matter of fact, the period covered by the data is insufficient. In this paper, the author adopts the financial development index issued by the International Monetary Fund (IMF). This financial development index is comprised of nine indices that quantify the depth, access, and efficiency of financial institutions and financial markets (Svirydzenka, 2016).

Regarding other explanatory variables, real GDP per capita, measured in constant 2015 U.S. dollars, is a representation of Economic Growth (Growth). Industrial Structure (Industry) is reflected in the industrial value-added to GDP ratio. Basically, Technology Innovation (Tech) is expressed in terms of expenditure on research and development (R&D) or the number of total patent applications (Fernandez et al., 2018; Saudi, 2019). This research considers R&D expenditure as a percentage of gross domestic spending to represent technology innovation since, as a macroeconomics article, this indicator is utilized to provide a more precise depiction of the amount of investment present in a national economy.

The previous research (Shahbaz et al., 2013; Omri et al., 2015) reveals that carbon dioxide emissions positively correlate with energy consumption, urbanization rate, and trade openness. This paper introduces three additional control variables (i.e. energy consumption, urbanization, and trade openness) to establish associations between carbon dioxide emissions and financial development. Energy Consumption (Energy) refers to the usage of energy (kg of oil equivalent per capita). The fraction of the urban population assesses Urbanization (Urban) in the overall population. Trade Openness (Trade) is calculated by taking the total amount of a country’s exports and imports of goods and services as a percentage of its gross domestic product.

Table 4.1 Description of variables and sources of data

Variable	Abbreviation	Definition	Measure	Source
Carbon Dioxide emissions	CO_2	It stems from the combustion of fossil fuels and the manufacture of cement; land use change is excluded	Per capita CO_2 emissions in metric tons	Global Change Data Lab (Our World in Data)
Financial Development	FD	A ranking of countries based on the depth, access, and efficiency of their institutions and financial markets; a combination of the Financial Institutions index and the Financial Markets Index	Financial Development Index	IMF Data
Economic Growth	Growth	Gross domestic product divided by the population at mid-year	GDP per capita (constant 2015 US dollars)	World Bank
Industrial Structure	Industry	It comprises value added in mining, manufacturing, construction, electricity, water, and gas. Value added is a sector's net output after totaling all outputs and subtracting intermediate inputs.	Industry (including construction), value added (% of GDP)	World Bank
Technology Innovation	Tech	Refers to gross domestic expenditures on research and development (R&D), which encompasses basic research, applied research, and experimental development	Research and development expenditure (% of GDP)	World Bank
Energy Consumption	Energy	Refers to the use of primary energy prior to its transformation into other end-use fuels, which equals indigenous production plus imports and stock changes minus exports and fuels supplied to ships and aircraft engaged in international transport	Energy use (kg of oil equivalent per capita)	World Bank
Urbanization	Urban	Refers to the inhabitants of urban areas	Urban population (% of total population)	World Bank
Trade Openness	Trade	Refers to the sum of exports and imports of goods and services measured as a share of gross domestic product	Trade (% of GDP)	World Bank

Source: Constructed by the author.

5 Empirical model specification

This research studies the total, direct, and indirect effects of financial development on carbon dioxide emissions using CEE samples. The total effect is composed of both direct and indirect effects. In studying the direct and indirect effects of financial development on carbon dioxide emissions, the paper introduces three mediating variables: economic growth, industrial structure, and technology innovation.

5.1 GMM-SYS model

The general model for carbon dioxide emissions is modified from Shahbaz et al. (2016), Acheampong et al. (2020):

$$CO_{2it} = f(FD_{it}, Growth_{it}, \ Industry_{it}, Tech_{it}, Energy_{it}, Urban_{it}, Trade_{it}) \quad (5.1)$$

where CO_{2it} is represented as a function of FD_{it}, $Growth_{it}$, $Industry_{it}$, $Tech_{it}$, $Energy_{it}$, $Urban_{it}$, and $Trade_{it}$; *i* denotes countries and *t* is the year. For accurate and reliable findings, all variables except the financial development index (FD_{it}) are converted into natural logarithms since FD_{it} is a comprehensive index (Shao et al., 2022). Based on the dynamic log-linear equation by Shahbaz et al. (2018), this paper incorporates the squared term of financial development (${FD_{it}}^2$) into the equation to identify whether the correlation between financial development and carbon dioxide emissions is in the form of an inverted U or not. This argument is built on the presumption that the financial sector was initially less concerned with environmental issues, stimulating carbon dioxide emissions; once the financial system matured, the developed financial sector reduced carbon dioxide emissions by financing environmentally friendly projects to sustain low-carbon production (Shahbaz et al., 2013). Considering that the change in carbon dioxide emissions is dynamic, emissions from the previous period will inevitably influence the emissions of the current period. We also include the lagged dependent variables ($lnCO_{2it-1}$) as one of the regressors to perform a dynamic system generalized method of moment (GMM-SYS) for panel data to address the potential endogeneity and omitted variable issues, which aids in modeling both short-run and long-run effects (Acheampong, 2019). The GMM-SYS is a dynamic panel model simultaneously estimating differences and levels (Blundell and Bond, 1998). In comparison to difference GMM, system GMM enhances estimation efficiency. The estimable equation is specified in Eq. (5.2).

$$lnCO_{2it} = \alpha_0 + \alpha_C lnCO_{2it-1} + \alpha_{F^2} FD_{it}{}^2 + \alpha_F FD_{it} + \alpha_E lnEnergy_{it} + \alpha_U lnUrban_{it} + \alpha_T lnTrade_{it} + \varepsilon_{it} \tag{5.2}$$

where i = 1...13 and t = 2000...2019, CO_{2it}, FD_{it}, $Energy_{it}$, $Urban_{it}$, and $Trade_{it}$ represent the per capita CO_2 emissions in metric tons, financial development index, energy use per capita, urban population ratio and the ratio of exports and imports values over GDP, respectively. ε_{it} presents the stochastic error term, reflecting the effect of factors that vary with individuals and time that are ignored in the model. The empirical model is used to verify the total impact of financial development on carbon dioxide emissions. It is expected that if $\alpha_{F^2} < 0$ then there is an inverted U-shaped link between FD and CO_2, which would justify our Hypothesis 1.

5.2 Mediational model

The paper assumes that financial development has both direct and indirect effects on carbon dioxide emissions via three transmission channels. In doing so, the study extends Model (5.2) to comprise the indicators of economic growth ($lnGrowth_{it}$), industrial structure ($lnIndustry_{it}$), and technology innovation ($lnTech_{it}$), respectively. To investigate the direct and indirect effects of financial development on carbon dioxide emissions through economic growth, industrial structure, and technology innovation, the paper employs the test of mediation effect. The fundamental idea of the mediation effect is to study whether the influence of the independent variable on the outcome variable goes through a mediator. In other words, the researcher needs to test whether there is an FD→mediators→CO_2 relationship.

The author visualizes the mechanism of three effects between variables, citing Baron and Kenny (1986), as shown in Figure 5.1. X, Y, and M denote the independent variable, the outcome variable, and the mediator. The corresponding equations are expressed as follows.

$$Y = cX + e_1 \tag{5.3}$$

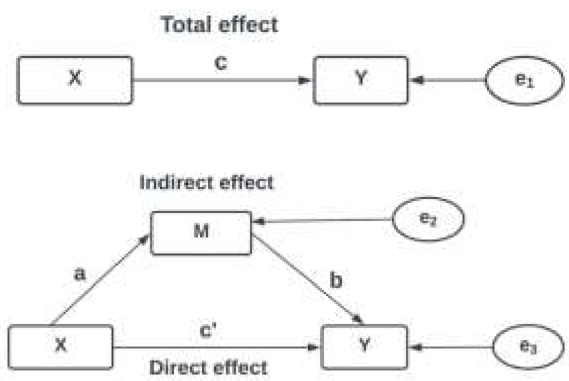
$$M = aX + e_2 \tag{5.4}$$

$$Y = c'X + bM + e_3 \tag{5.5}$$

The regression of X on Y is shown by Eq. (5.3), which is used to estimate the magnitude of the effect of the independent variable on the outcome variable before the inclusion of the mediating variable. c represents the total effect. Eq. (5.4) is a regression of X on M, and Eq. (5.5) represents the regression of X and M on Y, with the addition of the mediator. The direct effect, c', is the magnitude of the effect of the independent variable on the outcome variable after adding the mediator, whereas $a \cdot b$ is the indirect effect. The Eq. (5.6) describes the relationship between them.

$$c = c' + a \cdot b \tag{5.6}$$

Figure 5.1 Mediational model



Source: Baron & Kenny,1986; MacKinnon et al., 2000.

As displayed in Figure 5.1 of the mediational model, economic growth ($lnGrowth_{it}$), industrial structure ($lnIndustry_{it}$), and technology innovation ($lnTech_{it}$) would be treated as mediating factors in the following empirical models. Given that economic growth, industrial structure, and technology innovation are dynamic and continuously changing and that the value of the previous period affects the value of the current period, the paper incorporates the lagged terms of economic growth, industrial structure, and technology innovation into the respective models as explanatory variables. The linearity of the link between financial development and these three mediating variables is another crucial premise of this work. The empirical models are given below[7]:

Path A:

$$lnCO_{2it} = \alpha_0 + \alpha_C lnCO_{2it-1} + \alpha_{F^2} FD_{it}{}^2 + \alpha_F FD_{it} + \alpha_E lnEnergy_{it} + \alpha_U lnUrban_{it} + \alpha_T lnTrade_{it} + \varepsilon_{it} \quad (5.2)$$

Path B:

$$lnGrowth_{it} = \beta_0 + \beta_G lnGrowth_{it-1} + \beta_F FD_{it} + \beta_E lnEnergy_{it} + \beta_U lnUrban_{it} + \beta_T lnTrade_{it} + \varepsilon_{it} \quad (5.7)$$

$$lnIndustry_{it} = \beta_0 + \beta_I lnIndustry_{it-1} + \beta_F FD_{it} + \beta_E lnEnergy_{it} + \beta_U lnUrban_{it} + \beta_T lnTrade_{it} + \varepsilon_{it} \quad (5.8)$$

$$lnTech_{it} = \beta_0 + \beta_{Te} lnTech_{it-1} + \beta_F FD_{it} + \beta_E lnEnergy_{it} + \beta_U lnUrban_{it} + \beta_T lnTrade_{it} + \varepsilon_{it} \quad (5.9)$$

Path C:

[7] Referring to Qian (2019).

$$lnCO_{2it} = \gamma_0 + \gamma_C lnCO_{2it-1} + \gamma_{F^2} FD^2 + \gamma_F FD_{it} + \gamma_G lnGrowth_{it} + \gamma_E lnEnergy_{it} + \gamma_U lnUrban_{it} + \gamma_T lnTrade_{it} + \varepsilon_{it} \quad (5.10)$$

$$lnCO_{2it} = \gamma_0 + \gamma_C lnCO_{2it-1} + \gamma_{F^2} FD^2 + \gamma_F FD_{it} + \gamma_I lnIndustry_{it} + \gamma_E lnEnergy_{it} + \gamma_U lnUrban_{it} + \gamma_T lnTrade_{it} + \varepsilon_{it} \quad (5.11)$$

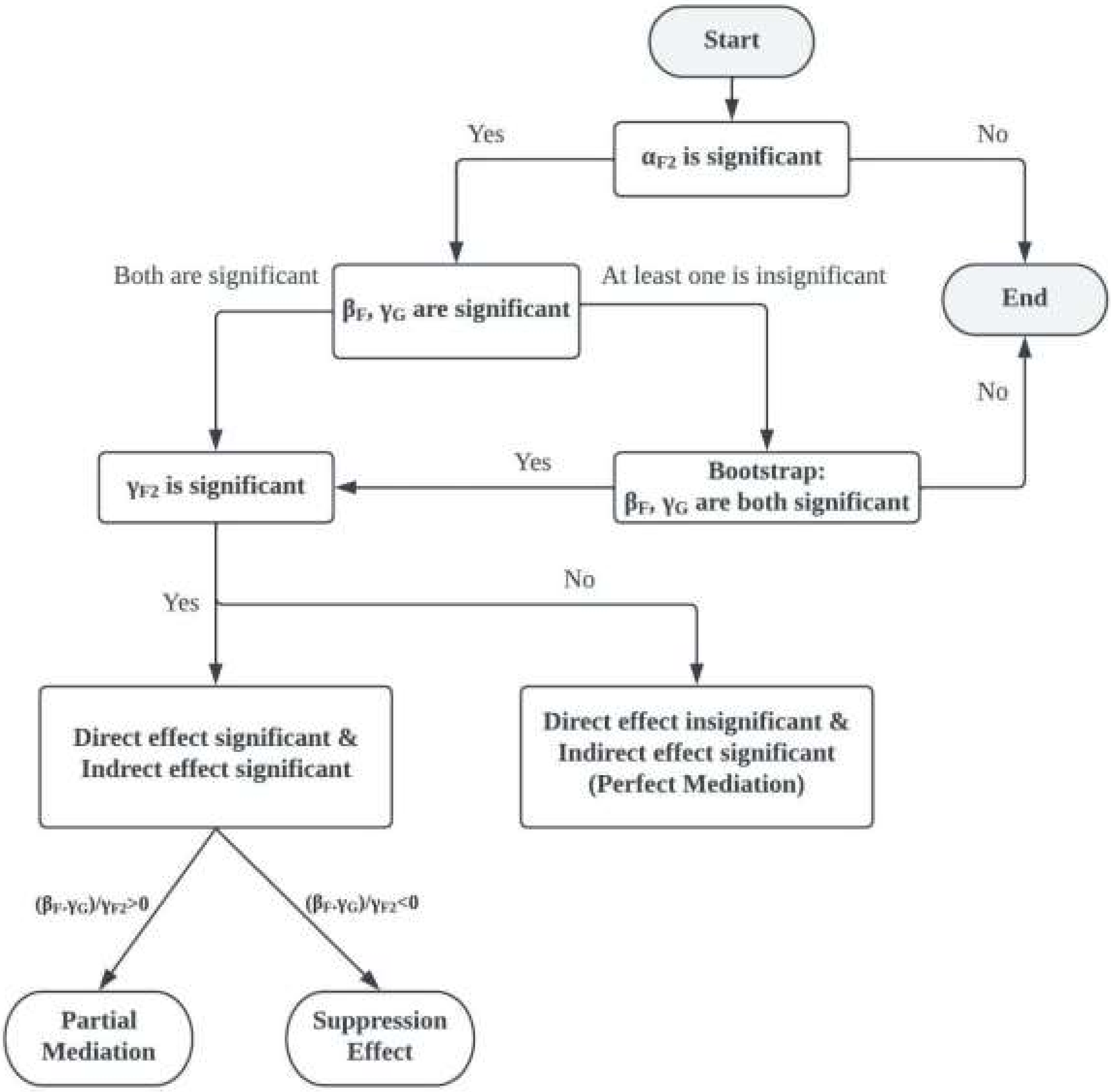
$$lnCO_{2it} = \gamma_0 + \gamma_C lnCO_{2it-1} + \gamma_{F^2} FD^2 + \gamma_F FD_{it} + \gamma_{Te} lnTech_{it} + \gamma_E lnEnergy_{it} + \gamma_U lnUrban_{it} + \gamma_T lnTrade_{it} + \varepsilon_{it} \quad (5.12)$$

where $Growth_{it}$, $Industry_{it}$, and $Tech_{it}$ are measured as per capita GDP, value-added of industry, and R&D expenditure. These three paths correspond to the mediational model of Figure 5.1. Specifically, Path A studies the total effect of financial development on carbon dioxide emissions without any mediators; Path B explores the impact of financial development on the indicators that serve as mediators; Path C represents the influence of financial development and mediators on carbon dioxide emissions with the inclusion of mediating variables. Combining the mediation test steps proposed by Baron and Kenny (1986) and Zhonglin et al. (2022), the following flowchart 5.2 is constructed. Figure 5.2 illustrates the precise stages involved in testing for mediating effects.

The paper considers economic growth as an example of a mediating variable. The first step is to test the total effect of financial development on carbon dioxide emissions in Path A. If α_{F^2} or α_F is significant at a 5% significance level, which means that financial development has a significant total effect on carbon dioxide emissions, the article will move to the next phase of Path B. Otherwise, financial development will be omitted from the list of factors affecting carbon dioxide emissions, and the analysis will end. As expected from the previous section, if $\alpha_{F^2} < 0$, the total effect of financial development on carbon dioxide emissions can be represented as an inverted U-shaped relationship. For the second step, β_F is estimated in the linear models of Path B, and γ_G is estimated in the model for Path C. If β_F and γ_G are statistically significant at any conventional significance levels simultaneously, then proceed to the estimation of γ_{F^2} in Path C. If one of the coefficients is insignificant, the paper will retest their significance using the Bootstrap approach if necessary. If the condition that both β_F and γ_G are statistically significant is never satisfied, the study would be terminated. In the third phase, the article goes on to check the significance of γ_{F^2} at a conventional significance level. A statistically significant γ_{F^2} suggests the presence of both direct and indirect effects. Otherwise, there is no direct effect and just an indirect one. In such a case, it is referred to as perfect/complete mediation. Perfect mediation occurs when the independent variable no longer impacts the outcome variable once the mediating variable is added. It is the case in which c' is zero (Baron & Kenny, 1986; Kenny & Judd, 2014). The last step requires the researcher to determine if the signs for $\beta_F \cdot \gamma_G$ and γ_{F^2} are the same or not. So long as $\beta_F \cdot \gamma_G$ and γ_{F^2} have the same sign, the author can infer the presence of partial mediation. Partial mediation holds when the mediator is under control, and the independent variable still has some effect on the outcome variable. If $\frac{\beta_F \cdot \gamma_G}{\gamma_{F2}} < 0$, the author believes that there is a suppression effect of the mediator. The suppression effect is the reverse of the partial mediating effect. In a partial mediating effect, the amplitude of the association between the independent variable and outcome variable is often diminished since the mediator partially explains the relationship. In contrast, the suppression effect refers to the suppression of the mediating effect, which statistically manifests as the addition of a third variable (i.e. suppression variable), making the relationship between the explanatory variable and the explained variable opposite (Chen et al., 2021). The aforementioned is the idea of analysis with economic growth as the mediating variable, and the same holds true for the mediational models with industrial structure and technology innovation as the mediators.

It is worth mentioning that only when the coefficient (γ_{F^2}) is significantly negative at the 1%, 5%, or 10% significance level does this prove Hypothesis 2 that the impact of financial development on carbon dioxide emissions is nonlinear and that, via economic growth, financial development initially stimulates carbon dioxide emissions and suppress them. Likewise, models (5.11) and (5.12) correspond to Hypotheses 3 and 4, accordingly. Through industrial structure and technology innovation, the author explores how financial development, directly and indirectly, affects the release of carbon dioxide.

Figure 5.2 Flowchart of the test of the mediating effect (e.g. economic growth as a mediator)



Note: Partial mediation also means the enhancing mediating effect. The suppression effect can also be called the suppressing mediating effect.

Source: Constructed by the author.

The preceding analysis analyses economic growth, industrial structure, and technology innovation as individual mediating variables. In reality, three indicators are not independent but interact with each other. In this regard, the paper introduces an interaction term of economic growth, industrial structure, and technology innovation ($lnGrowth_{it} \cdot lnIndustry_{it} \cdot lnTech_{it}$) to assess whether their interaction affects the FD-CO2 emissions model. Following the mediational model in Figure 5.1, the article will construct a mediation model with the interaction term as the mediator. The specified model is given as below:

Path A:

$$lnCO_{2it} = \alpha_0 + \alpha_C lnCO_{2it-1} + \alpha_{F^2} FD_{it}{}^2 + \alpha_F FD_{it} + \alpha_E lnEnergy_{it} + \alpha_U lnUrban_{it} + \alpha_T lnTrade_{it} + \varepsilon_{it} \quad (5.2)$$

Path B:

$$GIT_{it} = \beta_0 + \beta_{GIt} GIT_{it-1} + \beta_F FD_{it} + \beta_E lnEnergy_{it} + \beta_U lnUrban_{it} + \beta_T lnTrade_{it} + \varepsilon_{it} \quad (5.13)$$

Path C:

$$lnCO_{2it} = \gamma_0 + \gamma_C lnCO_{2it-1}{}_{\gamma^2} + \gamma_{F^2} lnFD_{it}{}^2 + \gamma_F lnFD_{it} + \gamma_{GIT} GIT_{it} + \gamma_E lnEnergy_{it} + \gamma_U lnUrban_{it} + \gamma_T lnTrade_{it} + \varepsilon_{it} \quad (5.14)$$

where GIT_{it} denotes $lnGrowth_{it} \cdot lnIndustry_{it} \cdot lnTech_{it}$. Model (5.13) is a regression of financial development on the interaction term. The financial development and the interaction term are regressed in Model (5.14). It is necessary to initially check the statistical significances of β_F and γ_{GIT} at the standard significance level. Only if the estimates of β_F and γ_{GIT} are found to be significant can the significance of γ_{F^2} be evaluated by the following step. At this point, the author can conclude if the interaction of economic growth, industrial structure, and technology innovation can play a mediating function as a mediator in the FD-CO_2 emissions model. Meanwhile, suppose the estimated γ_{F^2} is also significantly negative. In that case, the author will believe that the influence of the inverted U-shape of financial development on carbon dioxide emissions would be achieved through the interaction of these three indicators.

5.3 Methodological contribution

This methodological approach, in several ways, enriches research on financial development and carbon dioxide emissions: First, the SYS-GMM approach is introduced to address the endogeneity problem in the dynamic panel data model. Some researchers adopted the random effect model, ARDL, and 2SLS model, while they ignored the endogenous issues that may appear in dynamic panel models, which may lead to bias and hinder the consistency of estimates. Second, the paper extends the original model by proposing three distinct indicators to identify and explain the potential transmission channels through which financial development indirectly influences carbon dioxide emissions. Based on the traditional causal steps approach proposed by Baron & Kenny (1986), this paper develops an innovative mediational test model. Third, the interaction term is employed to integrate the three individual economic indicators and determine whether their combined effect might also work as a mediator in the mediational model.

6 Empirical results and discussions

6.1 Descriptive analysis

Appendix 5 summarizes the descriptive statistics for all variables across countries and the panel. The descriptive statistics show that the mean of CO2 is highest in Estonia (2.55%), followed by the Czech Republic (2.41%), Poland (2.14%), and Slovenia (2.04%), while Latvia has the smallest mean of carbon dioxide emissions (1.28%). Among 13 CEE countries, Estonia has the most carbon-intensive economy for two reasons. One, the primary fuel for Estonian power stations is oil shale (Agabus et al. 2007). Even since the 1950s, sedimentary rocks have been extracted for the production of electricity and, more recently, for the generation of liquid diesel fuel[8]. The expansion of the transport sector is another cause of carbon dioxide production. Estonia's transportation sector has been growing as a transit country between the West and East. As indicated in Table 6.1, road transport and private car transit account for the majority of growth. The Czech Republic is the second-largest emitter of carbon dioxide per capita out of 13 countries and the largest energy consumer, with a mean energy consumption of 8.32%. The majority of CO_2 emissions come from coal-fired power stations and heating plants. As seen in Appendix 2, the Czech Republic heavily relies on coal. The Czech Republic also exports energy abroad. As one of the top energy exporters in Europe, approximately a fifth of its electricity is exported annually, primarily to Austria. Furthermore, the Czech Republic has a robust automobile industry associated with heavy carbon dioxide emissions. The average value added of industry in the Czech Republic is about 3.5%. Poland, the third-largest emitter of CO_2 per capita, confronts a comparable dilemma, as coal accounts for more than 80% of its energy mix (see in Appendix 3). Kizik (2020) described that in contrast to its neighbours, Polish per capita consumption of fossil fuels had increased dramatically since 2000. In 2017, around 380kg of fossil fuels were burned per person in Poland, more than in Hungary, Lithuania, and Bulgaria consumed in 1990. Slovenia also boasts high CO2 emissions per capita. A report from Slovenia’s official statistics office

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[8] Teet Randma, “Estonia’s dirty secret,” publication date: 16.09.2018, access date: 04.07.2022. URL: https://estonianworld.com/opinion/teet-randma-estonias-dirty-secret/

shows that manufacturing and service activities contributed to 78.9% of total carbon dioxide emissions in 2019, with the majority of those emissions coming from the provision of electricity, gas, steam, and air conditioning. Households were responsible for 21.1% of all carbon dioxide emissions[9]. The relevant sources of CO_2 emissions in Slovenia are presented in Appendix 4.

Table 6.1 Energy consumption forecast for the transport sector (2005-2030)

	2005	2010	2020	2030
Road transport	18.1	18.9	22.6	26.6
Private cars	13	15	20	24
Air transport	2	1.8	2.6	3.9
Railways	1.8	2.5	2.8	2.9
Inland waterway	0.3	0.4	0.5	0.6

Source: Agabus, et al. 2007.

The descriptive statistics further show that, in the panel, the maximum value of the financial development index is 0.57, the minimum value is 0.0654, and the CV is 0.377, which indicates that financial development varies among countries. On average, the financial development index is high for Hungary (0.467), Slovenia (0.449), Croatia (0.443), and the Czech Republic (0.423); whereas the Czech Republic has the steadiest level of financial development among these four countries because of its low CV (0.118). Besides, the mean of the financial development indicator is relatively low in Belarus (0.141) and North Macedonia (0.202).

Regarding economic growth, the highest average level (9.91%) is shown in Slovenia with a standard deviation of 0.05%, while the lowest average is in Bosnia and Herzegovina (8.298%). Those high-income countries (i.e. Slovenia, Czech Republic, Estonia, Hungary, Croatia, Latvia, Lithuania, and Poland) outperform the upper-middle-income countries (i.e. Bulgaria, Serbia, Belarus, North Macedonia, as well as Bosnia and Herzegovina). Comparing the level of industrial structure indicator, the mean for

[9] Marko Pavlič, "In 2019 CO2 emissions decreased by 2.1% when compared to 2018," Republic of Slovenia Statistical Office, publication date: 14.09.2021, access date: 14/07/2022.
URL: https://www.stat.si/StatWeb/en/News/Index/9823

industrial value-added is both high in Belarus (3.54%) and the Czech Republic (3.5%), while the volatility in Belarus is greater than that in the Czech Republic, as its CV (0.02%) is higher than that of the Czech Republic (0.007%). Since 2000, more than 30% of Belarus' annual GDP has been derived from manufacturing, which comprises sectors such as mechanical engineering, petrochemical, metallurgical, and light industry[10]. Notable is the fact that Belarus specializes in the global production of mining, quarrying, and construction vehicles. For R&D expenditure, the average value of the panel data is approximate -0.42%. Most high-income CEE economies have higher R&D expenditure compared to the group of upper-middle-income countries, on average. Thereafter, on average, the energy use of all 13 CEE countries is 7.8%; the level of urbanization for samples is 4.13% and a CV of about 0.04%; the level of trade openness in the region is about 4.68%, and a CV of about 0.06%.

6.2 Correlation and multicollinearity analysis

The pair-wise correlation among variables is displayed in Table 6.2. Carbon dioxide emissions are highly correlated with financial development (31.6%), economic growth (41.01%), industrial structure (52.17%), technology innovation (42.18%), energy consumption (74.65%), urbanization (25.24%), and trade openness (24.31%), accordingly. A low association exists between independent variables. To further verify the absence of multicollinearity among the independent variables, the paper used the variance inflation factor (VIF) technique. The outcomes of the test for multicollinearity are presented in Table 6.3. Generally, there is a non-existence of multicollinearity issue if the VIF value of a variable is less than 5 or the tolerance is above 0.2. The results indicate that the empirical model does not exhibit multicollinearity, as the VIF values for each variable are smaller than 5, and the tolerance values are greater than 0.2, as indicated by the findings.

[10] Data source: World Bank.

Table 6.2 Correlation matrix for the panel data

	ln CO2	FD	ln Growth	ln Industry	ln Tech	ln Energy	ln Urban	ln Trade
ln CO2	1							
FD	0.3160*	1						
ln Growth	0.4101*	0.6784*	1					
ln Industry	0.5217*	-0.1408*	0.1516*	1				
ln Tech	0.4218*	0.5262*	0.7333*	0.4318*	1			
ln Energy	0.7465*	0.3658*	0.6049*	0.5825*	0.6058*	1		
ln Urban	0.2524*	0.0310	0.2646*	0.3549*	0.4918*	0.4693*	1	
ln Trade	0.2431*	0.1791*	0.5089*	0.2020*	0.4695*	0.4463*	0.5018*	1

Note: * indicates that the coefficient is significant at a 5% significant level.

Source: Constructed by the author using Stata 17.0.

Table 6.3 Test of multicollinearity

Indicators	VIF	Tolerance
FD	2.05	0.487
ln Energy	2.81	0.356
ln Growth	4.42	0.226
ln Tech	3.34	0.299
ln Urban	1.83	0.547
ln Industry	1.98	0.506
ln Trade	1.74	0.574
Mean	2.60	

Note: Dependent variables is $lnCO_2$. VIF is the variance inflation, and tolerance is 1/VIF.

Source: Constructed by the author using Stata 17.0.

6.3 Panel unit root test

In Econometrics, the unit root test for testing stationarity is conducted on a time series to avoid spurious regression and assure the validity of estimation results. The panel unit root test is growing in popularity due to its higher power and is more recent (Saidi and Mbarek, 2017). There are various methods of unit root tests, including the Levin-Lin-Chu (LLC) test, the Breitung test, the Im-Pesaran-Shin test (IPS), and the Augmented Dickey-Fuller (ADF) test. This research performs the LLC and IPS tests to produce strong robustness and persuasion in the test results. In the LLC test, the null hypothesis (H0) is that panels contain unit roots, and the alternative hypothesis (Ha) is that panels are stationary; in the IPS test, the null hypothesis is that all panels contain unit roots, and the alternative hypothesis is that some panels are stationary. If the null hypotheses for both tests are rejected, the paper will conclude that this time series is stationary; otherwise, it is non-stationary because of the existence of a unit root.

Table 6.4 exhibits the panel unit root results for LLC and IPS tests. It shows that for ln CO2, FD, FD^2, ln Growth, ln Industry, ln Tech, ln Energy, ln Urban, and ln Trade variables, the null hypothesis of unit root cannot be rejected at the level. For variables with unit roots in the form of level, the conventional way of obtaining stationary series is to make first-order differences. Furthermore, the author performs panel unit root tests on the series after first order differencing. All series are stationary at the first difference since the null hypothesis can be rejected even at a 1% significance level for the two tests. It is fair to presume that all series are integrated with order one (I (1)).

Table 6.4 Panel unit root results

			ln CO2	FD	FD^2	ln Growth	ln Industry	In Tech	ln Energy	ln Urban	ln Trade
At level	LLC test	Adjusted t-statistic	-5.9635**	10.2296	-13.6592**	-4.8760**	-9.5875**	-2.4640**	-2.2082*	5.0234	5.3991
		p-value	0.0000	1.0000	0.0000	0.0000	0.0000	0.0069	0.0136	1.0000	1.0000
	IPS test	z-t-tilde-bar statistic	0.0262	-0.7740	-0.6158	-0.0268	-1.3310	-1.2075	7.8522	3.9321	-3.0318**
		p-value	0.5105	0.2195	0.2690	0.4893	0.0916	0.1136	1.0000	1.0000	0.0012
At 1st difference	LLC test	Adjusted t-statistic	-7.3415**	-7.0098**	-5.9565**	-5.4995**	-7.6875**	-4.8826**	-3.9351**	-9.3842**	-4.4555**
		p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	IPS test	z-t-tilde-bar statistic	-8.0623**	-8.3673**	-8.1470**	-4.7547**	-7.3331**	-7.8299**	-6.2601**	-4.0197**	-7.1001**
		p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Note: Using the Xtunitroot command in Stata 17.0, the demean option is used to mitigate the influence of cross-sectional correlation, and the BIC criterion is used to determine the optimal lag order. * and ** indicate that the coefficient is significant at 5%, and 1% significance levels, respectively.

Source: Constructed by the author using Stata 17.0

6.4 Panel cointegration test

Even though the first differences of all variables are stationary, the economic implications of the variables after first-order differencing are not identical to the original series (i.e. the variables are in the form of level). In order to be able to use the original series for the following empirical models, this paper investigates the presence of cointegration. The panel cointegration analysis is utilized to detect whether or not the indicators exhibit long-term relationships. This study employs Pedroni's panel cointegration technique, an advancement over the classical cointegration test that takes into account heterogeneity across various panel individuals, as described in Pedroni (1999, 2004).

Table 6.5 displays the cointegration results of Pedroni. The null hypothesis is that there is no cointegration, and the alternative hypothesis is that all panels are cointegrated. The related findings show that at the 1% significance level, the probability of all test statistics is less than 0.01, rejecting the null hypothesis of no cointegration and supporting the alternative hypothesis that ln CO2, FD, FD^2, ln Growth, ln Industry, ln Tech, ln Energy, ln Urban, and ln Trade are cointegrated in all panels. That is, there are some long-run equilibrium relationships among variables.

Table 6.5 Results of the Pedroni cointegration test for different models

Models			
Model 1	Series: ln CO2, FD, FD^2, ln Energy, ln Urban, ln Trade		
		t-statistic	p-value
	Modified Phillips-Perron	3.7647	0.0001
	Augmented Dickey-Fuller	-2.3739	0.0088
Model 2	Series: ln CO2, FD, FD^2, ln Growth, ln Energy, ln Urban, ln Trade		
		t-statistic	p-value
	Modified Phillips-Perron	4.3563	0.0000
	Augmented Dickey-Fuller	-3.5865	0.0002
Model 3	Series: ln CO2, FD, FD^2, ln Industry, ln Energy, ln Urban, ln Trade		
		t-statistic	p-value
	Modified Phillips-Perron	4.4123	0.0000
	Augmented Dickey-Fuller	-3.0272	0.0012
Model 4	Series: ln CO2, FD, FD^2, ln Tech, ln Energy, ln Urban, ln Trade		
		t-statistic	p-value
	Modified Phillips-Perron	3.6598	0.0001
	Augmented Dickey-Fuller	-3.3471	0.0004

Note: Using the Xtcointtest command in Stata 17.0, all series are tested separately according to the models since the number of regressors could not exceed 7.

Source: Constructed by the author.

6.5 System generalized method of moments (GMM-SYS)

6.5.1 The total effect of financial development on carbon dioxide

The estimated total impact of financial development on carbon dioxide emissions using the GMM-SYS method is reported in Table 6.6. The test for autocorrelation and the instrument validity are presented in the lower part of Table 6.6. The Arellano-Bond test for AR(1) and AR(2) in the first differences are testing for the presence of first-order and second-order autocorrelation in the first differenced errors. In this dynamic panel data, the author detects the z-statistic (-1.144) and p-value (0.253) of AR(2). The p-value of AR(2) is greater than 0.1, which indicates no evidence of autocorrelation at a 10% significance level. The Sargan and Hansen tests are two main methods for evaluating the overall validity of the instruments. This paper concentrates on the outputs of the Hansen test, which is more robust than the Sargan test. Based on the works of the Hansen test, the author cannot reject the null hypothesis that instruments as a group are exogenous at conventional levels of significance.

The findings demonstrate that carbon dioxide emissions per capita from the previous period contribute to the next period's accumulation of per-capita carbon dioxide emissions. This implies that a 1% increase in carbon dioxide emissions per capita in the previous period increases carbon dioxide emissions per capita in the current period by 0.924%.

Besides, the estimated coefficient before FD_{it}^2 is negative and significant at a 10% significance level, which provides statistical evidence of an inverted U-shaped association between financial development and carbon dioxide emissions and conforms to Hypothesis 1 in Chapter 3. Financial development, which initially increases carbon dioxide emissions, will assist in reducing carbon dioxide emissions after the financial development index reaches an inflection point. The inverted U-shaped association between financial development and carbon dioxide emissions may be attributable to the fact that during the outset of financial development, controlled by the centrally planned economy, the financial sector in the CEE countries primarily emerged to implement government economic decisions. As members of the Soviet bloc, CEE countries pursued industrialization because of the importance of rapid growth in production capacity and heavy industrial output to assure their economic independence from the capitalist bloc and to bolster national defence. Coals, steels, and chemicals were examples of industries with high carbon dioxide emissions that received public funding. Due to this, carbon dioxide emissions rose steadily over time. Thereafter, the CEE countries experienced a transition and developed a financial system dominated by banks and supplemented by underdeveloped capital markets. Financial institutions such as banks were more conservative with their investments than the capital markets. They mainly invested in large-scale traditional secondary industries, further increasing carbon dioxide emissions. When a certain level of financial development was attained, the financial system began to assist green projects in energy, industry, transport, and property more aligned with sustainable development goals. For instance, new sustainability-related financial instruments, such as green bonds, have been on the rise in CEE countries. For banks and other financial institutions, in order to hedge or lower financial risks, are phasing out financing for coal-fired power and coal mining projects in response to environmental degradation and government commitments to reduce carbon dioxide emissions. Currently, CEE countries are discussing and creating Territorial Just Transition Plans, including a deadline for the phase-out of coal and the phase-out of public subsidies for fossil fuel investments.

The results of the empirical research suggest that carbon dioxide emissions are statistically affected by energy consumption. Increasing energy usage by 1% would increase per-capita carbon dioxide emissions by 0.088%. Thus, policies aimed at reducing fossil fuel combustion for energy and exploring renewable energy sources (e.g. wind, hydropower, solar, biomass, and geothermal) could be introduced to establish a low-carbon or even zero-carbon energy system. These policies could aid in mitigating carbon dioxide emissions without impeding financial development.

On the contrary, urbanization has a significantly negative influence on carbon dioxide emissions. For every 1% increase in urbanization, there is a 0.072% decline in carbon dioxide emissions per capita. This finding corroborates those from 19 emerging economies by Saidi and Mbarek (2017) that accelerated urbanization is conducive to curbing carbon dioxide emissions. The increased level of urbanization, as evidenced by the increased population density of towns and cities, not only generates an economy of scale effect, improving the effective use of infrastructure and public transportation, but also promotes changes in the lifestyle of residents and the development of low carbon awareness, thereby reducing carbon dioxide emissions.

The estimated coefficient for ln_Trade_{it} is not statistically significant at any conventional significance level, suggesting that trade has no statistically significant effect on carbon dioxide emissions. International trade is bidirectional, and its eventual impact on carbon dioxide emissions is contingent on the combinations of various impacts. On the one hand, trading nations can benefit from cutting-edge and low-carbon technology, producing less carbon dioxide. On the other hand, if the trading goods are highly polluting and carbon-emitting products, for the exporting country, a rise in export volume will certainly lead to an increase in carbon dioxide emissions during production, and the transportation sector accompanying the export trade will also exert environmental pressure. Obviously, the importing countries cleverly pass on the environmental burden connected with these commodities to the exporting countries. Thus, the multiple impacts nullify one another, rendering the relationship between trade and carbon dioxide emissions statistically irrelevant.

Table 6.6 System GMM panel estimation regression results in Path A

	Model (5.2) DV: ln_CO_{2it}
ln_CO_{2it-1}	0.924***
	(47.13)
FD_{it}	0.152
	(1.45)
FD_{it}^2	-0.332*
	(-2.10)
ln_Energy_{it}	0.088**
	(2.49)
ln_Urban_{it}	-0.072*
	(-2.11)
ln_Trade_{it}	-0.011
	(-0.54)
Constant	-0.201
	(-1.23)
AR (1)	-2.515**
AR (2)	-1.144
P-value of AR(2)	0.253
Hansen	8.918
P-value of Hansen	1.000
Sargan	212.566**
P-value of Sargan	0.011

Note: Using the Xtabond2 command in Stata 17.0. The table reports the t statistics in parentheses. *, **, and *** represents $p < 0.1$, $p<0.05$, and $p<0.01$, suggesting that the coefficient is significant at the 10%, 5%, and 1% significance level, respectively.

Source: Constructed by the author.

6.5.2 The direct and indirect impact of financial development on carbon dioxide

The outcomes for Path B using the GMM-SYS and Bootstrap approaches are displayed in Table 6.7, and the related outcomes for Path C are reported in Table 6.8.

6.5.2.1 Financial Development→Economic Growth→CO2 emissions

On the basis of the previously confirmed total effect of financial development on carbon dioxide emissions verified above, the mediating effect of economic growth is first examined, i.e. whether financial development can impact carbon dioxide emissions via economic growth. The GMM-SYS technique of Model (5.7) reveals that the paper cannot reject the null hypothesis of zero β_F at any conventional significance levels. This requires the author to employ the Bootstrap approach to further confirm whether financial development is significantly related to economic growth. The Bootstrap results of Model (5.7) show that at a 1% significance level, there is a statistically significant positive correlation between financial development and economic growth. A unit increase in the financial development index could lead to a 90.9% increase in economic growth since β_F is equal to 0.909. According to the results of Model (5.10) in Path C, γ_G and γ_{F^2} are significant at a 5% significance level, and γ_F is statistically significant at the 10% significance level, which demonstrates that economic growth does function as a mediator between the financial development and carbon dioxide emissions. Since the sign of $\beta_F \cdot \gamma_G$ and γ_{F^2} are identical, the economic growth holds a partial mediating effect, and the direction of the mediating effect is an enhancing effect. This partial mediating effect accounts for 7.12% of the total effect, as shown in the following arithmetic (6.1). In the mediational model of FD-Growth-CO_2, 7.12% of the total effect of financial development on carbon dioxide emissions is explained by economic growth.

$$\frac{\beta_F \cdot \gamma_G}{\alpha_{F^2}} = \frac{0.909 \times (-0.026)}{-0.332} = 0.0712 \tag{6.1}$$

Notably, the outcomes for γ_{F^2}<0 and γ_F>0 support Hypothesis 2, that through economic growth, financial development produces a rise in carbon dioxide emissions, which subsequently leads to a decrease in atmospheric carbon dioxide emissions.

Based on this empirical finding, the paper discusses it from two perspectives: enterprises and individuals. Firstly, at the beginning of the financial transformation, CEE countries adopted bank privatization and implemented interest rate liberalization reforms. CEE commercial banks absorbed deposits from savers (mainly from households) and financed profitable companies based on market-based interest rates, thereby maximizing financial support for the development of enterprises; the large influx of international banks made it easier to shift funds from less productive to more productive uses. The reduction in financing costs and diversity of financing sources incentivized enterprises to expand their size and increase production (e.g. extraction of energy, construction of factories, employment of workers, procurement of machinery and equipment). This extensive growth, which relies on increasing the number of inputs used to extend the scale of production and achieve economic growth, resulted in a significant consumption of natural resources and energy. Carbon dioxide was thus constantly increasing. With restricted natural resources and limited carrying capacity of an environment, however, the high-input, high-consumption, and high-emissions extensive growth would definitely be phased out. With the development of the financial system, financial institutions and capital markets have provided financial support for CEE countries to transform their economic growth from extensive growth to intensive one. An intensive growth has low consumption of energy and high utilization of production factors, which is conducive to mitigating carbon dioxide emissions. Secondly, from an individual perspective, financial development has an impact on income through financial services, which in turn affects carbon dioxide emissions. In an undeveloped financial system, banks in CEE were scrutinized for issuing consumer loans. With low personal income levels, the primary needs of individuals were physiological. The loans that consumers obtain from banks were mainly used to meet their physiological needs (e.g. food, clothing, transportation). In the later 1990s, the increasing demand for passenger cars by the populace stimulated the expansion of the passenger car industry. The manufacture and use of these goods released large amounts of carbon dioxide emissions. With the development of the financial system and the rise in income levels, physiological demands have given way to spiritual needs. In a developed financial market, consumers could obtain funds for spiritual consumption or invest in education through low-cost and efficient financial intermediaries. People have become more educated, environmentally aware, and voluntarily adjust their behaviour, reducing carbon dioxide emissions.

Overall, financial development has an inverted U-shaped impact on atmospheric carbon dioxide emissions under the influence of the mediating variable of economic growth.

6.5.2.2 Financial Development→Industrial Structure→CO2 emissions

In this part, the author investigates the relationship between financial development and carbon dioxide emissions via the role of industrial structure as a mediator. In Path B, the GMM-SYS outputs of Model (5.8) show no evidence of a statistically significant association between financial development and industrial structure; while the impact of financial development on the industrial structure is significant when the paper further applies recommended Bootstrapping. Coefficient β_F is 0.208 at the significance level of 1%. A unit increase in the financial development index causes an increase in the industrial structure of 20.8%. After testing Model (5.11) in Path C, the paper finds that the effect of industrial structure on carbon dioxide emission is significantly positive at a 1% significance level, with a value of 0.079 for γ_I. When other independent variables are controlled, a 1% increase in industrial structure corresponds to a 0.079% rise in CO_2 emissions. The p-values of γ_{F^2} and γ_F are both less than 0.01, which indicates that the paper can reject the null hypotheses of zero γ_{F^2} and γ_F at a significance level of 1%. The statistically significant β_F, γ_I, and γ_{F^2} suggest that the mediating effect is significant.

However, taking industrial structure as one of the mediating variables, the direction of the mediating effect is a suppressing effect due to the opposite signs of $\beta_F \cdot \gamma_I$ and γ_{F^2}. In other words, the relationship between financial development and carbon dioxide emissions, which was previously an inverted U-shape, would be converted to a positive U-shaped under the impact of industrial structure. This is not consistent with expectations, and Hypothesis 3 does not hold. According to the calculation results in (6.2), the suppressing effect of the industrial structure accounts for 44.42% of the total effect. In the mediational model of FD-Industry-CO_2, 44.42% of the total effect of financial development on carbon dioxide emissions can be explained by industrial structure.

$$\left|\frac{\beta_F \cdot \gamma_{In}}{\alpha_{F^2}}\right| = \left|\frac{0.208 \times 0.709}{-0.332}\right| = 0.4442 \tag{6.2}$$

The author explains this finding. In the 1990s and 2000s, the banking sector was relatively weak. It was changing and evolving and being acquired by foreign banks and financial houses. Thus, it took a great deal of time until the financial system stabilized. With insufficient capital assistance from financial institutions and the market, recovery of the secondary industry was challenging. Meanwhile, the land reforms implemented in the CEE region led to a recovery of agriculture in 1994. CEE countries are significant European producers and suppliers of agricultural products, and agriculture is an essential component of the economies of CEE countries. During the recovery of agriculture, agricultural production activities such as irrigation and tillage, the burning of waste such as straw, and the use of agricultural machinery all released large amounts of CO2. It is worth mentioning that deforestation is responsible for Romania's substantial amount of carbon dioxide emissions. After that, when the secondary industry improved, a large proportion of the labour force shifted from agriculture to industry, and the share of agriculture in GDP declined. Correspondingly, less carbon dioxide emissions were released from engaging in agricultural activities. However, when the financial system driven by banks was evolving gradually, the secondary sector, particularly the machine manufacturing industry, also was growing. This industrial structure, dominated by the secondary sector, has sharply increased carbon dioxide emissions. Even if the later emergence of tertiary and even quaternary industries caused the proportion of the secondary industry to decrease in GDP, it did not alter the fact that carbon dioxide emissions rose. This is because people are saving more money and are more prepared to spend it on vehicle trips and air travel, which generate a great deal of carbon dioxide.

Therefore, influenced by the industrial structure, financial development first reduces carbon dioxide emissions and raises them.

6.5.2.3 Financial Development→Technology Innovation→CO2 emissions

Regarding technology innovation, it acts as a partial mediator between financial development and carbon dioxide emissions as well. GMM-SYS results for Model (5.9) reveal that β_F is statistically significant at the 1% level of significance in Path B. β_F equals 0.362, meaning that a unit variation in the financial development index would reflect a 36.2% change in technology innovation from the same direction. In Path C, Model (5.12) findings permit the author to reject the null hypothesis that the value of γ_{Te} is zero with a 5% significance level. The interpretation of γ_{Te}=-0.016 is that a 1% growth in technology innovation diminishes carbon dioxide emissions by 1.6%, holding other explanatory variables constant. At the 10% conventional significance level, γ_{F^2} is significantly negative, exhibiting an inverted U-shaped relationship between financial development and CO_2.

For the extent to which the mediator of technology innovation plays a role in the model, the paper needs to compare the signs of $\beta_F \cdot \gamma_{Tech}$ and γ_{F^2}. Since the signs of $\beta_F \cdot \gamma_{Tech}$ and γ_{F^2} are the same, the paper concludes that technology innovation performs a partial mediating effect and the direction of the partial mediating effect is also an enhancing effect. According to the results of the following mathematical analysis (6.3), the effect of this partial mediation stands for 1.74% of the total effect. In the FD-Tech-CO_2 mediational model, 1.74% of the impact of financial development on carbon dioxide emissions can be explained by the mediating variable of technology innovation. Thereby, the author supports Hypothesis 4 that financial development is manifested in a rise and then a reduction in carbon dioxide emissions by fostering technology innovation.

$$\frac{\beta_F \cdot \gamma_{Te}}{\alpha_{F^2}} = \frac{0.362 \times (-0.016)}{-0.332} = 0.0174 \quad (6.3)$$

In the early stages of financial development, the banking-based financial systems in the CEE region were intended to invest in low-risk technologies. These early technical advancements were barely ecological mindful. The large-scale coal mining and the mechanization of agriculture and industry, benefiting from these technological advancements, resulted in massive carbon dioxide emissions. With the progress of the financial system, growth in financial aggregates or optimization of the financial structure would assist technology innovation in mitigating the intensity of carbon dioxide emissions. A well-developed financial system encourages technology innovation by lowering financing costs and distributing risks. R&D into low-carbon or carbon-free technology innovation has led to a decline in energy consumption per unit of GDP and, consequently, a decrease in carbon dioxide emissions intensity. Also, technology innovation develops a greater variety of new products to replace energy-intensive inputs, hence decreasing carbon dioxide emissions. The investment banks in the CEE region are more involved in the start-up and high-risk energy projects than in the past. For instance, the Three Seas Initiative Investment Fund (3SIIF), founded in 2019, plays a significant role in helping the energy transition in the CEE region. One of the investments made by 3SIIF enables the vision of decarbonizing the electricity markets to be accelerated.

In short, under the influence of the mediating variable of technology innovation, financial development has an inverted U-shaped power on carbon dioxide emissions.

Table 6.7 System GMM panel estimation regression & Bootstrap results in Path B

	GMM-SYS			Bootstrap	
	Model (5.7)	Model (5.8)	Model (5.9)	Model (5.7)	Model (5.8)
	DV: ln_Growth_{it}	DV: $ln\_Industry_{it}$	DV: ln_Tech_{it}	DV: ln_Growth_{it}	DV: $ln\_Industry_{it}$
ln_Growth_{it-1}	0.981^{***}			-0.610^{***}	
	(118.50)			(-2.82)	
$ln\_Industry_{it-1}$		0.962^{***}			0.490^{***}
		(48.85)			(5.69)
ln_Tech_{it-1}			0.911^{***}		
			(77.86)		
FD_{it}	-0.036	-0.020	0.362^{***}	0.909^{***}	0.208^{***}
	(-1.12)	(-1.05)	(3.55)	(4.80)	(2.60)
ln_Energy_{it}	0.016	0.010^{*}	0.043^{*}	0.117^{***}	0.111^{***}
	(1.77)	(1.84)	(1.85)	(2.78)	(5.95)
ln_Urban_{it}	0.005	-0.019	0.047	2.077^{***}	-0.479^{***}
	(0.23)	(-1.61)	(0.62)	(4.40)	(-3.46)
ln_Trade_{it}	0.017	0.018	0.127^{***}	0.692^{***}	-0.058^{**}
	(1.53)	(1.46)	(3.79)	(10.97)	(-2.11)
Constant	-0.003	0.037	-1.253^{***}	-3.909^{**}	4.573^{***}
	(-0.03)	(0.74)	(-3.30)	(-2.31)	(9.37)
AR (1)	-1.841	-2.464	-1.969		
AR (2)	-2.137	-1.415	-1.246		
P-value of AR(1)	0.066	0.014	0.049		
P-value of AR(2)	0.033	0.157	0.213		
Hansen	11.573	7.867	11.488		
P-value of Hansen	1.000	1.000	1.000		
Sargan	406.844	170.201	218.917		
P-value of Sargan	0.000	0.438	0.005		

Note: Using the Xtabond2 and Bootstrap command in Stata 17.0. The table reports the t statistics in parentheses. *, **, and *** represents $p < 0.1$, $p<0.05$, and $p<0.01$, suggesting that the coefficient is significant at the 10%, 5%, and 1% significance level, respectively.

Source: Constructed by the author.

Table 6.8 System GMM panel estimation regression in Path C

	Model (5.10) DV: ln_CO2	Model (5.11) DV: ln_CO2	Model (5.12) DV: ln_CO2
ln_CO2$_{it-1}$	0.921***	0.915***	0.925***
	(51.67)	(70.21)	(48.07)
FD$_{it}$	0.329*	0.367***	0.257
	(2.03)	(3.32)	(1.72)
FD$_{it}^2$	-0.507**	-0.634***	-0.419*
	(-2.21)	(-3.60)	(-1.96)
ln_Growth$_{it}$	-0.026**		
	(-2.22)		
ln_Industry$_{it}$		0.079***	
		(3.29)	
ln_Tech$_{it}$			-0.016**
			(-2.49)
ln_Energy$_{it}$	0.101**	0.071*	0.096**
	(2.48)	(2.05)	(2.44)
ln_Urban$_{it}$	-0.080**	-0.087*	-0.048*
	(-2.85)	(-2.00)	(-1.81)
ln_Trade$_{it}$	0.008	-0.008	0.001
	(0.40)	(-0.35)	(0.10)
Constant	-0.162	-0.302*	-0.461
	(-1.11)	(-1.88)	(-1.75)
AR (1)	-2.490	-2.489	-2.513
AR (2)	-1.126	-1.163	-1.175
P-value of AR(1)	0.013	0.013	0.012
P-value of AR(2)	0.260	0.245	0.240
Hansen	7.184	8.183	2.472
P-value of Hansen	1.000	1.000	1.000
Sargan	215.011	210.319	211.356
P-value of Sargan	0.008	0.015	0.013

Note: t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Constructed by the author.

6.5.3 The combined effect of three transmission channels

In this section, the paper adopts the interaction term of those three variables as a mediating variable. It investigates whether the interaction term is related to financial development and carbon dioxide emissions. In actuality, these three factors frequently interact and are interconnected. The related GMM-SYS regression findings are provided in Table 6.8. There is no second-order autocorrelation since the p-value for AR(2) is greater than 0.1. The outputs of the Hansen test show that instruments as a group are exogenous and plausible.

In the GMM-SYS regression model (5.13) of FD on GIT in Path B, β_F is significant at a 1% significance level. The value of β_F is 10.929, meaning there would be a 10.929-unit rise in the interaction term for each unit increase in the financial development index. The regression results in Model (5.14) show that γ_{GIT} is statistically significant at a 5% significance level with a value of -0.001. γ_{F^2} is significantly non-zero at a 10% significance level, and it has a value of -0.416. Because of the same sign for $\beta_F \cdot \gamma_{GIT}$ and γ_{F^2}, the mediating variable (i.e. the interaction term) matters as a partial mediation, and the direction of this mediating effect is an enhancing effect that lowers carbon dioxide emissions. In the paradigm of FD and CO_2 emissions, the combined effect of economic growth, industrial structure, and technology innovation can therefore have a mediating effect. Based on the formula (6.4), the partial mediating effect accounts for 3.29% of the total effect. That is, the interaction term could interpret 3.29% of the overall effect of financial development on carbon dioxide emissions.

$$\frac{\beta_F \cdot \gamma_{GIT}}{\alpha_{F^2}} = \frac{10.929 \times (-0.001)}{-0.332} = 0.0329 \qquad (6.4)$$

Since γ_{F^2} is negative, the author concludes that the initial increase and subsequent decline in carbon dioxide emissions is the result of financial development through the combined effect of economic growth, industrial structure, and technology innovation. This conclusion exactly confirms Hypothesis 5.

By breaking it into three stages following the state of financial development, the article clarifies the precise causes behind this discovery. The first phase was the early stages of the CEE financial transition in the 1990s. In general, CEE counties suffered periods of high inflation, during which banks refused to lend to enterprises and industries could not flourish, let alone technology innovation. In order to control or lower inflation rates, these countries enacted fiscal austerity and tight monetary policies, which eventually resulted in economic stagnation or even recession. The amounts of carbon dioxide emissions thereby were low. The second phase was the latter transitional period when CEE countries established a bank-based financial system. Companies were encouraged to expand their size and increase production. The associated technology innovation employed to boost manufacturing likewise advanced significantly. The proportion of the secondary sector to the GDP continued to rise. This extensive growth economy required a significant usage of natural resources and energy, contributing to a dramatic increase in carbon dioxide emissions. The third phase was the post-crisis era. The global financial crisis of 2008 and subsequent European sovereign debt crisis triggered CEE governments to reflect on the fragility and risks of the bank-based financial system. Thus, CEE nations have undertaken steps to enhance the effectiveness of banking services, improve the legal system of the financial system, and develop capital markets (Zhenjia & Hongzhong, 2019). In response to the challenges of scarce natural resources, environmental deterioration, and the demand for inter-governmental carbon dioxide emissions reductions, the financial system is supporting green industries and promoting the optimization and upgrading of traditional industrial structures. Also, the financial system is playing a critical role in financing the R&D of clean energy technology and riskier innovation ventures. CEE is transitioning from a high-carbon to a low-carbon economy, associated with decreased carbon dioxide emissions.

Table 6.9 System GMM panel estimation regression of model (5.13) and model (5.14)

	Model (5.13) DV: GIT_{it}	Model (5.14) DV: ln_CO_{2it}
GIT_{it-1}	0.907^{***}	
	(66.70)	
ln_CO_{2it-1}		0.927^{***}
		(49.32)
FD_{it}	10.929^{***}	0.260
	(3.64)	(1.77)
FD_{it}^2		-0.416^{*}
		(-1.97)
GIT_{it}		-0.001^{**}
		(-2.72)
ln_Energy_{it}	1.290^{*}	0.096^{**}
	(1.93)	(2.46)
ln_Urban_{it}	1.042	-0.052^{*}
	(0.42)	(-2.05)
ln_Trade_{it}	3.925^{***}	0.006
	(4.01)	(0.44)
Constant	-36.571^{***}	-0.467^{*}
	(-3.45)	(-1.83)
P-value of AR(1)	0.038	0.012
P-value of AR(2)	0.152	0.238
Hansen	4.724	8.101
P-value of Hansen	1.000	1.000
Sargan	215.461	211.200
P-value of Sargan	0.008	0.013

Note: t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Constructed by the author.

In brief, the model estimation findings suggest that financial development has total, direct, and indirect impacts on carbon dioxide emissions. In CEE countries, the total effect of financial development on atmospheric carbon dioxide emissions is inverted U-shaped. As shown in Table 6.9, the total effect of financial development on carbon dioxide emissions is decomposed into five components: economic growth, industrial structure, technology innovation, combined effect, and additional unidentified mediators. Specifically, economic growth and technology innovation are enhancing effects compatible with the direction of financial development's direct effect on carbon dioxide emissions, causing carbon dioxide to rise and then decrease. In the mediational models of FD-Growth-CO_2 and FD-Tech-CO_2, the indirect effects account for 7.12% and 1.74% of the total effect, respectively. In contrast, the industrial structure is a suppressing effect, as opposed to the direct effect of financial development on carbon dioxide emissions, which causes carbon dioxide emissions to decline first and subsequently rise. In the mediational model of FD-Industry-CO_2, the indirect effect accounts for 44.42% of the total effect. When there is a combined mediating effect of economic growth, industrial structure, and technology innovation in the mediational model of financial development and carbon dioxide emissions, it would also be an enhancing effect. Carbon dioxide emissions climb and subsequently decrease in response to financial development. 3.29% of the total effect was described by the combined effect. Other unidentified factors contribute an additional 43.43% influence. Comparing the indirect effects of financial development on carbon dioxide emissions under four different mediational models, the author concludes that financial development primarily influences carbon dioxide emissions through the mediating effect of industrial structure.

Table 6.10 Decomposition of the total effect of financial development on carbon dioxide emissions

Mediators	Economic growth	Industrial structure	Technology innovation	Combined	Unknown factors
Direction of mediating effect	Enhancing	Suppressing	Enhancing	Enhancing	Unknown
Contribution rate	7.12%	44.42%	1.74%	3.29%	43.43%

Note: the contribution rate refers to the proportion of indirect effects to total effects.

Source: Constructed by the author.

7 Conclusions and suggestions

This research aims to highlight financial development's total, direct, and indirect effects on carbon dioxide emissions in thirteen CEE countries from 2000 to 2019. The paper begins with a theoretical and empirical discussion of the total effect of financial development on CO2 emissions using a dynamic system GMM model. The article then constructs three mediational models to investigate financial development's direct and indirect effects on carbon dioxide emissions, with economic growth, industrial structure, and technology innovation as mediating variables. This is done to empirically verify the rationality of the three transmission channels through which financial development affects CO_2 emissions. The paper further comprises the interaction term of economic growth, industrial structure, and technology innovation into another mediational model, which is used to examine the mediating effect of the combined effect on the FD-CO_2 model. For further clarity, the detailed findings are summarized below.

1) The total effect of financial development on carbon dioxide emissions is inverted U-shaped. This entails that carbon dioxide emissions rise during the early stages of financial development and fall in the stable stages. Early, CEE countries established a bank-based financial system. The conservative nature of investment by banks led them to invest mainly in large-firm, low-risk but high-emitting secondary sectors. Consequently, carbon dioxide emissions grew dramatically. As financial size develops and financial efficiency improves, financial instruments such as green credit and green funds are designed to promote green projects better aligned with sustainable development goals. The economic resources migrate from high-carbon to low-carbon spheres, resulting in a drop in carbon dioxide intensity.

2) There are four transmission channels through which financial development affects carbon dioxide emissions. The first one is the FD→Growth→CO_2 channel. The mediating effect of economic growth is an enhancing mediating effect. Financial development creates more economic growth.

Then, economic growth causes carbon dioxide emissions to rise and subsequently fall. The second channel is FD→Industry→CO_2. The mediating effect of industrial structure is a suppressing mediating effect. Financial development fosters industrial constrcution. Low industrialization reduces carbon dioxide emissions. As the value added by industry increases, CO_2 emissions rise accordingly. The third transmission channel is FD→Tech→CO_2. The technology innovation's mediating effect is an enhancing mediating effect. Technology innovation is financially supported by financial development. The advancement of technology innovation produces an increase in carbon dioxide emissions, followed by a decline. The last path is FD-Combined-CO_2. The above three mediating variables together exert an enhancing mediating effect. The higher combined effect of economic growth, industrial structure, and technology innovation gives rise to growth and then lower carbon dioxide emissions.

3) The four mediating effects are not of equal importance in the process of financial development affecting carbon dioxide emissions. Specifically, in the channel of FD→Growth→CO_2, the mediating effect of economic growth has a contribution rate of 7.12% in the same direction as the total effect. Similarly, the mediating effect of technology innovation and the combined mediating effect are consistent with the total effect, with contribution rates of 1.74 and 3.29. On the contrary, the mediating effect of industrial structure is opposite to the total effect, with the most considerable contribution rate of 44.42%. This entails that financial development impacts on carbon dioxide emissions mainly by the mediating effect of industrial structure.

4) Among the three mediating variables (i.e. economic growth, technology innovation, and combined effect) that play an enhancing mediating effect, economic growth is the most important mediator in explaining the influence of financial development on carbon dioxide emissions.

The banks and capital markets are indispensable parts of attaining the carbon dioxide emissions reduction objective. In light of the above findings, several suggestions are provided as follows.

1) Central banking has a regulatory role in the transparency and disclosure of the financial industry. The central banks shall mandate that financial institutions declare monthly or quarterly the amount of carbon emission reduction loans they have issued, the related interest rates, and the number of projects funded. Also, it is imperative for central banks to re-evaluate the existing toolkits and develop new financial instruments to prevent threats to financial stability from climate change.

2) Development banks take an active role in leading sustainable and greening finance. Development should support to establish a sound public guarantee system to encourage commercial banks to offer financing to high-risk projects.

3) The commercial banking sectors are by far the most vital capital supplier in CEE countries, particularly for small and medium-sized enterprises, whose access to financial markets remains constrained. There are four strategies they can implement: first, limit the investments or loans in fossil energy-related businesses, which will exert pressure on traditional high-emitting sectors and force them to convert to low-carbon industries; second, finance green manufacturing and low-carbon environmentally friendly sectors and allocate the economic sources to low-carbon initiatives; third, support the sustainable technology innovation about improving energy efficiency (notably in the machinery, construction, and automotive industries) or creating breakthrough clean energy technologies; four, develop innovative eco-friendly consumer credit and service to boost green consumption. For instance, banks could offer low-interest or zero-interest loans to consumers who purchase electric vehicles, green intelligent home appliances, etc.

4) The insurance sector needs to make an effort for carbon neutrality. Firstly, insurers could selectively underwrite or differentiate insurance rates based on a company's environmental risk management. Secondly, insurance firms should launch more environmentally friendly products, focusing on sustainable energy, architecture, transportation, and technology. For instance, they can launch overlay guarantee insurance, carbon emission allowance pledge, green building, and electric car insurance.

5) The financial market should ensure that its acceleration is aligned with the targets. It is necessary to support the development of green capital markets, which would widen the financing sources of green projects. Financial instruments such as green stocks and funds facilitate developing environmentally friendly alternative-energy technology innovation.

Finally, the author would like to affirm that this paper is the first to explore the transmission channels in FD-CO2 in the CEE regions and the first to apply the mediational model to the context of CEE carbon finance. It is hoped that this paper will provide experience and implications for the future pathway towards CEE carbon neutrality.

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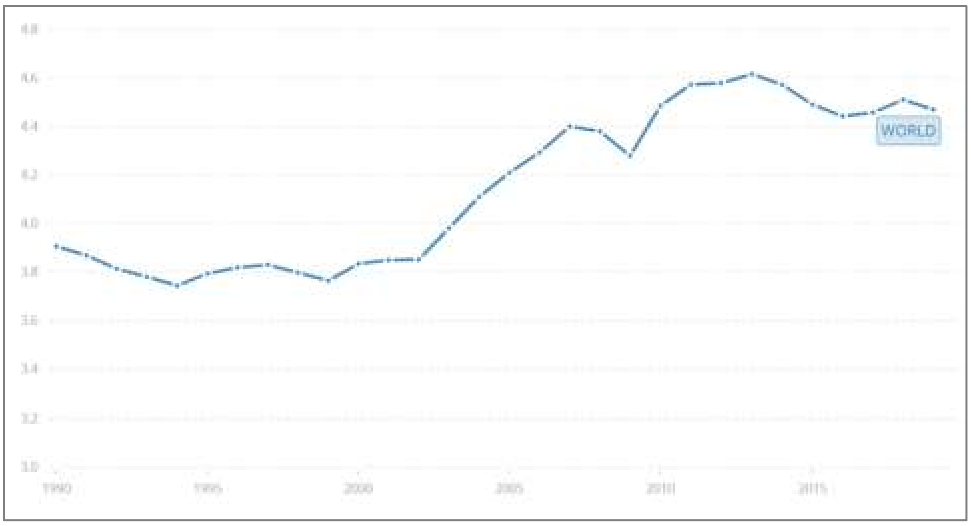
List of appendices

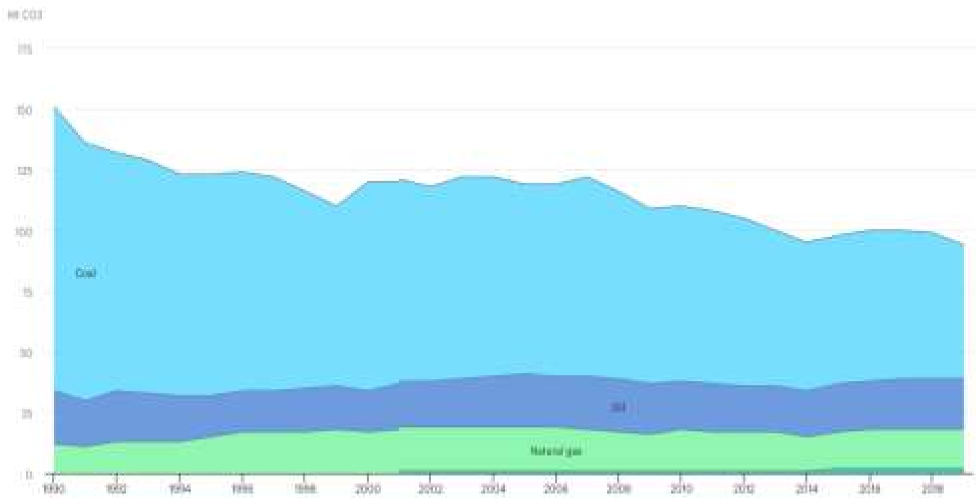
Appendices

Appendix 1: Worldwide trend of CO_2 emissions (metric tons per capita) (chart)



Source: World Bank database.

Appendix 2: CO_2 emissions by energy source, Czech Republic 1990-2019 (chart)

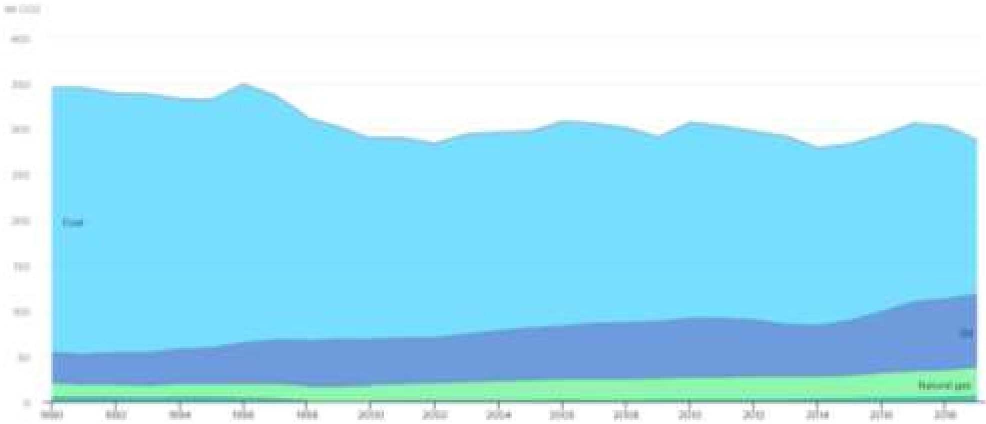


Source: International Energy Agency (IEA), “Explore energy data by category, indicator, country or region,” access date: 17.07.2022.

URL:

https://www.iea.org/data-and-statistics/data-browser?country=CZECH&fuel=CO2%20emissions&indicator=CO2BySource

Appendix 3: CO2 emissions by energy source, Poland 1990-2019 (chart)

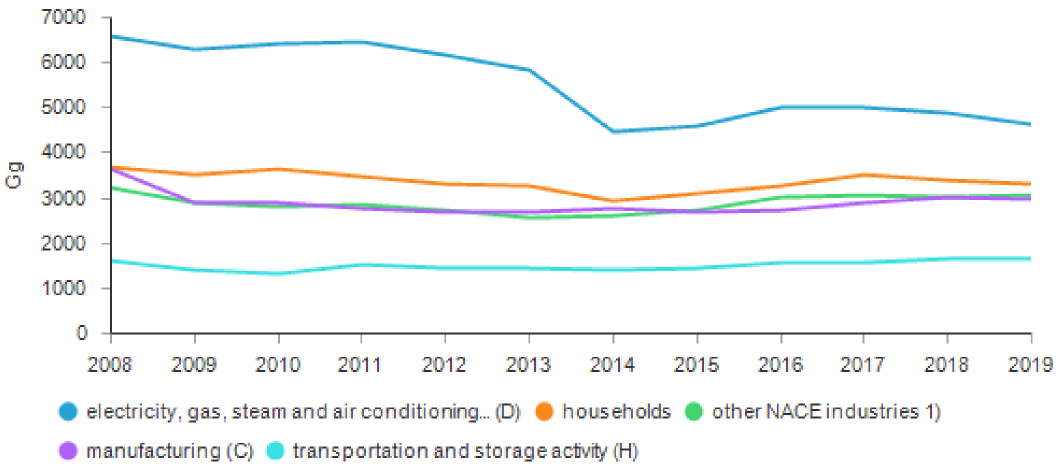


Source: International Energy Agency (IEA), “Explore energy data by category, indicator, country or region,” access date: 17.07.2022.

URL:

https://www.iea.org/data-and-statistics/data-browser?country=POLAND&fuel=CO2%20emissions&indicator=CO2BySource

Appendix 4: CO2 emissions, Slovenia 2008-2019 (chart)



Source: Marko Pavlič, “In 2019 CO2 emissions decreased by 2.1% when compared to 2018,” Republic of Slovenia Statistical Office, publication date: 14.09.2021, access date: 14/07/2022.

URL: https://www.stat.si/StatWeb/en/News/Index/9823

Appendix 5: Descriptive statistics for the individuals and panel, 2000-2019 (table)

Country	Descriptive statistics	ln CO2	FD	ln Growth	ln Industry	ln Tech	ln Energy	ln Urban	ln Trade
Belarus	N	20	20	20	20	20	20	20	20
	Mean	1.845	0.141	8.459	3.538	-0.448	7.965	4.31	4.862
	SD	0.0669	0.0389	0.306	0.0711	0.148	0.0789	0.0381	0.1
	Min	1.712	0.0654	7.87	3.433	-0.693	7.809	4.248	4.688
	Max	1.935	0.198	8.743	3.659	-0.0387	8.08	4.37	5.062
	CV	0.0363	0.277	0.0362	0.0201	-0.331	0.0099	0.0088	0.0206
Bosnia and Herzegovina	N	20	20	20	20	20	20	20	20
	Mean	1.641	0.212	8.298	3.093	-2.703	7.52	3.815	4.456
	SD	0.23	0.0467	0.2	0.0609	1.184	0.428	0.0423	0.0747
	Min	1.262	0.114	7.954	2.986	-4.184	7.02	3.747	4.301
	Max	2.018	0.262	8.627	3.2	-1.135	8.383	3.884	4.603
	CV	0.14	0.22	0.0241	0.0197	-0.438	0.057	0.0111	0.0168
Bulgaria	N	20	20	20	20	20	20	20	20
	Mean	1.862	0.349	8.694	3.183	-0.565	7.859	4.278	4.68
	SD	0.0704	0.0462	0.233	0.0507	0.252	0.0914	0.028	0.199
	Min	1.738	0.233	8.221	3.077	-0.843	7.731	4.233	4.321
	Max	1.996	0.429	9.016	3.28	-0.0492	8.077	4.322	4.87
	CV	0.0378	0.132	0.0268	0.0159	-0.445	0.0116	0.0066	0.0424
Croatia	N	20	20	20	20	20	20	20	20

	Mean	1.56	0.443	9.358	3.091	-0.141	7.598	4.01	4.428
	SD	0.101	0.0665	0.115	0.0673	0.118	0.137	0.0205	0.0994
	Min	1.424	0.3	9.083	2.99	-0.301	7.292	3.978	4.254
	Max	1.74	0.518	9.552	3.189	0.0781	7.757	4.047	4.623
	CV	0.0646	0.15	0.0123	0.0218	-0.833	0.018	0.0051	0.0224
Czech Republic	N	20	20	20	20	20	20	20	20
	Mean	2.408	0.423	9.686	3.503	0.373	8.315	4.298	4.843
	SD	0.101	0.0501	0.143	0.0227	0.233	0.0656	0.0034	0.175
	Min	2.244	0.308	9.418	3.45	0.0971	8.2	4.293	4.514
	Max	2.527	0.469	9.914	3.536	0.727	8.41	4.304	5.06
	CV	0.0417	0.118	0.0148	0.0065	0.625	0.0079	0.0008	0.0361
Estonia	N	20	20	20	20	20	20	20	20
	Mean	2.546	0.283	9.635	3.221	0.175	8.235	4.228	4.949
	SD	0.124	0.0264	0.2	0.0448	0.368	0.15	0.0062	0.111
	Min	2.234	0.229	9.206	3.135	-0.512	7.822	4.219	4.76
	Max	2.706	0.333	9.924	3.294	0.826	8.439	4.239	5.14
	CV	0.0489	0.0933	0.0208	0.0139	2.103	0.0182	0.0015	0.0223
Hungary	N	20	20	20	20	20	20	20	20
	Mean	1.671	0.467	9.36	3.256	0.114	7.846	4.223	5.005
	SD	0.103	0.0567	0.132	0.0341	0.211	0.0618	0.0348	0.126
	Min	1.489	0.396	9.102	3.21	-0.234	7.728	4.168	4.759
	Max	1.807	0.57	9.618	3.303	0.551	7.974	4.272	5.126
	CV	0.0618	0.121	0.0141	0.0105	1.855	0.0079	0.0082	0.0251

Latvia	N	20	20	20	20	20	20	20	20
	Mean	1.28	0.258	9.343	3.023	-0.618	7.631	4.219	4.652
	SD	0.0827	0.0368	0.251	0.0705	0.223	0.0937	0.0017	0.168
	Min	1.089	0.176	8.814	2.919	-1.02	7.389	4.217	4.401
	Max	1.405	0.314	9.684	3.162	-0.265	7.732	4.223	4.854
	CV	0.0647	0.142	0.0269	0.0233	-0.361	0.0123	0.0004	0.036
Lithuania	N	20	20	20	20	20	20	20	20
	Mean	1.466	0.23	9.334	3.308	-0.201	7.836	4.205	4.82
	SD	0.113	0.0359	0.287	0.0576	0.16	0.0893	0.0052	0.187
	Min	1.221	0.162	8.768	3.223	-0.536	7.62	4.199	4.423
	Max	1.619	0.303	9.755	3.402	0.0431	7.998	4.217	5.049
	CV	0.0768	0.156	0.0308	0.0174	-0.796	0.0114	0.0012	0.0389
North Macedonia	N	20	20	20	20	20	20	20	20
	Mean	1.48	0.202	8.331	3.076	-1.242	7.18	4.053	4.598
	SD	0.194	0.045	0.171	0.0757	0.342	0.0982	0.0079	0.207
	Min	1.211	0.13	8.061	2.943	-1.766	6.976	4.045	4.264
	Max	1.774	0.256	8.592	3.189	-0.661	7.324	4.07	4.931
	CV	0.131	0.223	0.0205	0.0246	-0.275	0.0137	0.002	0.0451
Poland	N	20	20	20	20	20	20	20	20
	Mean	2.137	0.417	9.247	3.355	-0.291	7.818	4.11	4.404
	SD	0.0317	0.0593	0.226	0.0295	0.293	0.0408	0.0102	0.188
	Min	2.075	0.275	8.903	3.282	-0.618	7.747	4.095	4.063
	Max	2.186	0.477	9.617	3.405	0.325	7.884	4.124	4.677

	CV	0.0148	0.142	0.0244	0.0088	-1.008	0.0052	0.0025	0.0427
Serbia	N	20	20	20	20	20	20	20	20
	Mean	1.677	0.225	8.496	3.325	-0.444	7.509	4.002	4.329
	SD	0.115	0.0342	0.204	0.0981	0.357	0.314	0.0202	0.352
	Min	1.43	0.127	8.069	3.215	-1.24	6.622	3.966	3.113
	Max	1.895	0.283	8.79	3.564	-0.0347	7.793	4.03	4.718
	CV	0.0683	0.152	0.024	0.0295	-0.804	0.0418	0.005	0.0812
Slovenia	N	20	20	20	20	20	20	20	20
	Mean	2.044	0.449	9.91	3.361	0.582	8.125	3.962	4.868
	SD	0.0981	0.0649	0.107	0.0477	0.232	0.0743	0.025	0.153
	Min	1.879	0.351	9.695	3.277	0.222	7.983	3.927	4.628
	Max	2.2	0.55	10.09	3.423	0.942	8.252	4.004	5.083
	CV	0.048	0.144	0.0108	0.0142	0.399	0.0091	0.0063	0.0315
Panel	N	260	260	260	260	260	260	260	260
	Mean	1.817	0.315	9.088	3.256	-0.416	7.803	4.132	4.684
	SD	0.381	0.119	0.574	0.167	0.898	0.348	0.148	0.279
	Min	1.089	0.0654	7.87	2.919	-4.184	6.622	3.747	3.113
	Max	2.706	0.57	10.09	3.659	0.942	8.439	4.37	5.14
	CV	0.21	0.377	0.0631	0.0512	-2.159	0.0446	0.0359	0.0595

Note: SD is standard deviation, and CV is coefficient of variation.

Source: Constructed by the author using Stata 17.0.

DISSERTATION PROJECT

Name: **YUANHAO LIU**
Programme: **International Masters in Economy State and Society: Economics and Business**
E-mail: **82482457@fsv.cuni.cz**
Academic year: **2**
Dissertation title: **The Impact of Financial Development on Carbon Dioxide Emissions: Evidence from CEEs**
Expected date of submitting: **02/08/2022**
Head of the Seminar: **Jiří Vykoukal**
Supervisor: **Pavel Szob**
Title: **PhDr., Ph.D..**
Short description of the topic: **A sample of 13 CEE countries from 2000 to 2019 is used to investigate the total, direct, and indirect effects of financial development on carbon dioxide emissions. This study introduces four mediating effects of financial development on carbon dioxide emissions, i.e. economic growth, industrial structure, technology innovation, and the combined effect. To assess mediating effects and decompose total effect, GMM-SYS methods and bootstrap are employed. These findings give additional empirical evidence for the mediational model and Environment Kuznets Curve hypothesis from the perspective of financial development, and also provide new ideas for CEE policy makers to reach carbon neutrality objective by 2050.**
Proposed structure: **1. Introduction** **2. Literature Review** **3. Theoretical Foundation and Hypothesis** **4. Data Description and Measurement of Financial Development Index** **5. Empirical Model Specification** **5.1 GMM-SYS model** **5.2 Mediational model** **5.3 Methodological contribution** **6. Empirical Results and Discussions** **6.1 Descriptive analysis** **6.2 Correlation and multicollinearity analysis** **6.3 Panel unit root test**

6.4 Panel cointegration test **6.5 System generalizedd method of moments (GMM-SYS)** **6.5.1 The total effect of financial development on carbon dioxide** **6.5.2 The direct and indirect impact of financial development on carbon dioxide** **6.5.3 The combined effect of three transmission channels** **7. Conclusion and Suggestions**
Sources (basic selection): **Bui, D. T. (2020). Transmission channels between financial development and CO2 emissions: A global perspective. Heliyon, 6(11), e05509.** **Chen, F. W., Tan, Y., Chen, F., & Wu, Y. Q. (2021). Enhancing or suppressing: The effect of labor costs on energy intensity in emerging economies. Energy, 214, 118964.** **Jianguo, D., Ali, K., Alnori, F., & Ullah, S. (2022). The nexus of financial development, technological innovation, institutional quality, and environmental quality: evidence from OECD economies. Environmental Science and Pollution Research, 1-22.** **Shoaib, H. M., Rafique, M. Z., Nadeem, A. M., & Huang, S. (2020). Impact of financial development on CO2 emissions: a comparative analysis of developing countries (D8) and developed countries (G8). Environmental Science and Pollution Research, 27(11), 12461-12475.** **Saidi, K., & Mbarek, M. B. (2017). The impact of income, trade, urbanization, and financial development on CO2 emissions in 19 emerging economies. Environmental Science and Pollution Research, 24(14), 12748-12757.**