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Why are some countries cleaner than others? New evidence from macroeconomic governance

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Abstract

This study aims to investigate why some countries are cleaner than the others with reference to macroeconomic governance (MEG) in order to explain how major macroeconomic aggregates should be governed to mitigate environmental pollution at the level of economic systems. Using per capita carbon dioxide emissions (CPC) as the proxy for air pollution, and macro-non-financial governance (MNFG) and macro-financial governance (MFG) as the proxies for MEG, the study introduces the systemic and fragmented governance of green complementarities (GCMs) and dirty complementarities (DCMs) as analytic concepts to compare the MEG models for managing pollution in 13 high-income countries (HICs), 10 upper-middle-income countries (UMICs), and nine lower-middle-income countries (LMICs) for the period 1994–2014. The paper concludes that (i) HICs reduced their CPC levels thanks to adopting green systemic governance by creating GCMs between both MNFG and MFG variables in the long run; (ii) UMICs experienced a remarkable increase in their CPC levels due to adopting dirty systemic governance by creating DCMs between the MNFG variables, but prevented pollution from being higher through creating GCMs between the MFG variables; and (iii) LMICs experienced the highest comparative increase in CPC due to adopting a fragmented governance in managing both MNFG–pollution and MFG–pollution nexus.

Keywords Pollution · Macroeconomic governance · Complementarities · Growth

1 Introduction

Environmental pollution is the world's leading environmental cause of morbidity and mortality. Of the major types of environmental pollution, air pollution[1] is the most significant environmental health risk, causing the death of more than seven million people annually (WHO, 2021; Burney & Ramanathan, 2014; Dockery et al., 1993; Graff Zivin & Neidell,

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[1] Air pollution denotes the presence of one or more contaminants in the atmosphere ranging from gas, dust, and fumes to mist, smoke, or vapor.

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2013; Kampa & Castanas, 2008; Saxena & Srivastava, 2020).[2] 91% of the world's population and 98% of residents of cities with populations greater than 100,000 in low- and middle-income countries live in places where 'nine out of ten people worldwide breathe air containing levels of pollutants that exceed World Health Organization limits' (UNEP, 2021a, b). Furthermore, a direct relationship has recently been established between the rapid increase in COVID-19 contagion and atmospheric pollution acting as a carrier and booster of the pandemic (Pozzer et al., 2020). In addition to its deadly health effects, air pollution also reduces labor productivity, increases health expenditures, and reduces crop yields. Its indirect effects originate in the reallocation of production factors across the economy, changes in international trade, and savings, which are induced by relative price changes (Adhvaryu et al., 2014; Ebenstein et al., 2016; Graff Zivin & Neidell, 2012; Hansen & Selte, 2000).

It is projected that exposure to PM$_{2.5}$ concentration would increase by 50% by 2030 if no new policies are implemented (UN, 2021c). The total annual costs of air pollution are projected to increase from 0.3% in 2015 to 1.0% by 2060 (Lanzi, 2016), with a 1 μg/m$_3$ increase in PM$_{2.5}$ concentration estimated to reduce real GDP by 0.8% (Dechezleprêtre et al., 2019). It is well established that air pollution is caused by human emissions of substances into the atmosphere as a negative externality of environmentally hazardous models of production (e.g., industrialization, exploration, and mining), consumption, trade, finance, urbanization, and population growth (Cole, 2004; Omri, 2013; Ukaogo et al., 2020; Xu & Lin, 2016). Thus, the mitigation of air pollution is an integral component of the United Nations Sustainable Development Goals in many areas ranging from atmosphere, health and population, employment and decent work to food security and sustainable agriculture, sustainable cities, and human settlements (UN, 2021b; Rafaj et al., 2018). As a corollary, the Ministerial Declaration of the United Nations Environment Assembly emphasizes 'the need for rapid, large-scale, and coordinated action against pollution' (UNEP, 2018: 3).

Against this backdrop, it is suggested that a full-fledged restructuration is indispensable for the air pollution–economy nexus by integrating environmental and economic policies through a long-term governance of ecology, economy, and public health. (Liu et al., 2018). This paper hypothesizes that the basic way of achieving such a transformation is to create a complementary dynamic between major macroeconomic variables in reducing air pollution. In order to substantiate this argument, the paper first divides macroeconomic governance into macro-non-financial governance, MNFG, and macro-financial governance, MFG, based on the functional clustering of major macroeconomic variables. (For a complete list of the abbreviations used in the paper, see Note 3.[3])

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[2] Air pollution causes a number of potentially deadly diseases and illness such as lung disease, asthma, cardiovascular and heart disease, cancer and pneumonia, premature deaths, and many hazardous environmental problems such as acid rain, smog, and haze.

[3]

Country groups		Macroeconomic governance		Complementarities	
HICs	Upper-middle-income countries	MEG	Macroeconomic governance	GCMs	Green complementarities
UMICs	High-income countries	MNFG	Macro-non-financial governance	DCMs	Dirty complementarities
LMICs	Lower-middle-income countries	MFG	Macro-financial governance		

Second, the paper introduces two modes of economic governance in managing macroeconomy–pollution nexus, systemic and fragmented governance. Third, the paper introduces green and dirty complementarities to explain the effects of macroeconomic variables on pollution under systemic and fragmented modes of macroeconomic governance. Fourth, the paper focuses on long-run (cointegrated) relationships between macroeconomic governance and takes carbon dioxide emissions, CO_2, as the proxy for air pollution given that CO_2 is a stock pollutant whose effect lasts more than one century. Fifth, the paper sets up two models that measure the impact of major financial and non-financial macroeconomic aggregates on pollution by (i) using Pedroni and Kao panel cointegration tests and panel autoregressive distributed lag (ARDL) technique executed by pooled mean group estimator (Pesaran & Smith, 1995; Pesaran et al., 1999), and (ii) by taking 13 high-income, 10 upper-middle-income, and 9 lower-middle-income countries for the period 1994–2014 based on the availability of statistically consistent set of data for all twelve variables included in the analysis.

The paper continues as follows. Section 2 explains the pollution–macroeconomy nexus from a complementarity-theoretic perspective. Section 3 presents the data and methodology. Section 4 presents the empirical findings. Section 5 makes a structured discussion on the paper's contributions, the policy implications of its findings at national and international level, and the relevance of its methodology and findings for future work on macroeconomy–pollution nexus. Section 6 provides the conclusion.

2 Explaining the macroeconomic governance–pollution nexus

Three main gaps can be found in the extant literature regarding the pollution–macroeconomy nexus that this paper aims to address. The first is the exclusively aggregative approach of the EKC hypothesis. The second relates to the ambiguity of the findings. The third is the fragmented selection of analytical variables.

First, as economic growth is in effect a matter of rise or fall in income, most studies investigate either pollution–growth or pollution–income nexus using the U-shaped or N-shaped environmental Kuznets curve (EKC) hypothesis (Kuznets, 1955; Bhattarai et al., 2009; Álvarez-Herránz et al., 2017). In their seminal study, Grossman and Krueger (1991) provided an empirical test of EKC hypotheses. Thereafter, several studies, such as Dinda and Coondoo (2006), Managi and Jena (2008), Stern (2004), and Shafik (1994), carried out their investigation on linear and nonlinear relationships between economic activity and emissions. However, the EKC hypothesis exclusively tests the aggregate growth–pollution nexus, but does not explain how each component of growth affects pollution in time or if their effects diverge from each other, which may restrain the specification of variable-specific policy options.

Second, an extensive review of the extant literature on the effects of macroeconomic variables on pollution demonstrates that the findings are too ambiguous (see Appendix 1, table 12). For example, the EKC hypothesis holds for both HICs and UMICs (Dong et al., 2020a, 2020b) or only for HICs (Lau et al., 2018; see Appendix 1, Table 13for more detailed and diverse results for the EKC hypothesis). Trade openness variably increases pollution (Shahbaz et al., 2013), reduces pollution in LMICs and UMICs but not in HICs (Halicioglu, 2009; Lau et al., 2018), has no significant impact on pollution (Javid & Sharif, 2016), has a positive effect only in the long run (Al-Mulali et al., 2018; Lv & Xu, 2019), or has a negative impact in the short run (Lv & Xu, 2019). Foreign direct investment has no effect on pollution (Wang et al., 2020; Nasir et al., 2019), a negative effect on pollution in HICs but a positive effect in developing countries (Khalil & Inam, 2006; Lau et al., 2018), a U-shaped effect in HICs (Christoforidis & Katrakilidis, 2021), a negative effect in both developed and developing countries (Essandoh et al., 2020), a negative effect only in developing countries (Pradhan, 2021), or a negative effect only in LMICs (Nguyen et al., 2020). Financial development reduces CO_2 emissions in HICs (Khaskheli et al., 2021) but increases emissions in LMICs and UMICs (Ehigiamusoe & Lean, 2019; Nasir et al., 2021; Thampanya et al., 2021), reduces CO_2 emissions in HICs, UMICs, and LMICs (Godil et al., 2020; Neog & Yadava, 2020), has no effect on pollution for HICs but has a negative effect on pollution in UMICs and LMICs (Di Vita, 2008), or has no effect on pollution for all cases (Katircioğlu, 2012; Öztürk & Acaravcı, 2013).

Third, the variables included in the analysis for macroeconomy–pollution nexus are in most cases selected fragmentedly, which might cause the findings to be inconsistent or ambiguous, reducing the efficiency of policy proposals (see 'Variables' in Tables 12 and 13 in Appendix 1). In fact, there may be a general perception of the MEG–pollution nexus. Economic development, growth, energy consumption, and trade openness may increase pollution faster in LMICs and UMICs than in HICs in both the short and long run (Dong et al., 2020a; Ehigiamusoe, 2019; Wu et al., 2018). Because the developing world uses energy-intensive production technologies based on fossil fuels—predominantly nonrenewable energy sources (Dong et al., 2019, 2020b; Hu et al., 2018; Ehigiamuoe & Lean, 2019)—developed countries generally have illiberal trade models based on the export of dirty commodities (Fakher, 2018; Lv & Xu, 2019). Furthermore, developing countries typically do not have green or strict regulations on FDI; neither do they have nation-wide standardized regulations on environmental quality (Danlami et al., 2019; Song, Li, et al., 2021; Song, Zhang, et al., 2021; Song, Zhang, et al., 2021; L. Zhang et al., 2021) nor effective, democratic, and nation-wide standardized mechanisms of environmental governance (Zhang et al., 2021). Likewise, public awareness of environmental degradation tends to be low (Mujtaba et al., 2020; Zhang et al., 2021). CPC levels in our case countries of three income groups support, *prima facie*, this general perception. As Fig. 1 illustrates, in the period 1994–2014, CPC declined by 0.8 percent in HICs and increased on average by 2.1 percent and 2.9 percent in UMICs and LMICs, respectively. However, as noted above, the findings on the macroeconomy–pollution nexus for each country group are so ambiguous that they are hardly able to produce a clear-cut group-specific relationship pattern for HICs, UMICs, and LMICs; this is because the perception of the nexus is based on an estimation using not a systematic but rather a fragmented set of macroeconomic variables.

Given these three points, we first focus on the *root cause* of the generation of income and growth, macroeconomic governance, rather than to the income or growth itself. This is significant because pollution–income or pollution–growth nexus is dependent on the pollution–macroeconomy nexus. It is the mode of macroeconomic governance, as detailed below, that determines the rate of growth or the level of income in a country. Accordingly, we do not make an EKC-based analysis, because we suggest that greening economic systems in a full-fledged manner requires the greening of overall macroeconomic structure with its financial and non-financial dynamics (Heijdra & Heijnen, 2013). Such an approach entails disaggregating the macroeconomy–pollution nexus by bringing all these individual variables into the analysis simultaneously rather than investigating the aggregate growth–pollution nexus itself. On this basis, second, we cluster the major macroeconomic variables into two groups and then set up our econometric models to test the effects of the macroeconomic variables in each group on pollution in terms of both their individual and complementary effects. This is necessary both for structuring the effects of major

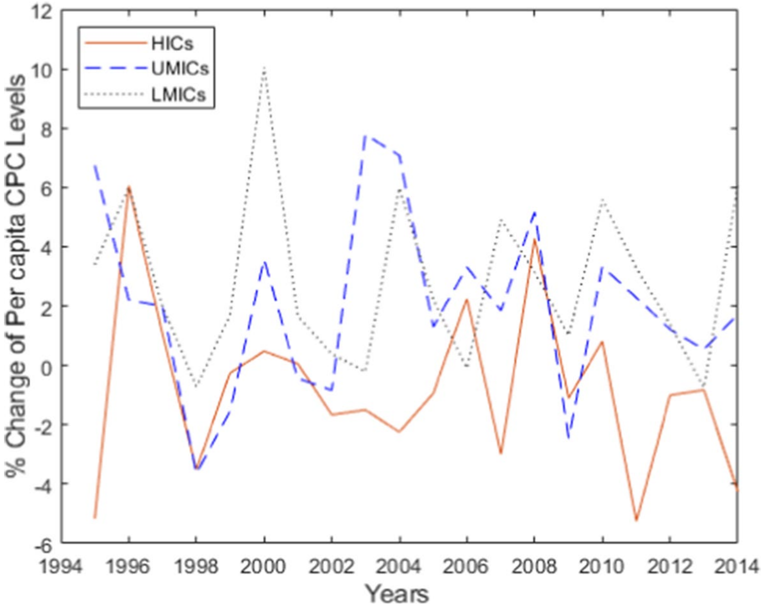

Fig. 1 Per capita carbon emissions in HICs, UMICs, and LMICs, 1994–2014. *Source*: World Bank (2020)

macroeconomic variables on air pollution to remove the potential shortcomings of the ambiguous findings and for coming up with structured policy suggestions not only for the relationships between each macroeconomic variable and pollution but also for the overall macroeconomy–pollution nexus.

In so doing, we introduce two modes of economic governance in managing the macroeconomy–pollution nexus based on green and dirty complementarities. Economic governance can be defined, in broad strokes, as a patterned or unpatterned system of interaction between public or private actors for adjusting or monitoring one or more market structures under the guidance of predetermined rules and procedures. In specific, macroeconomic governance is the collective ordering of micro–macro policy choices in deploying financial and non-financial institutions, underlying public–private and national–international economic relations.Macroeconomic governance can basically be financial and non-financial based on the functional clustering of major macroeconomic variables. An economic system relies mainly on two functions. The first is the real economic activity consisting of production, consumption, trade, and foreign direct investment. The second is the financial flows that fund these activities at public and private sectors. Macro-non-financial governance is a policy mix that consists of the propensity of (a) governments to adjust the size of their purchases; (b) non-financial sector to adjust the size of fixed capital investment; (c) non-financial businesses to adjust the size of imports or exports; and (d) foreign direct investors to adjust the size of their investments across countries. In a similar vein, macro-financial governance represents a policy mix that consists of (a) the adjustment of the size of government debt for financing public purchases; (b) the adjustment of gross savings (to buy financial assets such as debt securities, corporate equities, and mutual fund shares, or the depositing of money as time and savings deposits); (c) the adaptation of an accommodative or non-accommodative monetary policy mainly by changing the *quantity* of (broad) money; (d) the transferring of portfolio investment funds across countries, and (e) the development of financial markets by financial investors and intermediaries.

It is hence the collective ordering of governments', businesses', central banks', foreign direct investors', portfolio investors', and financial investors' choices that determine economic performance, the rate of growth, or the level of income in a country or between countries. We suggest that it is the same ordering that determines the impact of macroeconomic governance on ecological pollution including air pollution. This impact can be explained based on the complementary dynamics of macroeconomic aggregates. Complementarities can be defined as the mutual reinforcement among a certain group of variables in part or all of a social structure that improves or worsens clustering relative to alternative configurations (Hall & Soskice, 2001). There would emerge four types of relationships between the components of macro-financial and macro-non-financial governance in affecting pollution: (i) a 'green' complementary relationship in reducing pollution, (ii) a 'dirty' complementary relationship in increasing pollution, (iii) the conflation of the first two options, which is more realistic, and (iv) the lack of any relationship. We sketch out the first two cases. The delineation of the last two options is a matter of empirical analysis.

For example, based on the literature summarized in Table 1 on the potential pollution-reducing and pollution-increasing impacts of the major macroeconomic variables, governments can stimulate the development of greener products by funding R&D in energy efficiency as well as directly subsidizing firms to produce them. The greater energy efficiency and the lower cost of green production may enable firms to invest more funds in cleaner capital goods and technologies, thus becoming more internationally competitive in green products. Accruing higher revenue from green goods may stimulate governments to maintain their policy perspective. At the same time, greater savings may both reduce aggregate demand and augment financial development by increased investment in financial assets such as shares. Further financial market development can enable firms to have faster and easier access to cheaper and long-term funds, consolidating their ability to sustain their green production strategy for the predictable future. Monetary policy can complement this virtuous cycle by first providing necessary liquidity to financial markets and then achieving equilibrium in the quantity of money, respectively. Thus, green complementarities—GCMs—would emerge (i) between government consumption expenditures, private investment expenditures, and exports in the MNFG–pollution nexus, and (ii) between savings, financial market development, and monetary policy in the MFG–pollution nexus.

Moreover, the macroeconomy–pollution nexus may also operate in the exact opposite way. Governments can provide insufficient funds to stimulate green products both by underfunding R&D in energy efficiency and by eliminating subsidies to firms to produce them. With insufficient government stimulus, firms may continue using more energy-intensive and energy-inefficient technologies, increasing their competitive power in dirty goods. Accruing higher revenue from dirty goods may stimulate governments to maintain their policy perspective. In terms of the MFG–pollution nexus, the reduced savings may result from higher investment and consumption expenditures, leaving a lower level of investment in shares. The consequent slow or inadequate level of financial market development may stimulate firms to maintain their dirty production strategy, concentrating on short-run gains by using cheap natural resource-intensive energy instead of transitioning to long-run productivity and cost advantages as a result of energy efficiency. A contractionary monetary policy can worsen this vicious cycle by not supplying the necessary quantity of liquidity to financial markets and by worsening economic predictability as a result of failing to meet the demand for money. Consequently, there would emerge dirty complementarities (DCMs) (i) between government purchases, investment expenditures, and exports in the

Table 1 Examples for pollution-reducing and pollution-increasing impacts of major macroeconomic aggregates

Variable	Pollution-reducing impact achieved by	Pollution-increasing impact caused by
Gross fixed capital investment	Investment in less energy-intensive sectors, lower use of natural resources, and energy efficiency thanks to using cleaner technologies and production techniques (Sarkodie & Strezov, 2018)	Energy-intensive production using higher quantity of factors of production (scale effect) or energy inefficient/environmentally unfriendly technologies (Bilan et al., 2019; Rahman & Ahmad, 2019)
Government consumption expenditures	Stimulus programs in or consuming clean and renewable energy, environmentally friendly public goods such as efficient public transportation and high-speed trains, and green buildings (Halkos & Paizanos, 2013; Ghalipour and Farzanegan, 2018)	Higher quantity of government expenditures underlying higher emissions by stimulating higher fixed capital investment, creating a multiplier impact on investment and consumption expenditures (Dai et. al., 2012; Halkos & Paizanos, 2013; Galinato and Islam, 2014; Lopez and Palacios, 2014; Islam and Lopez, 2015)
Exports and Imports	Encouraging competition in producing clean products (Shahbaz et. al., 2013); an export-led strategy based mainly on raw materials and other agricultural products (Javid & Sharif, 2016; Zhang & Gangopadhyay, 2012); achieving energy-efficient production by importing clean capital goods and technologies (Javid & Sharif, 2016)	Exporting natural resource-intensive goods or using dirty technologies in producing exports; importing pollution-intensive products or dirty technologies (Khalil & Inam, 2006; Nasir, 2019; Solarin, 2017; Halıcıoğlu, 2009)
Foreign Direct Investment	Encouraging R&D in reducing emissions, using less energy-intensive production techniques and green technologies, particularly in high-income countries (Demena & Afesorgbor, 2020; Marques & Caetano, 2020)	Using outdated technologies, investing in most polluting industries or consuming arable lands (Nasir et al., 2019; Zhang, 2011; Xie et. al., 2020; Kivyiro & Arminen, 2014)
Savings	Reducing the rate of domestic aggregate demand or trade in goods and services (Hamilton & Clemens, 1999); Stimulating financialization and deindustrialization (Palley, 2013)	Growth-oriented intermediation of savings by finance sector, in particular in developing countries (Aghion et al., 2016), when growth rests upon energy-intensive techniques and consumption patterns

Table 1 (continued)

Variable	Pollution-reducing impact achieved by	Pollution-increasing impact caused by
Broad money	Contractionary monetary policy stimulating lower quantity of domestic demand due to increasing interest rates, reserve ratios, and causing credit contraction; stimulating the purchase of green products by green quantitative easing programs (Dafermos et. al. 2018) Expansionary economic policy stimulating critical public expenditures on or private investment in environmental protection, energy-efficient technologies, and environmental R&D	Expansionary monetary policy stimulating higher investment, energy consumption, and consumption expenditures due to reducing interest rates, reserve ratios, and causing credit expansion (Islam and Lopez, 2015; Al-mulali & Sab, 2012; Gök, 2020) Contractionary economic policy curtailing critical public expenditures on or private investment in environmental protection, energy-efficient technologies, and environmental R&D; structural adjustment or austerity measures causing deforestation or excessive extraction and the use of underpriced natural resources for comparative cost advantage (Holden et al., 1998)
Public debt	Using public funds in applying tax cuts for or financially stimulating green technologies and products, supporting R&D in green technologies (Carratù et. al., 2019; Cetin and Bakirtaş, 2020)	Funding expansionary government policies, in particular above a certain threshold, stimulating higher carbon emissions (Clootens, 2017); applying tax cuts for or financially stimulating dirty technologies or products; either not supplying or substantially reducing the funds for R&D in green technologies, discouraging the use of energy-efficient technologies
Portfolio investment	Supplying higher quantity of funds (Klein & Olivei, 1999) in sustainable economies or to non-financial businesses that invest in less energy-intensive sectors and use green technologies; large-scale withdrawal both squeezing and destabilizing the supply of funds, underlying lower quantity of investment and consumption expenditures as well as the quantity of imports not only during but also after the crises due to the adoption of austerity or structural adjustment measures (Grabel, 1996)	Stimulating higher growth in particular in the short run in environmentally unsustainable economies (Klein & Olivei, 1999; Shahbaz et al., 2020); destabilizing macroeconomic and financial systems due to high risks of liquidity and unregulated financial openness, causing instability in the supply of financial funds, in particular foreign currency and tempting short-termism in continuing to use dirty technologies and energy-intensive investment for sustaining comparative cost advantages (Reinhard and Reinhart, 2009)

Table 1 (continued)

Variable	Pollution-reducing impact achieved by	Pollution-increasing impact caused by
Financial development	A sophisticated financial system urging reputational finance and thus encouraging firms to be environmentally responsible (Dasgupta et al., 2001); stimulating environmental R&D and technological innovation, increasing the efficiency of energy consumption (Omri et. al., 2015; Tamazian and Bhaskara Rao, 2010; Tamazian et al., 2009; Shahbaz et. al., 2013); declining propensity to invest or consume due to financialization (Palley, 2013)	Stimulating higher quantity of fixed capital investment enabling firms to buy higher quantity of factors of production in dirty sectors, fostering industrialization, enabling consumers to consume more through cheaper and less costly credits, and stimulating higher FDI in particular in the long run (Sadorsky, 2010; Shahbaz & Lean, 2012; İbrahim & Vo, 2021; Khan & Ozturk, 2021; Hunjra et. al., 2020)
Energy consumption		(Zhang et al., 2019; Wang et. al., 2020; Muhammad, 2019; Ummalla & Goyari, 2020)

MNFG–pollution nexus, and (ii) between savings, financial market development, and monetary policy in the MFG–pollution nexus.

Evidently, GCMs and DCMs or their conflation in a third case lead to an especially complex set of policy choices and outcomes (Warford et al., 1997: 48). The key point of today under the rising threat of COVID-19 and imminent other pandemics is how to govern these choices and outcomes. We suggest two broad modes of governance, systemic governance, and fragmentation, which can be used to explain pollution–macroeconomy nexus in terms of the joint environmental impact of the cited choices and outcomes. Explaining their 'joint' impact in a 'multivariate' setting is significant as it is their joint, complementary or simultaneous rather than separate impact per se that determines the *overall* level of pollution (Apsimon et al., 2009; Warford et al., 1997: 65–80; Girma, 1992).

Systemic mode of governing pollution–macroeconomy nexus can be defined as a process of decision-making, regulation, or monitoring that aims to manage present and evolutionary complexities of this nexus. There are two points to be noted. First, it refers to governing the mix of GCMs and DCMs, so as either (i) to achieve a transformation into sustainable growth or (ii) to sustain current profits, employment, rents, or other interests, creating a regime of unsustainable growth. A mode of governance that achieves first and second targets based on GICs and DICs, respectively, can be considered as green and dirty systemic governance, respectively. Both targets arise out of the convergence of major and separate economic and environmental policy choices.

The lack of systemic governance ends up with fragmentation or disjointed policy choices, causing up either the deterioration of environmental pollution or the failure in achieving green growth. In specific, fragmentation makes sense with either (a) the lack of any relationships between the MEG's variables and pollution or (ii) the conflicting impacts of the MEG's variables on pollution. Each option illustrates the lack of a convergence between the MEG's variables in reducing or mitigating pollution.

In parallel with the above-noted third case, there might be a mix of GCMs and DCMs between environmental and macroeconomic policy choices under both systemic and fragmented modes of governance. This mixed order can, inter alia, turn out in one of two ways: (i) MNFG and MFG can separately increase or decrease pollution, or (ii) only one of them would have an impact on pollution, whereas the other would not.

In theoretical terms, we suggest that the specific drivers of the differences between the three country groups can and should be explained by making a system-level analysis of the macroeconomic determinants of pollution in these countries. For this purpose, we bring major macroeconomic aggregates into the analysis, as illustrated in Fig. 2. In empirical terms, we run a multivariate causality analysis taking MNFG and MFG variables together as independent variables in two separate models. In so doing, it will be possible, (i) first, to explain the drivers of pollution in terms of how MNFG and MFG variables converge or diverge from each other in reducing or increasing pollution through GCMs, DCMs, or disjointed strategies between themselves, and (ii) then devise structured and systemic policy suggestions to mitigate CPC for each group.

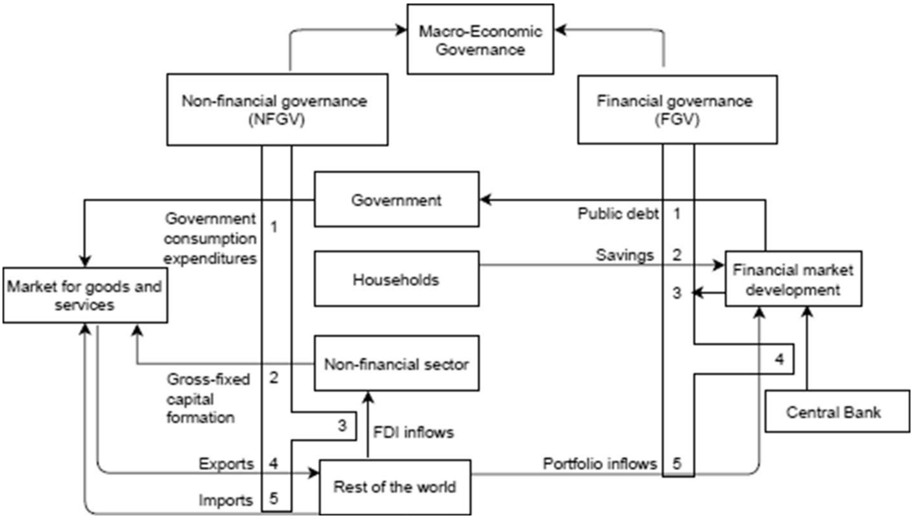

Fig. 2 Macro-financial and macro-non-financial governance

3 Data and methodology

The paper has two major points in selecting an econometric technique for the estimation of the pollution–macroeconomy nexus. The first is to estimate the long-run and short-run causal relationships between pollution and macroeconomic governance. The second point is to make a holistic analysis of the pollution–macroeconomy, as noted above.

The long run[4] matters when it comes to establishing the existence or the lack of a stable and dynamic relationship between the two or more variables, which is an indication of a systemic or fragmented mode of governance for managing the nexus, respectively. Systemic governance can be inferred when there is a mutual reinforcement between the *majority* of the major variables of MNFG and MFG in reducing or increasing pollution in the long run. The *majority* matters because we can expect a noticeable and sustained increase or decrease in pollution when the majority of the MNFG's and MFG's variables complement each other or converge to the extent of reducing or increasing pollution, respectively. Fragmentation can be inferred when (i) there is a mutual reinforcement between the *few* of the same variables in increasing or decreasing pollution, or (ii) there is a lack of relationship between them in the long run.

The econometric technique to cover the two points noted above is panel data cointegration that estimates, first, the long-run and short-run relationships, and second, in a multivariate setting. The first point matters as it illustrates the existence or the lack of comovement or trending relationship between the variables. A trending relationship is an indication of an ordered mode of governance because it illustrates in macroeconomic terms that variables

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[4] In our analysis, long run denotes a time period when the macroeconomic variables and CO_2 emissions comove in a patterned manner. The 'patterned' here denotes, for example, a relationship dominated by green or dirty complementarities (see Figs. 3, 4, and 5). Short run denotes the subperiods when this patterned relationship diverges from the long-run equilibrium of the patterned relationship. That the ECT is negative and statistically significant denotes that these short-run divergences from the long-run equilibrium converge to the long-run equilibrium.

complement each other or have a mutually reinforcing relationship in achieving a certain purpose. This achievement may be because of an action that may or may not be concerted. The focal point of our analysis is the complementary or non-complementary relationship itself. The second point in this regard matters as it illustrates the existence or the lack of a system-level trending relationship in a complementary manner. The 'complementary relationship' here refers specifically to the existence of convergence between the majority or few variables of a model in reducing or increasing pollution (see Figs. 3, 4, and 5).

The paper used per capita carbon dioxide emissions (CPC) as a proxy for environmental pollution. The data sources for both CPC and for the MNFG and MFG's variables are given in Table 2. The case countries are 13 HICs, 10 UMICs, and 9 LMICs (Table 3). The basic criteria in selecting the sample countries were first to be able to gather all the data in a statistically consistent manner and second to cover the longest time available, considering that the higher the degrees of freedom, the more robust the cointegration analysis would be.

A vast majority of the studies use CO_2 emissions to investigate the nexus between economic growth and environmental degradation (Bibi & Jamil, 2021; Cialani, 2007; Destek et al., 2020; Dinda & Coondoo, 2006; Dogan & Inglesi-Lotz, 2020; Franklin & Ruth, 2012; Friedl & Getzner, 2003; Lazăr et al., 2019; Ongan et al., 2021; Zhang & Gao, 2016). The reason why we select CPC for pollution is that our primary focus is on the long-term relationships between the macroeconomy and pollution. Pollutants are twofold: flow and stock pollutants. Flow pollutants only have an immediate effect on the environment. The atmospheric lifetime of sulfur dioxide (SO_2), nitrogen oxide (NO_x), and carbon monoxide (CO) is 1–4 days, 2–5 days, and 1–3 months, respectively. But stock pollutants accumulate in the air, and their effects last a century or longer (Lieb, 2004; Liu & Liptak, 2000; Moore, 2009; Ukaogo et al., 2020). Furthermore, a high correlation between SO_2, NO_x, and CO_2 demonstrates that CO_2 emissions matter for the short run as well (Angelopoulos

Table 2 List of variables and their descriptions

Variable	Definition	Source
cpc_{it}	Per capita carbon dioxide emissions	World Development Indicators (WDI)
MNFG's Variables (Model 1)		
$gexd_{it}$	Government consumption expenditures*	WDI
fcf_{it}	Investment expenditures*	WDI
exp_{it}	Exports*	WDI
imp_{it}	Imports*	WDI
fdi_{it}	Inward foreign direct investment*	WDI
$engy_{it}$	Per capita energy use	WDI
MFG's Variables (Model 2)		
bmn_{it}	Broad money*	WDI
svg_{it}	Gross savings*	WDI
$prft_{it}$	Inward portfolio investment*	WDI
$pbdt_{it}$	Public debt*	IMF Global Debt Database
fmd_{it}	Financial market development	IMF Financial Development Index Database

Annual data between 1994 and 2014 (T=21) for three different income groups; *As percent of GDP; Source: World Bank (2020); IMF (2020a, b)

Table 3 Country groups

	High income (HICs)	Upper middle income (UMICs)	Low income (LMICs)
1	Australia	Argentina	Bangladesh
2	Chile	Botswana	Cameroon
3	Czech Republic	Brazil	India
4	Denmark	China	Kenya
5	Israel	Indonesia	Morocco
6	Korea, Rep	Malaysia	Nigeria
7	Norway	Mexico	Pakistan
8	Singapore	South Africa	Philippines
9	Sweden	Thailand	Sri Lanka
10	Switzerland	Turkey	
11	UK		
12	USA		
13	Uruguay		

et al., 2010; Fischer & Heutel, 2013; Smulders, 2004). In other words, the key analytical concern between stock and flow pollutants is that the former matter both for the long and short run, whereas the latter are relevant only for the short run. The fact that CO_2 data are consistently available for a large number of countries is another key reason for selecting it as a proxy for pollution.

We developed two models, which can be written in the following formal algebraic forms. The first model estimates the long-run and short-run relationships between MNFG and pollution, whereas the second between MFG and pollution. The variables represented by the acronyms are defined in Table 2.

$$\ln cpc_{it} = f\left(\ln gexd_{it}, \ln fcf_{it}, \ln \exp_{it}, \ln imp_{it}, \ln fdi_{it}, \ln engy_{it}, e_{1,it}\right), \tag{1}$$

$$\ln cpc_{it} = f\left(\ln bmn_{it}, \ln svg_{it}, \ln pbdt_{it}, \ln prft_{it}, \ln fmd_{it}, \ln engy_{it}, e_{2,it}\right), \tag{2}$$

where $i = 1, 2, \dots N$; $t = 1, 2, \dots T$ and $e_{1,it}$, and $e_{2,it}$ are error terms.

The panel cointegration tests comprise four steps: (i) first, to estimate cross section dependence between the panels, (ii) second, to run panel unit root tests, (iii) third, to estimate the cointegration relationship, and (iv) fourth, to estimate long-run and short-run models if the cointegrated relationship is established (see Appendix 2for technical details on panel unit root, cross section, and cointegration tests).

In panel cointegration tests, the existence of cross section dependence or independence is significant in selecting either the first- or the second-generation panel unit root tests. (In the existence of cross section dependence, the second-generation unit roots tests should be used as they allow cross section dependence.) We ran the cross section dependence test using the Breusch and Pagan (1980) Lagrangian multiplier (LM) test, the Pesaran et al. (2008) bias-adjusted LM test, and the Pesaran (2004) CD test.

According to the results in Tables 4 and 5, we fail to reject the null of cross section independence for both Model 1 and Model 2 in all country groups, because either all or the majority of the tests are not statistically significant at 1 percent, 5 percent, or 10 percent level.

Table 4 The results of cross-sectional dependence tests for Model 1

Test	HICs		UMICs		LMICs	
	Statistic	*p* value	Statistic	*p* value	Statistic	*p* value
LM	66.72	0.8149	50.29	0.2720	33.17	0.6039
LM adj	− 3.672	0.0002	− 0.5759	0.5621	− 1.791	0.0732
LM CD	1.277	0.2014	1.27	0.2041	0.1365	0.8914

Table 5 The results of cross-sectional dependence tests for Model 2

Test	HICs		UMICs		LMICs	
	Statistic	*p* value	Statistic	*p* value	Statistic	*p* value
LM	97.05	0.0710	45.31	0.4590	32.31	0.6449
LM adj	0.8137	0.4158	− 1.638	0.1014	− 2.255	0.0241
LM CD	1.488	0.1368	1.27	0.2041	− 0.5977	0.5501

Given the results of cross section dependence, we use the following first-generation panel unit root tests that precondition cross section independence both for Model 1 and for Model 2: (i) LLC, proposed by Breitung (2001), Levin et al. (2002); (ii) IPS, proposed by Im et al. (2003); and (iii) ADF-PP, proposed by Maddala and Wu (1999) and Choi (2001) (Table 6).

The results from the panel unit root tests using individual intercept and trend models are reported in Tables 6, 7, and 8 for HICs, UMICs, and LMICs, respectively. We conclude that all the variables in Model 1 and Model 2 are non-stationary at level and become stationary at first differences as the results of either all or the great majority of the panel unit root tests are not statistically significant at level and are statistically significant at first differences, respectively.

For cointegration analysis, we use two widely used tests, Pedroni (1999, 2004) and Kao (1999). Table 9 documents the results of the panel cointegration tests for Model 1 and Model 2. For both HICs and UMICs, we can reject the null hypothesis of no cointegration for both models as either all or the majority of Pedroni and Kao test statistics are significant at 1 or 5 percent level. For LMICs, we fail to reject the null hypothesis for Model 1 but can reject for Model 2 as the majority of Pedroni and Kao test statistics are not and are significant at 1 or 5 percent levels, respectively. Thus, we conclude that there are cointegration (long-run) relationships between CPC and the MNFG variables (Model 1) only for HICs and UMICs, and between CPC and the MFG variables (Model 2) for all country groups.

The fourth step in estimating panel cointegration models after establishing the cointegrated relationship is to estimate long-run and short-run relationships between variables, for which we use panel autoregressive distributed lag approach. For running panel ARDL models, we used a dynamic panel estimator, PMG.[5]

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[5] The main advantage of panel ARDL approach (Pesaran et al., 1999) is to be able to estimate cointegrated relationships irrespective of the order of integration, which might be *I(0)*, *I(1)* or a mix of *I(0)* and *I(1)*. Panel ARDL cannot, however, be employed when the dependent variable is not *I(1)* or any of the variables is *I(2)*. As all variables in the both models we established are *I(1)*, we are able to run oanel ARDL for our models. The PMG estimator highlights both pooling by the homogeneity restrictions on the long-run coefficients and averaging across groups to obtain means of the estimated error correction coefficients and the other short-term parameters of the model.

Table 6 The Results of Panel Unit Root Tests for HI Countries

Variables	LLC		Breitung		IPS		ADF		PP	
	Level	First Diff	Level	First Dif	Level	First Dif	Level	First Dif	Level	First Dif
lncpc_{it}	−0.22	−9.42*	3.97	−1.60*	0.95	−8.92*	29.53	135.12*	28.32	218.49*
lngexd_{it}	−2.07	−10.46*	−2.61	−5.77*	−2.55	−9.58*	41.63	131.28*	32.66	247.53*
lnfcf_{it}	−4.55	−9.06*	−1.74	−3.81*	−2.92	−8.72*	53.34	119.56*	27.38	140.37*
lnexp_{it}	−1.17	−12.69*	−4.32	−5.85*	0.23	−10.84*	28.00	147.75*	23.06	176.14*
lnimp_{it}	−3.06**	−11.23*	0.67	−5.40*	−2.86	−11.95*	49.20	165.81*	50.39	267.13*
lnfdi_{it}	−9.09	−11.72*	−3.12	−5.17*	−6.34	−10.80*	86.88	138.83*	149.67	264.76*
lnengy_{it}	−0.90	−10.60*	4.98	−5.22*	−0.42	−10.36*	35.75	152.02*	37.55***	205.87*
lnbmn_{it}	0.47	−10.67*	0.87	−7.46*	−0.20	−9.23*	26.33	126.55*	36.22***	171.21*
lnsvg_{it}	−.70***	−9.66*	−2.24	−3.10*	−2.75	−10.20*	44.73	143.32*	26.47	272.60*
lnprft_{it}	−1.04	−14.68*	−4.39	−6.90*	−6.25	−14.86*	18.31	196.07*	18.83	256.44*
lnpbdt_{it}	−1.01	−4.03*	0.51	−2.90*	0.66	−5.30*	24.02	72.94*	9.30	64.29*
lnfmd_{it}	−4.35	−9.15*	0.02	−5.17*	−3.41	−8.82*	58.89	117.32*	94.12	156.06*

*, **, and *** denote statistical significance at the 1 percent, 5 percent, and 10 percent levels, respectively

Table 7 The Results of Panel Unit Root Tests for UMI Countries

Variables	LLC		Breitung		IPS		ADF		PP	
	Level	First Diff	Level	First Dif	Level	First Dif	Level	First Dif	Level	First Dif
lncpc_{it}	0.38	−6.16*	0.49	−3.95*	−1.09	−5.75*	24.90	67.04*	16.20	105.87*
lngexd**it**	1.67	−3.04*	−2.85	−2.86*	−2.80	−5.19*	6.92	61.60*	6.61	105.35*
lnfcf_{it}	0.59	−4.63*	−2.21	−4.72*	−3.24	−5.06*	10.90	58.59*	10.71	91.71*
lnexp_{it}	1.16	−2.02*	1.26	−5.47*	−4.79	−5.97*	5.68	71.33*	5.20	135.16*
lnimp_{it}	0.59	−5.87*	−1.87	−8.08*	−1.70	−7.29*	31.28***	87.61*	41.14	144.87*
lnfdi_{it}	−0.87	−**11.54***	−3.64	−2.52*	−5.03	−10.22*	17.31	101.29*	23.98	163.95*
$\text{Inengy}_{\text{it}}$	−2.37***	−5.96*	0.55	−5.32*	−2.34	−6.82*	37.45	83.39*	20.71	116.15*
lnbmn_{it}	−0.67	−4.65*	−1.05	−5.31*	−2.66	−7.51*	39.16	92.39*	28.59***	141.21*
lnsvg_{it}	−1.00	−7.13*	−3.30	−4.28*	−2.36	−7.58*	33.55	85.37*	28.01	113.96*
$\text{lnprft}_{\text{it}}$	0.31	−11.16*	−3.10	−4.83*	−6.22	−10.27*	10.41	117.08*	9.14	187.83*
$\text{lnpbdt}_{\text{it}}$	1.14	−14.67*	−0.56	−2.83*	−1.43	−9.55*	35.01	69.39*	46.77	89.18*
lnfmd_{it}	−3.07	−8.22*	−2.58	−7.78*	−1.44	−8.32*	28.36	100.93*	26.28	146.59*

*, **, and *** denote statistical significance at the 1 percent, 5 percent, and 10 percent levels, respectively

Table 8 The Results of Panel Unit Root Tests for LI Countries

Variables	LLC		Breitung		IPS		ADF		PP	
	Level	First Diff	Level	First Dif	Level	First Dif	Level	First Dif	Level	First Dif
lncpc$_{it}$	0.12	− 6.94*	− 0.83	− 2.93*	− 0.67	− 7.36*	21.68	78.48*	17.83	86.90*
lngexd$_{it}$	− 1.16	− 9.40*	− 2.45	− 6.74*	− 0.87	− 7.87*	21.26	82.78*	14.44	87.31*
lnfcf$_{it}$	− 3.69	− 4.76*	− 0.63	− 3.85*	− 0.75	− 7.01*	24.41	83.27*	24.84	87.23*
lnexp$_{it}$	− 1.56	− 5.31*	− 0.36	− 4.39*	− 1.20	− 6.24*	31.63	72.87*	41.85	117.62*
lnimp$_{it}$	− 1.83	− 6.97*	− 1.80	− 7.36*	− 0.47	− 7.56*	20.75	80.93*	23.83	134.04*
lnfdi$_{it}$	− 2.22	− 11.84*	1.08	− 1.75*	− 3.36	− 5.03*	61.81	65.54*	66.50	161.52*
lnengyit	− 0.21	− 7.71*	2.82	− 2.59*	0.63	− 6.39*	18.53	73.14*	10.10	74.81*
lnbmn$_{it}$	2.45	− 3.17*	− 2.44	− 3.98*	− 2.05	− 5.69*	36.17	64.99*	27.40	93.71*
$^{\text{lnsvg}}$it	− 2.19	− 6.37*	0.40	− 4.92*	− 1.33	− 6.68*	28.96	71.82*	17.14	114.50*
lnprft$_{it}$	− 2.08	− 5.03*	1.81	1.94*	− 2.26	− 6.94*	25.24	100.23*	25.64	127.83*
lnpbdt$_{it}$	1.86	− 5.63*	0.63	− 5.22*	1.51	− 4.21*	12.69	46.34*	5.22	44.13*
lnfmd$_{it}$	− 1.94	− 7.21*	− 0.50	− 7.15*	− 1.99	− 6.03*	31.22	66.00*	17.96	93.25*

*, **, and *** denote statistical significance at the 1 percent, 5 percent, and 10 percent levels, respectively

Table 9 Pedroni and Kao cointegration results

	Model 1				Model 2			
	Pedroni		Kao		Pedroni		Kao	
HICs	Statistic	*p* value	Statistic	*p* value	Statistic	*p* value	Stat	*p* value
Modified Phillips–Perron t	37.553	0.0001	20.659	0.0194	42.001	0.0000	− 16.024	0.0545
Phillips–Perron t	− 35.985	0.0002	19.797	0.0239	− 18.128	0.0349	− 18.236	0.0341
Augmented Dickey–Fuller t	− 31.769	0.0007	15.277	0.0633	− 16.464	0.0498	− 33.198	0.0005
UMICs								
Modified Phillips–Perron t	36.855	0.0001	− 15.744	0.0577	27.277	0.0032	− 34.157	0.0003
Phillips–Perron t	− 35.209	0.0002	− 18.230	0.0342	− 36.103	0.0002	− 29.812	0.0014
Augmented Dickey–Fuller t	− 34.879	0.0002	− 17.178	0.0429	− 34.022	0.0003	− 23.146	0.0103
LMICs								
Modified Phillips–Perron t	31.473	0.0008	− 0.8423	0.1998	30.757	0.0010	− 37.080	0.0001
Phillips–Perron t	− 14.349	0.0757	− 13.430	0.0896	− 34.326	0.0003	− 31.609	0.0008
Augmented Dickey–Fuller t	− 14.835	0.0690	− 0.1873	0.4257	− 19.816	0.0238	− 20.107	0.0222

The long-term models have been constructed as follows:

$$\begin{aligned} Incpc_{it} =& \gamma_{1i} + \sum_{j=1}^{p} \gamma_{2i} Incpc_{i,t-j} + \sum_{i=0}^{q} \gamma_{3i} Infcf_{i,t-j} + \sum_{i=0}^{q} \gamma_{4i} Ingexd_{i,t-j} \\ & + \sum_{i=0}^{q} \gamma_{5i} In\exp_{i,t-j} + \sum_{i=0}^{q} \gamma_{6i} Inimp_{i,t-j} + \sum_{i=0}^{q} \gamma_{7i} Infdi_{i,t-j} + \sum_{i=0}^{q} \gamma_{8i} Inengy_{i,t-j} \\ & + \varepsilon_{1,it} \end{aligned} \tag{3}$$

$$\begin{aligned} Incpc_{it} =& \delta_{1i} + \sum_{j=1}^{p} \delta_{2i} Incpc_{i,t-j} + \sum_{i=0}^{q} \delta_{3i} Insvg_{i,t-j} + \sum_{i=0}^{q} \delta_{4i} Inbmn_{i,t-j} + \sum_{i=0}^{q} \delta_{5i} Inpbdt_{i,t-j} \\ & + \sum_{i=0}^{q} \delta_{6i} Inprfti_{i,t-j} + \sum_{i=0}^{q} \delta_{7i} Infmd_{i,t-j} + \sum_{i=0}^{q} \delta_{8i} Inengy_{i,t-j} + \varepsilon_{2,it} \end{aligned} \tag{4}$$

where *Incpc* is the logged dependent variable for both the models; the remaining (logged independent) variables such as *Infcf* and *Insvg* are the MNG's and the MFG's variables, which are defined in Table 2; $i = 1, \ldots. N$ are cross section units; $t = 1, \ldots. T$ are time periods; p and q are optimal lag orders; γ_{1i} and δ_{1i} are the group-specific intercepts; $\gamma_{2i} \ldots \gamma_{8i}$ and δ_{2i} ... δ_{8i} are long-term coefficients; and ε_{1it} and ε_{2it} are the error terms.

After estimating the long-run model, we construct the short-term (error correction) model as follows:

$$\begin{aligned} \Delta Incpc_{it} =& \alpha_{1i} + \sum_{j=1}^{p} \alpha_{2i} \Delta Incpc_{i,t-j} + \sum_{j=0}^{q} \alpha_{3i} \Delta Infcf_{i,t-j} + \sum_{j=0}^{q} \alpha_{4i} \Delta Ingexdi, t-j \\ & + \sum_{j=0}^{q} \alpha_{5i} \Delta In\exp i, t-j + \sum_{j=0}^{q} \alpha_{6i} \Delta Inimpi, t-j \\ & + \sum_{j=0}^{q} \alpha_{7i} \Delta fdii, t-j + \sum_{j=0}^{q} \alpha_{8i} \Delta Inengyi, t-j + \delta_{3i} ECT_{i,t-1} + \epsilon_{1,it} \end{aligned} \tag{5}$$

$$\begin{aligned} \Delta Incpc_{it} =& \beta_{1i} + \sum_{j=1}^{p} \beta_{2i} \Delta Incpc_{i,t-j} + \sum_{j=0}^{q} \beta_{3i} \Delta Insvg_{i,t-j} + \sum_{j=0}^{q} \beta_{4i} \Delta Inbmni, t-j \\ & + \sum_{j=0}^{q} \beta_{5i} \Delta Inpbdti, t-j + \sum_{j=0}^{q} \beta_{6i} \Delta prfti, t-j + \sum_{j=0}^{q} \beta_{7i} \Delta Infini, t-j \\ & + \sum_{j=0}^{q} \beta_{8i} \Delta Inrexci, t-j + \delta_{3i} ECT_{i,t-1} + \epsilon_{2,it} \end{aligned} \tag{6}$$

where Δ is the first-difference operator and ECT_i represents the error correction term obtained from the long-run model. That the ECT is negative and statistically significant indicates that the short-run deviations adjust to the long-run equilibrium, and δ indicates the speed of this adjustment.

Tables 10 and 11 indicate the results of long-run and short-run estimations using PMG estimator, respectively. We do not estimate Model 1 for LMICs as there is no cointegrated

Table 10 The results of panel ARDL models with PMG estimator (long run)

	HICs		UMICs		LMICs	
Variables	Coeff	*p* value	Coeff	*p* value	Coeff	*p* value
Model 1						
constant	−0.227	0.007*	−0.262	0.021**	−0.249	0.035**
$\Delta\mathrm{lngexd}_{it}$	−0.627	0.000*	0.221	0.003*	−0.211	0.028**
$\Delta\mathrm{lnfcf}_{it}$	−0.719	0.000*	0.120	0.002*	0.277	0.067***
$\Delta\mathrm{lnexp}_{it}$	−0.325	0.003*	0.090	0.043**	−0.004	0.954
$\Delta\mathrm{lnimp}_{it}$	0.427	0.001*	−0.109	0.198	0.242	0.001*
$\Delta\mathrm{lnfdi}_{it}$	0.060	0.000*	−0.011	0.544	0.038	0.004*
$\Delta\mathrm{lnengy}_{it}$	1.229	0.000*	0.529	0.000*	0.081	0.477
Model 2						
constant	−0.142	0.010*	−0.381	0.021**	−0.384	0.005*
$\Delta\mathrm{lnbmn}_{it}$	−0.253	.000*	−0.235	.000*	−0.002	.981
$\Delta\mathrm{lnsvg}_{it}$	−0.194	.014**	−0.116	.028**	−0.031	.547
$\Delta\mathrm{lnprft}_{it}$	−0.136	.000*	−0.123	.000*	−0.022	.115
$\Delta\mathrm{npbdt}_{it}$	−0.182	.000*	−0.123	.000*	−0.211	.000*
$\Delta\mathrm{lnfmd}_{it}$	−0.011	.791	−0.001	.991	0.027	.395
$\Delta\mathrm{nengy}_{it}$	0.557	.002*	1.311	.000*	0.835	.000*

*, **, and *** denote statistical significance at the 1, 5, and10% levels, respectively. ECT represents the coefficient of the error correction term

The appropriate lags have been selected as 1 via the BIC

Table 11 The results of panel ARDL models with PMG estimator (short run)

Variables	HICs		UMICs		LMICs	
	Coeff	*p* value	Coeff	*p* value	Coeff	*p* value
Model 1						
Constant	−1.085	0.008*	−0.998	0.025*	−0.327	0.027**
$\Delta\mathrm{lngexd}_{it}$	0.585	0.002*	−0.117	0.095***	−0.082	0.334
$\Delta\mathrm{lnfcf}_{it}$	0.181	0.136	0.088	0.281	−0.048	0.563
$\Delta\mathrm{lnexp}_{it}$	−0.374	0.545	−0.107	0.201	−0.020	0.661
$\Delta\mathrm{lnimp}_{it}$	0.248	0.543	0.095	0.223	−0.004	0.918
$\Delta\mathrm{lnfdi}_{it}$	−0.007	0.373	0.018	0.033**	−0.001	0.840
$\Delta\mathrm{lnengy}_{it}$	0.971	0.000*	0.573	0.081***	.599	0.062***
Model 2						
Constant	−0.058	0.052***	−2.144	0.020**	−0.766	0.009*
$\Delta\mathrm{lnbmn}_{it}$	0.001	0.987	.071	0.163	0.202	0.121
$\Delta\mathrm{lnsvg}_{it}$	−0.073	0.260	0.051	0.256	0.073	0.132
$\Delta\mathrm{lnprft}_{it}$	−0.003	0.843	−0.013	0.723	−0.024	0.270
$\Delta\mathrm{npbdt}_{it}$	−0.081	0.324	0.045	0.137	.035	0.586
$\Delta\mathrm{lnfmd}_{it}$	0.221	0.322	0.054	0.002*	0.082	0.058***
$\Delta\mathrm{nengy}_{it}$	1.071	0.000*	0.576	0.022**	1.331	0.128

*, **, and *** denote statistical significance at 1, 5, and 10% levels, respectively. The appropriate lags have been selected as 1 via the BIC

relationship between MNFG's variables and CPC. As the ECT for the both models estimated for HICs and UMICs as well as for Model 2 estimated for LMICs is statistically significant and negative, we conclude that short-run deviations from the long-run equilibrium converge to long-run equilibrium in the models and therefore we can interpret the estimated coefficients for the long-run model.

4 Empirical findings

As Fig. 3 illustrates, an increase in the key variables of MNFG (fixed capital formation, government expenditures, and exports) and in all the MFG variables, except financial market development, caused a decline in CPC in the HICs in the long run. This result illustrates that HICs achieved a reduction in their CPC levels by adopting a systemic mode of macroeconomic governance in operating GCMs. We infer this 'green systemic governance' for the long run considering that the great majority of the variables of MEG converge in creating GCMs. That imports and inward foreign direct investment cause an increase in CPC does not change our result as both the majority and the key variables of macroeconomic variables converge in creating GCMs, which underlies the reduction in CPC levels in these countries in the long run. In the short run, only government expenditures out of MNFG variables have a positive effect on CPC. The remaining MNFG variables and all the MFG variables have no short-run relationship with CPC. Thus, there is an institutional fragmentation in governing the macroeconomy–pollution nexus for HICs in the short run, which may have hindered a faster and/or higher reduction in pollution levels in these countries.

As Fig. 4 illustrates, an increase in the key variables of MNFG (fixed capital formation, government expenditures, and exports) causes an increase in CPC in the UMICs. Thus, we can conclude that there is a systemic mode of MNFG in increasing CPC levels in the UMICs—'dirty systemic governance.' This does not mean that the countries make an intentional effort to increase their CPC levels, but rather that the convergence of public–private investment policy and public consumption policy leads to this outcome. However, the key domestic variables of MFG (broad money, public debt, and savings) converge

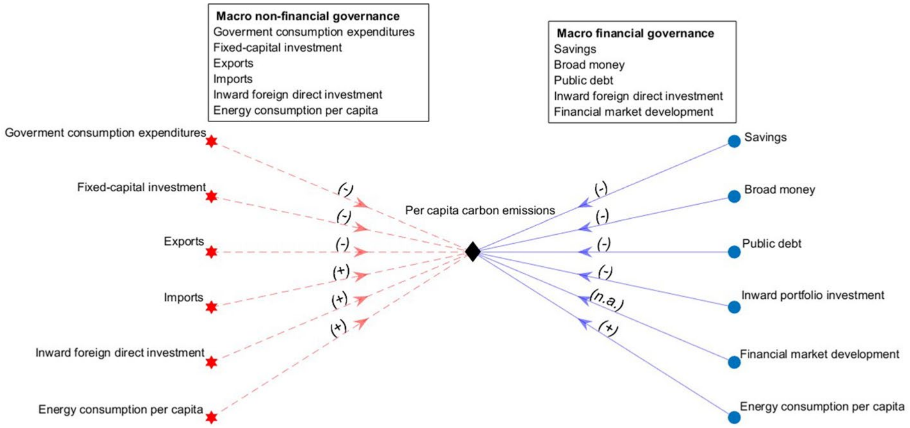

Fig. 3 The effects of MNFG's and MFG's variables on CPC in HICs

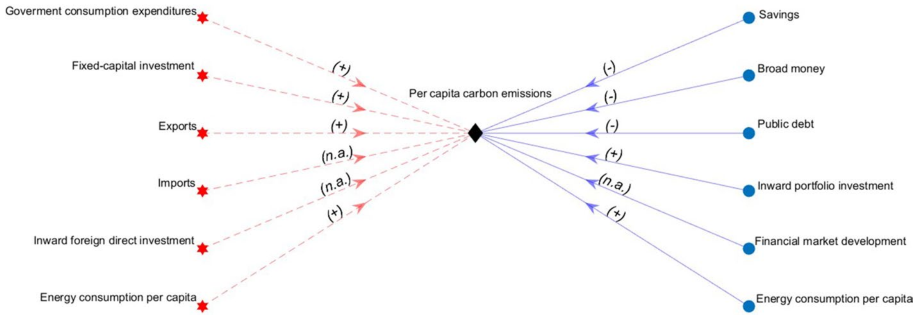

Fig. 4 The effects of MNFG's and MFG's variables on CPC in UMICs

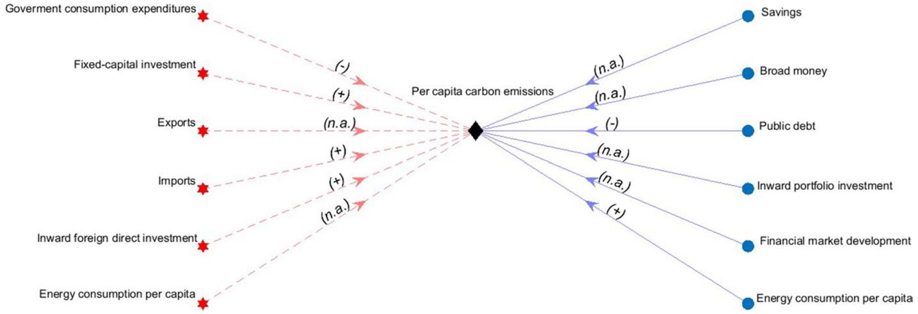

Fig. 5 The effects of MNFG's and MFG's variables on CPC in LMICs

in creating a green complementary effect. There are two relevant points in terms of the unified impact of the MNFG and MFG in the UMICs on CPC. First, the production, consumption, and trade variable of the MNFG model that have a direct impact on CPC may have underlay the increase in CPC in the UMICs. In contrast, that the MFG was executed in the form of green systemic governance can be suggested as an underlying factor that helps explain why the increase in pollution in UMICs was lower than that in LMICs. When it comes to the short run, only the foreign direct inflows out of the MNFG variables have a statistically significant positive impact on CPC, and only financial market development of the MFG variables has a statistically significant negative impact on CPC. We can thus safely conclude that there was a fragmented governance model in the examined UMICs in the short run, which may have factored into the remarkable increase in CPC in these countries.

We can conclude that the macroeconomy–pollution nexus was managed by a fragmented governance model in LMICs, which may have underlay the highest increase in pollution compared to the HICs and the UMICs in the 1994–2014 period. This conclusion lies in two facts. First, as Fig. 5 illustrates, there is no long-run cointegrated relationship between MNFG's variables and CPC, and there is no statistically significant relationship between MFG's major variables and CPC, too, except a negative effect running from portfolio investment to CPC. What may have consolidated this result is the lack of a statistically significant relationship between CPC and MFG's variables in the LMICs in the short run.

Our study confirms a number of findings in the extant literature about the relationships between individual macroeconomic variables and pollution. For example, our findings for the HICs confirm that real economic activity in HICs reduces pollution (Chen & Taylor, 2020; Hamit-Haggar, 2012; Salari et al., 2021). Specifically, our results confirm the negative effects running from FDI to CO_2 (Bulus & Koc, 2021) and from financial market development to CO_2 (Shoaib et al., 2020), and the positive effect running from imports to CO_2 in HICs (Ali & Kirikkaleli, 2021). Our empirical findings for UMICs confirm, in general, that real economic activity increases CO_2 emissions in these countries (Ahmed & Shimada, 2019; Bhat, 2018; Ummalla & Goyari, 2020), in particular regarding the positive effect running from government expenditures to CO_2 (Carlsson & Lundström, 2001; Fan et al., 2020), from international trade to CO_2 (Wu et al., 2021a, 2021b), and from investment expenditures to CO_2 (Nugraha & Osman, 2018; Shahbaz et al., 2020). Our findings for LMICs also confirm, in general, that real economic activity increases CO_2 emissions in these countries (Antonakakis et al., 2017; Ben Jebli et al., 2020; Ehigiamusoe & Lean, 2019; Halkos & Gkampoura, 2021; Zaman & Moemen, 2017), specifically confirming the positive effect running from imports to CO_2 (Alola & Joshua, 2020) and from FDI to CO_2 (Lau et al., 2018; Shi et al., 2020).

5 Discussion

Pollution in general and air pollution in specific are the most significant environmental causes of worldwide morbidity and mortality. Underlying are the emissions of substances into the atmosphere by human activities such as production, consumption, trade and finance, which are governed predominantly by macroeconomic policies. Given these two basic facts, the paper aimed to provide new evidence for how to structure macroeconomic policies in a way to reduce environmental pollution, which might be a part of a rapid, large-scale, and coordinated action against pollution, required by the United Nations Environment Assembly (UNEP, 2018: 3). This section, in this context, aims to make a structured discussion on (i) the paper's contributions to the understanding and governance of macroeconomy–pollution nexus, (ii) the policy implications of the paper's findings at national and international level, and (iii) the implications of the paper's findings for future work on macroeconomy–pollution nexus.

The first contribution of this paper is to introduce the systemic and fragmented governance of GCMs and DCMs as analytical tools to explain the effect of each variable of macroeconomic governance on air pollution in conjunction with the others, thereby providing systemic insight into how the macroeconomic governance–pollution nexus works as a whole. This matters because a *ceteris paribus* approach is neither realistic nor explanatory and may be misleading when used for cultivating policy suggestions. In specific, this contribution matters for cultivating feasible and conclusive policy inferences by explaining and understanding (i) what to do to make an economic *system* environmentally friendly, (ii) how to decide what to do *first*, and (iii) how to restructure *variable-specific* policy options (See policy implications).

The second contribution of the paper is to illustrate the need for disaggregating the EKC hypothesis in order to demonstrate how each component of growth rather than only aggregate growth itself affects pollution in time so that variable-specific policy suggestions may be imagined. Given the results for each country group, it can be suggested that the higher the level of income, the more environment friendly the macroeconomic governance.

Evidently, this result confirms the EKC hypothesis in terms of the comparative performance of high-income, upper-middle, and lower-income countries but not in terms of the *changing levels* of income for the *same* country groups over time. In other words, we did not test the ordinary EKC hypothesis. Instead, we first grouped countries based on their levels of income and then investigated the effects of macroeconomic variables on pollution in the selected countries. However, it turns out that a dynamic approach to the macroeconomy–pollution nexus using the EKC hypothesis would be a valuable exercise to understand the changing effects of macroeconomic governance on pollution for the same group of countries with changing levels of income. Evidently, such a dynamic approach would yield the formulation of stage-specific policy inferences for governing the relationship between each variable of macroeconomic governance and pollution.

The third contribution of the paper is to introduce how to make a full-fledged analysis of pollution–macroeconomy nexus by a systematic selection of macroeconomic variables. In the extant literature, most of the macroeconomic variables have been examined in terms of their effects on pollution. But either only few variables have been selected or these variables have been modeled regardless of the systemic conduct of macroeconomic regime. A key result of this way of action is that there has yet to be formulated common characteristics for macroeconomy–pollution nexus for HICs, UMICs, and LMICs. The paper contributed to the joint explanation of the effect of macroeconomic variables on pollution, thereby mitigating the ambiguity of the findings on various income groups.

The paper has both national and international policy implications for governing macroeconomy–pollution nexus. At national level, it becomes evident that HICs should attach specific and primary importance to their foreign (real) economic relations, because both imports and FDI in these countries increase CO_2 emissions, whereas the domestic (real) economic activity altogether reduces it. Specifically, HICs should prioritize greening financial market development as it is a significant variable in providing both public and private (real) economic actors with necessary funds for the said reorganization. The UMICs should reorganize the relationship between their entire domestic (real) economic activity and pollution rather than the relationships of only one of these variables (e.g., government expenditures, investment expenditures, and exports) with pollution. Apparently, any variable-specific policy option in reorganizing these relationships free from each other cannot be expected to create a *green economic model* in UMICs. Greening financial market development should also be achieved simultaneously with this reorganization as it will be impossible to achieve in the absence of the necessary financial funds. When it comes to LMICs, they need a system-wide reorganization both for domestic and for foreign real economic activities. In so doing, they may prioritize fixed capital formation, exports, and imports over government expenditures.

From the above group-specific policy proposals, there emerges a meta-regime of macroeconomic governance at the international or global level in orchestrating the requirements of these proposals, too. A systemic mode of green macroeconomic governance may be used as a best practice or benchmark for international organizations to make a green world possible, as the fragmented, variable-specific or country-specific policy approach may not be sufficient to drive a worldwide transformation of the macroeconomy–pollution nexus. In this regard, international organizations, including the IMF, the World Bank, and the OECD, which either impose their structural adjustment programs or make policy recommendations to their member countries, should take concerted action in cooperation with organizations such as the United Nations, the European Environment Agency, and the Earth System Governance Project in greening macroeconomic regimes. The necessity of systemic or green approaches in dealing with the macroeconomy–pollution nexus becomes even more urgent during the pandemic and in the post-COVID-19 era. First, as noted earlier, air pollution exacerbates the deadly effects of COVID-19 (Pozzer et al., 2020) and the WHO makes recurrent warnings about the pandemic ahead (WHO, 2020). Second, there has already been a process of deglobalization and economic recession with rising protectionism, disruption of global supply chains, a sharp fall in international commercial and financial flows, an increasing shortage of raw materials and final products, sharp slumps in stock markets, a heightened volatility of financial asset prices, and finally, a rapid drop in (domestic and foreign) aggregate demand (WEF, 2020). Thus, short-run policy actions focusing exclusively on stimulating quantitative growth at all costs may make economic systems less sustainable in the long run by either disrupting the complementary effects of the majority of the MEG variables in HICs in reducing pollution or by deepening the pollution-increasing effects of the MNFG variables in UMICs or in LMICs. A long-run, focused fine-tuning of macroeconomic and environmental priorities may be possible only by handling these trade-offs from a systemic approach elaborated on in this paper.

Six principal points have emerged from our study that can be investigated by further work. The first is to explain the weight and comparative significance of MNFG and MFG in the overall increase or decrease in CPC levels (not only by looking at coefficient values but also by comparing the joint impact of their respective variables). The second is to study how long-run and short-run modes of MEG can be organized so as to complement each other in creating GCMs. This is relevant in particular for (i) how the pollution-reducing effects of long-run and green systemic governance in the HICs can be complemented by the same mode of governance in the short run, and (ii) how the long-run and green systemic governance model for managing the MFG–pollution nexus in the UMICs can be extended to the MNFG–pollution nexus, and how it can be adapted in the short run both for the MNFG–pollution and for the MFG–pollution nexus. The third issue is to deepen the analysis by explaining the specific GCMs between the MEG variables in each country group or in individual countries; the models used in the paper investigated system-wide complementarities and did not illustrate the specific complementarities that create mutual reinforcement between the MEG variables in reducing or increasing pollution. Another area for further research is to determine if green systemic governance can work better when adapted by concerted action, possibly through the comparison of coordinated and liberal market economies. The sixth and final point is to study the existence and adaptability of systemic governance in an international context during a stage when there is an urgent need for a complementary action by national, regional, international, and global actors in tackling severe environmental challenges.

6 Conclusion

The paper concludes, first, that the clustering of major macroeconomic variables into macro-financial and macro-nonfinancial governance yields to the systematic explanation of the relationships between macroeconomic variables and pollution. Second, such a systematic approach yields to the formulation of system-wide policy proposals in a way that demonstrates, first, what to do to make an entire macroeconomic system environmentally friendly, then, how to decide on what to do first to achieve this objective, and finally how to restructure variable-specific policy options. Third, the green and dirty complementarities as analytic tools that mediate the clustering of the converging pollution-increasing or pollution-decreasing effects of macroeconomic variables on pollution underlie the systematization and structuring of both the theoretical analysis and empirical policy inferences. Fourth, it is the systemic and fragmented modes of governance that underlie the explanation of the macroeconomy–pollution nexus from a complementary-theoretic approach by presenting a framework through which the existence or absence of complementarities between macroeconomic variables and pollution can be contextualized into an ordered analytic perspective. Fifth, (i) the systemic and fragmented governance models of GCMs and DCMs are, inter alia, the key drivers of countries' CPC levels, and (ii) environmental pollution can be tackled effectively when adopting green systemic governance in managing the variables of MNFG and MFG both in the long run and in the short run for all country groups. Sixth, it turns out that the EKC hypothesis needs to be *systematically disaggregated* for the understanding of how each component of macroeconomic governance has a *dynamic* effect on pollution. This disaggregation is necessary both (i) for explaining if the EKC hypothesis holds for the relationship between each component of growth and pollution in the same direction and magnitude as that between aggregate growth and pollution itself, (ii) thereby coming up with variable-specific policy suggestions to illustrate when and how to green each macroeconomic variable.

Appendix 1

See Tables 12, 13.

Table 12 Literature review on the effects of macroeconomic variables on CO_2

No	Author	Country and Period	Variables	Method	Results
1	Salari et al. (2021)	States across USA (1997–2016)	CO_2 emissions, Energy Consumption, GDP	Static and dynamic models	A long-run relationship exists between various forms of energy consumption and CO_2 emissions at the state level The relationship between CO_2 emissions and GDP is inverted-U shaped, providing sufficient evidence to support the environmental Kuznets curve (EKC) hypothesis across states
2	Adedoyin and Zakari (2020)	UK 1985–2017	UK's CO2 emissions in tons per capita (CO_2), real GDP (RGDP), energy consumption (EU) economic policy uncertainty (EPU)	ARDL, Granger causality	The model indicates that EPU is the most beneficial in the short run, since it decelerates the growth of CO_2 emissions, but its continued usage in the UK has a dubious effect, as CO_2 emissions continue to increase
3	Chen and Taylor (2020)	Singapore 1900–2017	A heavy metal (chromium, Cr) is utilized as a proxy for environmental quality in this case. GDP, energy use	Granger Causality	Findings verified the EKC hypothesis about Cr emissions in Singapore. Additionally, the findings show that Singapore's post-industrial growth may have contributed to the region's pollution havens
4	Essandoh et al. (2020)	Developed and developing countries 1991–2014	CO_2 emissions, international trade, and FDI inflows	Granger causality	The decreasing trend in foreign direct investment tends to impede the detrimental effects of CO_2 emission

Table 12 (continued)

No	Author	Country and Period	Variables	Method	Results
5	Bulus and Koc (2021)	Korea 1970–2018	CO_2, FDI, GDP, energy use, renewable energy, government expenditures, exports, imports	ARDL	N-shaped link between GDP per capita and CO2 emissions per capita. Furthermore, the PHH is somewhat applicable in Korea, and the negative impact of FDI on environmental quality is generally restricted. Additionally, government spending increases the quality of the environment
6	Akbar et al. (2021)	33 OECD nations from 2006 to 2016	Healthcare spending, carbon dioxide (CO_2) emissions, and the human development index (HDI)	Panel vector autoregression	-Healthcare expenditures, CO_2 emissions, and HDI, exhibit a causal relationship -Healthcare expenditures and CO_2 emissions exhibit bidirectional causality, implying that CO_2 emissions significantly increase healthcare expenditures in OECD countries
7	Valodka et al. (2020)	EU Countries 2000–2016	CO_2 emissions and imports	The multi-regional input–output (MRIO) approach	The findings indicate that the EU did not reduce CO_2 emissions but rather outsourced them

Table 12 (continued)

No	Author	Country and Period	Variables	Method	Results
8	Ali and Kirikkaleli (2021)	Italy	Asymmetric influence of trade, renewable energy, and economic growth on consumption-based CO_2 emissions	The Gregory–Hansen test for cointegration, Markov switching regression, Nonlinear autoregressive distributed lag (NARDL), and a frequency domain causality test	-Import has a positive asymmetric effect on consumption-based CO_2 emissions, implying that increasing import is associated with a decline in consumption-based environmental quality -Export, renewable consumption, and economic growth all help Italy reduce consumption-based CO_2 emissions
9	Thampanya et al. (2021)	61 countries classified as high- and middle-income economies 1990–2018	The influence of positive and negative shocks in financial development on CO_2 emissions	Linear and nonlinear ARDL (NARDL)	Financial development factors in reducing CO_2 emissions in the long term for high-income economies, it increases CO_2 emissions and thereby degrades environmental quality in middle-income economies
10	Sephton and Mann (2016)	UK 1857–2007	GDP per cap, CO_2, SO_2	Nonlinear cointegration, threshold cointegration	Inverted U-shaped relationship
11	Shahbaz et al. (2016)	25 Developed Economies 1970–2014	Carbon emissions, non-renewable energy GDP	CIPS test, Westerlund cointegration, Granger causality	Globalization increases carbon emissions for most of the developed countries
12	Giovanis (2013)	UK 1991–2009	Household income, weather data, demographic and household characteristics	Dynamic panel data	No evidence of EKC hypothesis
13	Friedl and Getzner (2003)	Austria 1960–1999	GDP, CO_2, trade, structural change	Time series cointegration	Cubic (i.e., N-shaped) relationship between GDP and CO_2

Table 12 (continued)

No	Author	Country and Period	Variables	Method	Results
14	Franklin and Ruth (2012)	US 1800–2000	CO_2, GDP per cap, Gini coefficient, ratio of exports to imports, inflation adjusted energy prices	Time series, level, cubic; OLS, Prais–Winsten AR (1) regression model	Inverted U-shape
15	Fosten et al. (2012)	UK 1830–2008	CO_2, SO_2 and GDP per cap	Cointegration, nonlinear error correction	CO2 and SO2 emissions having an inverse-U relation with real GDP per capita
16	Hamit-Haggar (2012)	Canada 1990–2007	Industrial energy, CO_2, GDP	Pedroni cointegration test, FMOLS, VECM Granger causality	Inverted U-shaped relationship
17	Shoaib et al., 2020	G8 and D8 nations 1999–2013	Financial development and CO2 emissions	PMG panel ARDL approach	In the long run, financial development has a substantial and beneficial effect on carbon emissions at the 1% statistical level in both panels. Financial development and energy consumption have a greater influence on the D-8 and G(8) nations, respectively. Energy consumption and trade openness have a beneficial effect, but GDP has a substantial effect in reducing carbon emissions by 1% statistically
18	Ahmed and Shimada (2019)	30 Emerging and developing countries 1994–2014	GDP constant USD prices, gross fixed capital formation, labor force, CO_2, renewable and non-renewable energy consumption	Panel co-integration test, FMOLS and DOLS	GDP and non-renewable energy consumption cause the increase in CO_2 emissions

Table 12 (continued)

No	Author	Country and Period	Variables	Method	Results
19	Banday and Aneja (2019)	5 BRICS Countries 1990–2017	GDP constant USD prices, renewable energy consumption, non-renewable energy consumption, CO_2	Bootstrap Dumitrescu and Hurlin panel causality	There is unidirectional causality from GDP to CO_2 for India, China, Brazil, South Africa and no causality for Russia
20	Bhat (2018)	5 BRICS countries 1992–2016	GDP at market prices, gross fixed capital formation, labor force, population GDP per head of population, renewable energy consumption, non-renewable energy consumption, CO_2	Panel cointegration	Population, per capita income, and non-renewable energy consumption increase CO_2 emissions
21	Muhammad (2019)	68 countries—developed, emerging and Middle East and North Africa countries 2001–2017	GDP, energy consumption per capita, CO_2, labor force, gross national expenditure, financial development, population, urban population, trade openness, bank financial development, merchandise trade	SUR, GMM	CO_2 emissions increase in all countries because of energy consumption. CO_2 emissions increase, while the energy consumption decreases in developed and MENA countries but energy consumption increases and CO_2 emissions decrease in emerging countries due to the increase in economic growth
22	Ummalla and Goyari (2020)	5 BRICS countries 1992–2014	GDP, labor force, CO_2, clean energy consumption, energy consumption, population	Panel cointegration, panel Granger causality	Energy consumption and GDP increase CO_2 while clean energy consumption significantly reduces it

Table 12 (continued)

No	Author	Country and Period	Variables	Method	Results
23	Vo et al. (2019)	5 ASEAN members 1971–2014	CO_2, energy consumption, renewable energy consumption, GDP per capita, population	Granger causality and VECM	There is no long-run relationship among CO_2 emissions, energy consumption, renewable energy, population growth, and GDP in the Philippines and Thailand, but there is a relationship in Indonesia, Myanmar, and Malaysia
24	Pradhan et. al. (2021)	5 BRICS nations 1992–2014	CO_2, energy use, GDP per cap, FDI	Panel cointegration, FMOLS and DOLS	Foreign direct investment reduces CO_2 emission
25	Fan et al. (2020)	China 2007–2015	CO_2, population, government expenditure, energy consumption, GDP	Decomposition analysis	Disparities in government expenditure play an important role in regional emission inequality
26	He et al. (2020)	5 BRICS countries 1970–2018	CO_2, trade, FDI	Bootstrap ARDL	CO_2 emissions have a causal relationship with trade
27	Wu et. al. (2021b)	China 2000–2017	CO_2, trade, GDP	Decomposition method	International trade increases CO_2 emissions
28	Zhao and Yang (2020a, 2020b)	29 Chinese provinces 2001–2015	CO_2, financial development, GDP, energy consumption, urban population	Panel data analysis	The regional financial development has significantly lagged inhibitory effects on CO_2 emissions. Moreover, in the long run, there is a two-way causality between the variables
29	Nugraha and Osman (2018)	Indonesia 1971–2014	CO_2, energy consumption, household final expenditures, agriculture sector, industry sector	ARDL and Granger causality	An increase in household final consumption expenditure has a negative effect on CO_2 emission in the short term in Indonesia

Table 12 (continued)

No	Author	Country and Period	Variables	Method	Results
30	Al-mulali and Sab (2012)	19 selected countries 1980–2008	CO_2, broad money, domestic credit provided by banking sector, domestic credit provided to private sector, GDP, energy consumption	Panel data analysis	Broad money increases the CO_2 emission level in these countries
31	Mitić et al. (2020)	9 Balkan countries 1996–2017	CO_2, gross fixed capital formation, industry, services	Panel cointegration tests and panel causality tests	Gross fixed capital formation has statistically significant on CO_2 emissions
32	Shahbaz et. al. (2013)	South Africa 1965–2008	CO_2, GDP, financial development, trade, coal consumption	ARDL bounds testing and ECM	Trade openness improves the quality of environment
33	Halkos and Paizanos (2013)	77 selected countries 1980–2000	CO_2, GDP, government expenditure	Panel data analysis	Government expenditures have a negative direct effect on CO_2 emissions
34	Gholipour and Farzanegan (2018)	14 MENA countries 1996–2015	CO_2, government expenditure, trade openness, resource rents, weather conditions	ECM	Government expenditures directly reduce CO_2 emissions in MENA countries
35	Xie et. al. (2020)	11 emerging countries 2005–2014	CO_2, FDI, GDP, population, energy consumption, trade openness	Panel smooth transition regression (PSTR)	An increase in FDI has a significant influence on CO_2 emissions and population Energy consumption and trade openness are the key factors in increasing CO_2 emissions
36	Nasir et al. (2019)	ASEAN-5 economies 1982–2014	CO_2, FDI, GDP, financial development, bank credit to bank deposit	Panel data analysis	An increase in FDI will cause an increase in CO_2 emissions in emerging ASEAN countries
37	Carlsson and Lundström (2001)	75 selected countries 1975–1995	CO_2, GDP, political freedom, size of government, freedom to trade with foreigners, structure and use of markets, price stability and legal security	Panel data analysis	An increase in the government expenditures may indirectly lead CO_2 emissions to increase

Table 12 (continued)

No	Author	Country and Period	Variables	Method	Results
38	Halicioglu (2009)	Turkey 1960–2005	CO_2, energy use, GDP, foreign trade	The ARDL bounds testing and Granger causality	An increase in trade inflows causes CO_2 emissions to increase
39	Chandran and Tang (2013)	ASEAN-5 economies	CO_2, energy consumption, GDP, FDI	Granger causality	Foreign direct investment has an insignificant impact on CO_2 emissions
40	Shahbaz et. al. (2020)	China 2007–2015	CO_2, investment, population, GDP, technological innovations, exports, FDI	Bootstrapping autoregressive distributed lag modeling (BARDL)	There is a positive relationship between investment and carbon emissions
41	Zhao et. al. (2016)	China 1993–2013	CO_2, fossil fuels consumption, total energy consumption, gross output value, fixed asset investment, gross fixed asset investment	Extended logarithmic mean Divisia index (LMDI)	An increase in investment leads CO_2 emissions to increase
42	Ben and Ben (2021)	12 countries (MENA region) (1970–2015)	Co2 emissions, real GDP per capita, real GDP per capita square, energy use, trade openness, FDI inflows, financial development	Panel threshold regression model	There is a strong regime dependence relationship between income and air pollutants Carbon emission patterns differ among countries with identical energy intensities

Table 12 (continued)

No	Author	Country and Period	Variables	Method	Results
43	Halkos et al. (2021)	119 countries 32 lower middle income 7 low income (2000–2018)	Total electricity production, population, electricity production from oil, gas and coal sources, electricity production from renewable sources, excluding hydroelectric, electricity production from hydroelectric sources, CO_2 emissions, GDP per capita, population density	Fixed effect and GMM and Granger causality	EKC hypothesis is confirmed for high- and upper-middle-income countries For low-income levels GDP per capita has negative effect on CO2; however, from a certain threshold, higher GDP per capita increases CO2 emissions While electricity production from fossil fuels causes environmental degradation, electricity production from renewable sources has an inverse relationship with CO2. For low- and lower-middle-income countries, population diversity is a small driver of CO2 emissions
44	Dong et al. (2020)	130 countries (1997–2015)	-CO_2 emissions from fuel combustion, GDP	Decomposition (identity) analysis	UMI countries are the main contributors to recent CO_2 emission growth For the last two decades, while income increase had positively affected global CO_2 growth, declining energy intensity had a mitigating effect

Table 12 (continued)

No	Author	Country and Period	Variables	Method	Results
45	Abban et al. (2020)	44 Countries, 16 low- and lower middle-income countries (1995–2015)	CO2 emission, GDP per capita, GDP squared, EI (kilograms of oil equivalent), FDI inflows	Westerlund–Edgerton cointegration, AMG estimation	EKC is only confirmed in HICs. Bidirectional causal effect between CO_2 and FDI Except LMICs, there is a bidirectional relation among EI and CO2 emissions For LMICs, there is a one-way causal effect from CO_2 to EI, and bidirectional relation among GDP and CO2 emissions Unidirectional causal effect from GDP to CO_2 emissions in HICs and LICs
46	Khaskheli et al. (2021)	19 Low-income countries (1990–2016)	Environmental degradation is estimated by CO_2 emissions, Private credit by banks as a percentage of GDP, GDP per capita, International trade percentage of GDP, population	Panel smooth transition regression model (PSTR)	The environmental measures of low-income countries are nonexistent. However, the implementation of measures mitigates environmental quality by decreasing CO_2 emissions FD has a positive relation with CO_2 in low regimes; however, on higher regimes effect turns in to negative GDP, international trade, and population has a positive effect on CO_2; however, in higher regimes, it has a diminishing effect

Table 12 (continued)

No	Author	Country and Period	Variables	Method	Results
47	Alola and Joshua (2020)	217 countries with low, lower middle, upper middle and high income (1970–2014)	Renewable energy, fossil fuel, globalization, CO_2 emission	Panel pooled mean group and Granger causality	Fossil fuel energy usage is the leading cause for increased carbon emissions in each of the included income groups Except lower-middle-income group, renewable energy negatively and globalization positively affect CO_2 emissions In the short run, renewable energy usage and globalization improve environmental quality; however, their impacts turns into negative in the long run
48	Wu et al. (2021a)	56 countries; 14 lower middle income, low income (1991–2018)	CO_2 emissions, GDP, urbanization, energy, consumption per capita, industry, value-added, export	Principal component analysis and CCEMG	Urbanization and economic structure increases CO_2 emissions on LMIC and LIC, GDP has bidirectional relation with CO_2 on all country groups
49	Pham et al. (2020)	44 Lower middle-income countries (2003–2014)	CO2 emissions, merchandise exports on GDP, merchandise imports on GDP, net FDI inflow on GDP, real GDP, renewable energy consumption	Pooled mean group regression	Merchandise import, FDI and renewable energy consumption mitigate environmental quality. -Merchandise export worsens it

Table 12 (continued)

No	Author	Country and Period	Variables	Method	Results
50	Shi et al. (2020)	147 countries; 37 lower-middle income 16 low-income (1995–2015)	CO2 emissions, total population, net inflow of international tourists, total primary energy consumption per capita, expenditure of inbound tourists per capita, GDP per capita	IPAT equation and cointegration and Granger causality	The main contributor of global CO2 emissions is primary energy consumption For low-income countries, expenditure of inbound tourists per capita has a positive impact on CO_2 emissions As countries' income decreases, the impact of tourism on CO_2 emissions increases
51	Danlami et al. (2019)	LMI and Middle East and North African (MENA) countries (1980–2011)	CO2 emissions, GDP growth, gross capital formation, FDI -Energy production	Two separate ARDL models for LMI and MENA countries and FMOLS for the two regions over the same period	GDP and FDI have a positive relationship with CO2 emissions Contribution of CO_2 emissions by MENA countries is immense
52	Acheampong (2019)	46 Sub-Saharan African countries (2000–2015)	CO2 emissions, real GDP per capita growth, energy consumption, trade openness, population, urbanization, financial development (6 variables, domestic credit to private sector as a share of GDP, domestic credit to private sector by banks as a share of GDP, domestic credit to private sector by financial sector as a share of GDP, broad money as a share of GDP, liquid liabilities, international capital flow)	GMM	While financial development has a detrimental effect on the environment, FDI has a moderating role on CO_2 emissions The direct and indirect effect of financial development has mixed results among income groups and regions

Table 12 (continued)

No	Author	Country and Period	Variables	Method	Results
53	Dong et al., (2019)	110 countries; LI 10 LMI 28 (1980–2015)	Emission coefficient, population income level, energy intensity, energy consumption structure, CO_2 emission	Extended logarithmic mean and Divisia index	While CO_2 emissions continue to increase, the effects of driving forces of CO_2 emissions are similar in all periods Main driving forces of CO_2 emissions, income and population, respectively Main mitigating factors are energy intensity and energy consumption structure, respectively Countries that positively contribute to environmental quality by reducing CO_2 reductions most effectively were mainly UMI countries For HICs, energy intensity was the primary mitigating factor For low-income countries, the main mitigating factor was energy consumption UMI countries will mitigate environment by 2030 at a higher level than the other income country groups

Table 12 (continued)

No	Author	Country and Period	Variables	Method	Results
54	Ehigiamusoe and Lean (2019)	122 countries; 13 low income, 32 lower middle income (1990–2014)	Energy consumption, economic growth, financial development, CO_2 emissions	DOLS and FMOLS	Energy consumption has a positive effect on CO_2 emissions regardless of income groups While economic growth and financial development reduce CO_2 emissions in HI countries, its environmental effects are detrimental for middle-income and low-income countries
55	Lau et al. (2018)	100 countries 13 low-income, 28 lower middle-income, 25 upper middle income, 34 high income (2002–2014)	CO2 emissions, GDP per capita, FDI, trade, rule of law, control of corruption	GMM	EKC hypothesis is only valid in high-income countries Except low-income countries, rule of law has a positive impact on the environment For high-income countries, FDI, control of corruption has positive impact on CO_2 emissions. However, trade openness has adverse effects on the environment For developing countries, while trade openness contributes to CO_2 reduction, FDI has adverse environmental effects

Table 12 (continued)

No	Author	Country and Period	Variables	Method	Results
56	Zaman and Moemen (2017)	90 countries (25 low 42 lower middle and upper middle income 23 high income) (1975–2015)	Carbon dioxide emissions, GDP per capita, GDP per capita square, FDI, inflows, trade openness, population, energy use, agriculture, value-added, industry, value-added, services, value-added, health expenditures per capita, government expenditures on education	Panel GMM and panel fixed effect regression	EKC hypothesis is confirmed Sectoral value added has positive impact on CO_2 emissions, Industry value-added, service value-added and energy consumption increase CO_2 emissions Because of the shift of polluting industries from developed countries to developing countries, low-income countries are the most polluting countries
57	Antonakakis et al., (2017)	106 countries; 12 low, 24 lower middle income (1971–2011)	Real GDP per capita, CO2 emissions, final consumption of total energy consumption (5 subcomponents (1) Electricity (2) Oil (3) Renewable (4) Gas (5) Coal energy)	Panel VAR	Enduring growth aggravates the greenhouse gas emissions. EKC hypothesis cannot be confirmed There is a bidirectional causality between economic growth and energy consumption There is not any statistically significant evidence for the fact that renewable energy consumption is conducive to economic growth

Table 13 Literature review on the EKC hypothesis

No	Author	Country and period	Variables	Method	Results
1	Bibi and Jamil (2021)	Latin America, East Asia and the Pacific, Europe and Central Asia, South Asia, the Middle East and North Africa, and Sub-Saharan Africa (2000–2018)	Per capita CO2 emissions, per capita GDP, trade openness, FDI, education financial development indicator, institutional quality	Random effect and fixed effect models	The EKC hypothesis is supported in all the regions except in the Sub-Saharan Africa region. Consequently, different regions have dissimilar EKC relationships
2	Shikwambana et al. (2021)	South Africa (1994–2019)	GDP, CO_2, black carbon (BC), SO_2, CO	The sequential Mann–Kendall (SQMK)	EKC hypothesis showed an N-shape for SO_2 and CO. Emissions levels are generally correlated with economic growth
3	Amar (2021)	UK (1751–2016)	Per capita GDP, CO2 emissions	Dynamic correlation, Squared cross-wavelet coherency	The EKC hypothesis holds in the UK
4	Ongan et al. (2021)	USA (1990–2019)	CO2 emissions, Per capita disposable income, per capita renewable, fossil energy consumptions	ARDL	The undecomposed model does not detect evidence of the EKC hypothesis for the USA. However, the decomposed model (where the per capita income series is decomposed into its increases and decreases as two new time series and only one series, which contains income increases, is used) strongly does so
5	Minlah and Zhang (2021)	Ghana (1960–2014)	Per capita CO_2 emissions, per capita GDP	VAR Bootstrap rolling window Granger causality	Environmental Kuznets curve for carbon dioxide emissions for Ghana is upward sloping. Thus, EKC does not hold

Table 13 (continued)

No	Author	Country and period	Variables	Method	Results
6	Adeel-Farooq et al. (2020)	Association of Southeast Asian Nations (1985–2012)	Per capita GDP, Methane emissions, Energy consumption, Trade openness	Mean group (MG) Pooled MG (PMG)	Economic growth causes CH4 emissions to decrease
7	Jiang et al. (2020)	286 cities in China and 228 cities and counties in South Korea (2006–2016)	Per capita GRP, per capita SO_2 emissions, SO_2 emissions intensity, SO_2 emissions density, employment, share of manufacturing, industry in GRP, energy consumption, population density	Simultaneous equation model (SEM)	There is an inverted U-shaped pattern in metropolitan areas and a U-shaped pattern of non-metropolitan areas
8	Dogan and Inglesi-Lotz (2020)	Austria, Bulgaria, Finland, France, the Netherlands, Sweden, and Turkey (1980–2014)	GDP, CO_2 emissions, Industry value added, Energy intensity, Urbanization, Population	Fully modified OLS (FMOLS)	EKC hypothesis does not hold where higher levels of industrialization promote reductions in the emission levels. The channel might be through access to modern, cleaner, more efficient technologies that promote environmentally friendly behaviors of the overall economy
9	Pata and Aydin (2020)	Brazil, China, Canada, India, Norway and the USA (1965–2016)	GDP, Ecological footprint, Hydropower energy consumption	Fourier bootstrap ARDL	The EKC does not hold in the top six hydropower energy consuming countries -There is no causal nexus between hydropower energy consumption and ecological footprint Hydropower energy is not used effectively enough to reduce ecological footprint

Table 13 (continued)

No	Author	Country and period	Variables	Method	Results
10	Lazăr et al. (2019)	Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia (1996–2015)	Per capita CO2 emissions, Per capita GDP, Per capita energy consumption, Index of economic freedom	Mean Group (MG) estimator Mean Group Fully Modified Least Squared (MG-FMOLS) estimator Augmented Mean Group (AMG)	Aggregate results reveal an increasing nonlinear link between GDP and CO_2 for the group of CEE countries. However, at a disaggregated or country level, the relationship between GDP and CO_2 is diverse among CEE countries, namely: N-shaped, inverted-N, U-shaped, inverted-U, monotonic, or no statistical link
11	Sephton and Mann (2018)	USA (1857–2007)	GDP per capita, CO_2, SO_2	Nonlinear cointegration, threshold cointegration	Inverted U-shaped relationship
12	Yang et al. (2015)	29 Chinese provinces (1995–2010)	CO_2, industrial dust, Ind. gas, Ind., smoke, Ind. SO2, Ind. waste water, GDP, % of exports, imports, domestic trade, ratio of entry of FDI/GDP, population density	Fixed and random effects models	Positive linear relationship EKC does not hold
13	Bölük and Mert (2015)	Turkey (1961–2010)	CO_2, GDP per cap electricity production from renewables	ARDL	Inverted U-shape
14	Zhang and Zhao (2014)	28 Chinese provinces (1995–2010)	GDP per cap, energy intensity, income CO_2, inequality, urbanization, share of industry sector in GDP	Fixed effect model	N-shape

Table 13 (continued)

No	Author	Country and period	Variables	Method	Results
15	Shahbaz et al. (2013)	Indonesia (1975–2011)	CO_2, GDP per cap, energy consumption per cap, real domestic credit to private sector per cap, trade openness	ARDL VECM Granger Causality	Economic growth and energy consumption increase CO_2 emissions, while financial development and trade openness compact it Bidirectional causality between CO_2 and GDP Financial development Granger causes CO2 emissions
16	Giovanis (2013)	UK (1991–2009)	Household income, weather data, demographic, household characteristics	Fixed effects model, Arellano–Bond GMM, binary logit model with fixed effects	No evidence of EKC hypothesis
17	Franklin and Ruth (2012)	USA (1990–2000)	GDP, CO_2, service and manufacturing, employment, Gini coefficient, real fuel prices, Genuine Progress Indicator, trade	OLS	Inverted U-shaped relationship
18	Hamit-Haggar (2012)	Canada (1990–2007)	Industrial energy, CO_2, GDP	FMOLS, VECM Granger causality	Inverted U-shaped relationship
19	Jayanthakumaran et al. (2012)	India–China (1971–2005)	GDP per cap, CO_2 energy consumption, ratio of exports plus imports to GDP, manufacturing value added	ARDL	Growth and structural changes in manufacturing, and increased energy consumption influence CO_2 emissions in China Income and energy consumption increase emissions in India The role of structural change in India is ambiguous
20	Fosten et al. (2012)	UK (1830–2008)	CO_2, SO_2, GDP per cap	OLS Error correction model	CO_2 and SO_2 emissions have an inverse-U relation with GDP per capita

Table 13 (continued)

No	Author	Country and period	Variables	Method	Results
21	Franklin and Ruth (2012)	The USA (1800–2000)	Co_2, GDP per cap, Gini coefficient, ratio of exports to imports, inflation adjusted energy prices	OLS Prais–Winsten AR(1)	Inverted U-shape
22	Soytas and Sari (2009)	Turkey (1960–2000)	Energy consumption; carbon emissions; labor, gross fixed capital investment; GDP	VAR Toda–Yamamoto	No long-run causal link between income and emissions
23	Dutt (2009)	124 countries (1960–2002)	CO_2, GDP per capita, governance, political institutions, socioeconomic conditions, population density, education	Robust OLS, fixed effect model	Linear between 1960 and 1980; Inverted U-shape between 1984 and 2002
24	Managi and Jena (2008)	16 states in India (1991–2003)	GSP, SO_2, No_2, and suspended particular matter	Productivity measurement technique	EKC exists between environmental productivity and income The effect of income on environmental productivity is negative
25	Halicioglu (2008)	Turkey (1960–2005)	CO2, energy, GDP. Foreign Trade	ARDL Granger causality	Strong connection between GDP and CO_2
26	Soytas et al. (2007)	USA (1960–1995)	Energy, GDP	VAR Granger causality	EKC does not hold in the case of USA In the long run, the main cause of CO_2 emissions in the USA is energy consumption
27	Dinda and Coondoo (2006)	88 countries (1960–1990)	CO_2 per cap, GDP per cap	ECM/fixed effects model	Bidirectional relationship Results confirm pollution haven hypothesis
28	Friedl and Getzner (2003)	Austria (1960–1999)	GDP, CO2, trade, structural change	Cointegration structural model	N-shaped relationship between GDP and CO2

Appendix 2

Panel unit root, cross section dependence, and panel cointegration tests

Panel unit root tests

Levin et al. (2002) and Breitung (2001) tests are estimated using the following models:

$$\Delta y_{it} = \kappa_i + \alpha y_{it-1} + \sum_{j=1}^{k} d_{ij} \Delta y_{it-j} + \varepsilon_{it} \tag{1}$$

and

$$\Delta y_{it} = \kappa_i + \alpha y_{it-1} + \beta_i t + \sum_{j=1}^{k} d_{ij} \Delta y_{it-j} + \varepsilon_{it} \tag{2}$$

Tests use panel versions of the augmented Dickey–Fuller (ADF) unit root test (with and without a trend). α is restricted to be identical across cross-sectional units, but the lag order for the first difference terms to vary across cross-sectional units is allowed in these tests, which in this study are countries. Pooled ordinary least squares (POLS) estimates Eqs. 1 and 2 for t_α critical values are tabulated by Levin et al. (2002) via Monte Carlo simulations for various combinations of N and T commonly employed in applied work. $H_0 : \alpha = 0$ and $H_1 : \alpha < 0$ are the null and the alternative hypothesis, respectively. Under the H_0, there is a unit root, while under the H_1 alternative there is no unit root.

While the Levin et al. (2002) test requires bias correction factors to correct for cross-sectionally heterogeneous variances to ensure efficient POLS estimation, the Breitung (2001) test achieves the same result by appropriate variable transformations. α, in Eqs. 10 and 11, is restricted to be identical across countries under both the null and alternative hypotheses is one of the drawbacks of the Levin et al. (2002) and Breitung (2001) tests.

Im et al. (2003), here after IPS, is proposed a t-bar test using the following model:

$$\Delta y_{i,t} = \alpha_i + \vartheta_i t + \theta_t + \rho_i y_{i,t-1} + \sum_{j=1}^{p} \varphi_{i,j} y_{i,t-j} + v_{i,t}. \tag{3}$$

It has the advantage over the Levin et al. (2002) and Breitung (2001) tests it does not assume that all countries converge toward the equilibrium value at the same speed under the alternative hypothesis and thus is less restrictive. The IPS test is the adjusted version of ADF individual unit root test statistics. As T and N goes to infinity, the IPS statistics is asymptotically normally distributed. The null and alternative hypothesis of IPS test:

$$\begin{aligned} H_0 &: \rho_i = 0 \text{ for all } i \\ H_1 &: \rho_i < 0 \; i = 1, 2, \dots, N \\ &\quad \rho_i = 0 \; i = N_1 + 1, N_1 + 2, \dots, N, \end{aligned}$$

While H_0 assumes that each series in the panel has a unit root for all cross-sectional units, H_1 means stationary of panel series.

The test statistic of IPS unit root test is modeled as follows:

$$\bar{t}_T = \frac{1}{N}\sum_{i=1}^{N} t_{i,t}\left(P_i\right) \tag{4}$$

where $t_{i,t}$ is the ADF t-statistics for the unit root tests of each country and P_i is the lag order in the ADF regression. The test statistic is calculated as follows:

$$A_T = \frac{\sqrt{N(T)\left[\bar{t}_T - E\left(t_T\right)\right]}}{\sqrt{\mathrm{var}\left(t_T\right)}} \tag{5}$$

The values for $E\left[t_{it}\left(P_i, 0\right)\right]$ are obtained from the results of the Monte Carlo simulation carried out by IPS. Simulations indicate that the $\bar{t}_T$ statistics is more powerful even for small sample sizes in the presence of no cross-sectional dependency.

Cross section dependence tests

A key limitation of the Breusch and Pagan (1980) LM test is to exhibit substantial size distortions when $N > T$. The CD test proposed by Pesaran (2004) converged to a normal distribution with a mean of 0 and a variance of 1 under the null hypothesis of cross-sectional independence when both N and $T \rightarrow \infty$. Further, Pesaran et al. (2008) proposed a bias-adjusted LM test that successfully controlled the size and maintained reasonable power in panels with exogenous regressors and normal errors, even when the cross section mean of the factor loadings was close to zero where the CD test had little power. Simulation evidence provided by Pesaran et al. (2008) indicates that the test had a good size and power for T > 20. All three tests were relevant for our analysis as N < T and T > 20 in both our models.

Panel cointegration tests

Kao (1999) develops two types of panel cointegration tests, the Dickey–Fuller (DF) and augmented Dickey–Fuller (ADF) types. The tests are based on the estimated residuals derived from the following long-run regression model:

$$y_{it} = \alpha_i + x_{it}^{'}\beta + \epsilon_{it}, \tag{6}$$

where y_{it} and $\boldsymbol{x}_{it}$ are assumed to be $I(1)$. The structure of estimated residuals is as follows:

$$\hat{\epsilon}_{it-1} = \rho\hat{\epsilon}_{it} + v_{it}, \tag{7}$$

where ρ is assumed to be common for all units. Under the null hypothesis, all tests show the absence of cointegration, whereas the alternative hypothesis indicates the existence of cointegration. All tests are asymptotically distributed as $N(0, 1)$.

Pedroni (1999) assumes that all panels have individual slope coefficients in Eq. (6). Allowing unit-specific ρ_i instead of ρ, the proposed panel cointegration tests are obtained by testing for a unit root in the estimated residuals.

The test statistics are

$$\text{Modified PP} - t \equiv \text{TN}^{-1/2} \sum_{i=1}^{N} \left(\sum_{t=1}^{T} \hat{e}_{it-1}^{2} \right)^{-1} \sum_{t=1}^{T} \left(\hat{e}_{it-1} \Delta \hat{e}_{it} - \hat{\alpha}_i \right)$$

$$PP - t \equiv N^{-1/2} \sum_{i=1}^{N} \left(\hat{\sigma}_i^2 \sum_{t=1}^{T} \hat{\int}_{it-1}^{2} \right)^{-1/2} \left(\hat{\in}_{it-1} \Delta \hat{\in}_{it} - \hat{\alpha}_i \right)$$

$\text{ADF} - t \equiv N^{-1/2} \sum_{i=1}^{N} \left(\sum_{t=1}^{T} \tilde{s}^{*^2} \hat{\in}_{it-1}^{2*} \right)^{-1/2} \sum_{t=1}^{N} \hat{\in}_{it-1}^{*} \Delta \hat{\in}_{it}^{*}$ where $\hat{\lambda}_i = \frac{1}{2}\left(\hat{\sigma}_i^2 - \hat{s}_i^2 \right)$ and $\tilde{S}_{N,T}^{*^2} = \frac{1}{N} \sum_{i=1}^{N} \hat{S}^{*^2}$.

The null and alternative hypotheses are

$$H_0 : \rho_i = 1$$

$$H_1 : \rho_i < 1,$$

for all i. Under the null hypothesis, there is no cointegration for all spesific units, whereas the alternative hypothesis indicates cointegration.

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References

Abban, O. J., et al. (2020). Analysis on the nexus amid CO2 emissions, energy intensity, economic growth, and foreign direct investment in Belt and Road economies: Does the level of income matter? *Environmental Science and Pollution Research, 27*(10), 11387–11402. https://doi.org/10.1007/s11356-020-07685-9

Acheampong, A. O. (2019). Modelling for insight: Does financial development improve environmental quality? *Energy Economics, 83*, 156–179. https://doi.org/10.1016/j.eneco.2019.06.025

Adedoyin, F. F., & Zakari, A. (2020). Energy consumption, economic expansion, and CO2 emission in the UK: The role of economic policy uncertainty. *Science of the Total Environment, 738*, 140014. https://doi.org/10.1016/j.scitotenv.2020.140014

Adeel-Farooq, R. M., Raji, J. O., & Adeleye, B. N. (2020). Economic growth and methane emission: testing the EKC hypothesis in ASEAN economies. *Management of Environmental Quality: An International Journal.*

Adhvaryu, A., Kala, N., & Nyshadham, A. (2014). Management and shocks to worker productivity: evidence from air pollution exposure in an Indian garment factory. *Unpublished working paper, University of Michigan.*

Aghion, P., Comin, D., Howitt, P., & Tecu, I. (2016). When does domestic savings matter for economic growth. *IMF Economic Review, 64*, 381–407. https://doi.org/10.1057/imfer.2015.41

Ahmed, M. M., & Shimada, K. (2019). The effect of renewable energy consumption on sustainable economic development: Evidence from emerging and developing economies. *Energies, 12*(15), 29–54. https://doi.org/10.3390/en12152954

Akbar, M., et al. (2021). The dynamic association between healthcare spending, CO2 emissions, and human development index in OECD countries: Evidence from panel VAR model. *Environment, Development and Sustainability, 23*(7), 10470–10489. https://doi.org/10.1007/s10668-020-01066-5

Ali, M., & Kirikkaleli, D. (2021). The asymmetric effect of renewable energy and trade on consumption-based CO2 emissions: The case of Italy. *Integrated Environmental Assessment and Management*. https://doi.org/10.1002/ieam.4516

Al-mulali, U., & Sab, C. N. B. C. (2012). The impact of energy consumption and CO2 emission on the economic and financial development in 19 selected countries. *Renewable and Sustainable Energy Reviews, 16*, 4365–4369. https://doi.org/10.1016/j.rser.2012.05.017

Al-Mulali, U., Sab, C. N. B., & Che, S. (2018). Electricity consumption, CO2 emission, and economic growth in the Middle East. *Energy Sources, Part b: Economics, Planning, and Policy, 13*(5), 257–263.

Alola, A. A., & Joshua, U. (2020). Carbon emission effect of energy transition and globalization: Inference from the low-, lower middle-, upper middle-, and high-income economies. *Environmental Science and Pollution Research, 27*, 38276–38286. https://doi.org/10.1007/s11356-020-09857-z

Álvarez-Herránz, A., Balsalobre, D., Cantos, J. M., & Shahbaz, M. (2017). Energy innovations-GHG emissions nexus: Fresh empirical evidence from OECD countries. *Energy Policy, 101*, 90–100. https://doi.org/10.1016/j.enpol.2016.11.030

Amar, A. B. (2021). Economic growth and environment in the United Kingdom: robust evidence using more than 250 years data. *Environmental Economics and Policy Studies*, 1.

Angelopoulos, K., Economides, G., & Philippopoulos, A. (2010). What is the best environmental policy? Taxes, permits and rules under economic and environmental uncertainty.

Antonakakis, N., et al. (2017). Energy consumption, CO2 emissions, and economic growth: An ethical dilemma. *Renewable and Sustainable Energy Reviews, 68*, 808–824. https://doi.org/10.1016/j.rser.2016.09.105

Apsimon, H., Amann, Mi., Åström, S., & Oxley, T. (2009). Synergies in addressing air quality and climate change. *Climate Policy, 9*, 669–680. https://doi.org/10.3763/cpol.2009.0678

Banday, U. J., & Aneja, R. (2019). Renewable and non-renewable energy consumption, economic growth and carbon emission in BRICS. *International Journal of Energy Sector Management, 14*(1), 248–260. https://doi.org/10.1108/IJESM-02-2019-0007

Ben Cheikh, N., & Ben Zaied, Y. (2021). A new look at carbon dioxide emissions in MENA countries. *Climatic Change*. https://doi.org/10.1007/s10584-021-03126-9

Ben Jebli, M., et al. (2020). Renewable energy, CO2 emissions and value added: Empirical evidence from countries with different income levels. *Structural Change and Economic Dynamics, 53*, 402–410. https://doi.org/10.1016/j.strueco.2019.12.009

Bhat, J. A. (2018). Renewable and non-renewable energy consumption impact on economic growth and CO2 emissions in five emerging market economies. *Environmental Science and Pollution Research, 25*, 35515–35530. https://doi.org/10.1007/s11356-018-3523-8

Bhattarai, K., Paudel, K. P., & Poudel, B. N. (2009). Searching for an environmental Kuznets curve in carbon dioxide pollutant in Latin American countries. *Journal of Agricultural and Applied Economics, 41*(1), 13–27. https://doi.org/10.1017/S1074070800002522

Bibi, F., & Jamil, M. (2021). Testing environment Kuznets curve (EKC) hypothesis in different regions. *Environmental Science and Pollution Research, 28*(11), 13581–13594.

Bilan, Y., Streimikiene, D., Vasylieva, T., Lyulyov, O., Pimonenko, T., & Pavlyk, A. (2019). Linking between renewable energy, CO2 emissions, and economic growth: Challenges for candidates and potential candidates for the EU membership. *Sustainability, 11*(6), 1528. https://doi.org/10.3390/su11061528

Bölük, G., & Mert, M. (2015). The renewable energy, growth and environmental Kuznets curve in Turkey: An ARDL approach. *Renewable and Sustainable Energy Reviews, 52*, 587–595.

Breitung, J. (2001). *The local power of some unit root tests for panel data*. Emerald Group Publishing Limited.

Breusch, T. S., & Pagan, A. R. (1980). The lagrange multiplier test and its applications to model specification in econometrics. *The Review of Economic Studies, 47*(1), 239–253. https://doi.org/10.2307/2297111

Bulus, G. C., & Koc, S. (2021). The effects of FDI and government expenditures on environmental pollution in Korea: The pollution haven hypothesis revisited. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-021-13462-z

Burney, J., & Ramanathan, V. (2014). Recent climate and air pollution impacts on Indian agriculture. *Proceedings of the National Academy of Sciences, 111*(46), 16319–16324.

Carlsson, F. and Lundström, S. (2001). "Political and Economic Freedom and the Environment: The Case of CO2 Emissions." Working Paper in Economics No. 29 Gothenburg University.

Carratù, M., Chiarini, B., D'Agostino, A., Marzano, E., & Regoli, A. (2019). Air pollution and public finance: Evidence for European countries. *Journal of Economic Studies, 46*(7), 1398–1417. https://doi.org/10.1108/JES-03-2019-0116

Cetin, M. A., & Bakirtas, I. (2020). The long-run environmental impacts of economic growth, financial development, and energy consumption: Evidence from emerging markets. *Energy and Environment, 31*(4), 634–655. https://doi.org/10.1177/0958305X19882373

Chandran, V. G., & Tang, C. F. (2013). The impacts of transport energy consumption, foreign direct investment and income on CO2 emissions in ASEAN-5 economies. *Renewable and Sustainable Energy Reviews, 24*, 445–453. https://doi.org/10.1016/j.rser.2013.03.054

Chen, Q., & Taylor, D. (2020). Economic development and pollution emissions in Singapore: Evidence in support of the Environmental Kuznets Curve hypothesis and its implications for regional sustainability. *Journal of Cleaner Production, 243*, 118637. https://doi.org/10.1016/j.jclepro.2019.118637

Choi, I. (2001). Unit root tests for panel data. *Journal of International Money and Finance, 20*(2), 249–272.

Christoforidis, T., & Katrakilidis, C. (2021). Does foreign direct investment matter for environmental degradation? Empirical Evidence from Central-Eastern European Countries. *Journal of the Knowledge Economy*. https://doi.org/10.1007/s13132-021-00820-y

Cialani, C. (2007). Economic growth and environmental quality: An econometric and a decomposition analysis. *Management of Environmental Quality: An International Journal*.

Clootens, N. (2017). Public debt, life expectancy, and the environment. *Environmental Modeling and Assessment, 22*(3), 267–278. https://doi.org/10.1007/s10666-016-9535-1

Cole, M. A. (2004). Economic growth and water use. *Applied Economics Letters, 11*(1), 1–4.

Dafermos, Y., Nikolaidi, M., & Galanis, G. (2018). Climate change, financial stability and monetary policy. *Ecological Economics, 152*, 219–234. https://doi.org/10.1016/j.ecolecon.2018.05.011

Dai, H., Toshihiko, M., Matsuoka, Y., & Fujimor, S. (2012). The impacts of China's household consumption expenditure patterns on energy demand and carbon emissions towards 2050. *Energy Policy, 50*, 736–750.

Danlami, A. H., et al. (2019). Energy production, carbon emissions and economic growth in lower-middle income countries. *International Journal of Social Economics, 46*(1), 97–115. https://doi.org/10.1108/IJSE-07-2017-0274

Dasgupta, S., Laplante, B., & Mamingi, N. (2001). Pollution and capital markets in developing countries. *Journal of Environmental Economics and Management, 42*(3), 310–335. https://doi.org/10.1016/j.enpol.2012.08.023

Dechezleprêtre, A., Rivers, N., & Stadler, B. (2019). The economic cost of air pollution: Evidence from Europe.

Demena, B. A., & Afesorgbor, S. K. (2020). The effect of FDI on environmental emissions: Evidence from a meta-analysis. *Energy Policy, 138*, 111192. https://doi.org/10.1016/j.enpol.2019.111192

Destek, M. A., Shahbaz, M., Okumus, I., Hammoudeh, S., & Sinha, A. (2020). The relationship between economic growth and carbon emissions in G-7 countries: Evidence from time-varying parameters with a long history. *Environmental Science and Pollution Research, 27*, 29100–29117.

Di Vita, G. (2008). Capital accumulation, interest rate, and the income–pollution pattern. A simple model. *Economic Modelling, 25*(2), 225–235. https://doi.org/10.1016/j.econmod.2007.04.017

Dinda, S., & Coondoo, D. (2006). Income and emission: A panel data-based cointegration analysis. *Ecological Economics, 57*, 167–181. https://doi.org/10.1016/j.ecolecon.2005.03.028

Dockery, D. W., Pope, C. A., Xu, X., Spengler, J. D., Ware, J. H., Fay, M. E., Ferris, B. G., Jr., & Speizer, F. E. (1993). An association between air pollution and mortality in six US cities. *New England Journal of Medicine, 329*(24), 1753–1759.

Dogan, E., & Inglesi-Lotz, R. (2020). The impact of economic structure to the environmental Kuznets curve (EKC) hypothesis: Evidence from European countries. *Environmental Science and Pollution Research, 27*(11), 12717–12724.

Dong, K. Y., et al. (2020a). How renewable energy consumption lower global CO2 emissions? Evidence from countries with different income levels. *World Economy, 43*(6), 1665–1698. https://doi.org/10.1111/twec.12898

Dong, K. Y., Hochman, G., & Timilsina, G. R. (2020b). Do drivers of Co2 emission growth alter overtime and by the stage of economic development? *Energy Policy*. https://doi.org/10.1016/j.enpol.2020.111420

Dong, K. Y., Jiang, H. D., Sun, R. J., & Dong, X. C. (2019). Driving forces and mitigation potential of global Co2 emissions from 1980 through 2030: Evidence from countries with different income levels. *Science of the Total Environment, 649*, 335–343. https://doi.org/10.1016/j.scitotenv.2018.08.326

Dutt, K. (2009). Governance, institutions and the environment-income relationship: A cross-country study. *Environment, Development and Sustainability, 11*, 705–723. https://doi.org/10.1007/s10668-007-9138-8

Ebenstein, A., Lavy, V., & Roth, S. (2016). The long-run economic consequences of high-stakes examinations: Evidence from transitory variation in pollution. *American Economic Journal: Applied Economics, 8*(4), 36–65.

Ehigiamusoe, K. U., & Lean, H. H. (2019). Effects of energy consumption, economic growth, and financial development on carbon emissions: Evidence from heterogeneous income groups. *Environmental Science and Pollution Research, 26*(22), 22611–22624. https://doi.org/10.1007/s11356-019-05309-5

Essandoh, O. K., et al. (2020). Linking international trade and foreign direct investment to CO2 emissions: Any differences between developed and developing countries? *Science of the Total Environment*. https://doi.org/10.1016/j.scitotenv.2019.136437

Fakher, H.-A., Abedi, Z., & Shaygani, B. (2018). Investigating the relationship between trade and financial openness with ecological footprint. *Economic Modeling, 11*(40), 49–67.

Fan, W., Li, L., Wang, F., & Li, D. (2020). Driving factors of CO2 emission inequality in China: The role of government expenditure. *China Economic Review, 64*, 101545. https://doi.org/10.1016/j.chieco.2020.101545

Fischer, C., & Heutel, G. (2013). Environmental macroeconomics: Environmental policy, business cycles, and directed technical change. *Annu. Rev. Resour. Econ., 5*(1), 197–210.

Fosten, J., et al. (2012). Dynamic misspecification in the environmental Kuznets curve: Evidence from CO2 and SO2 emissions in the United Kingdom. *Ecological Economics, 76*, 25–33. https://doi.org/10.1016/j.ecolecon.2012.01.023

Franklin, R. S., & Ruth, M. (2012). Growing up and cleaning up: The environmental Kuznets curve redux. *Applied Geography, 32*(1), 29–39. https://doi.org/10.1016/j.apgeog.2010.10.014

Friedl, B., & Getzner, M. (2003). Determinants of CO2 emissions in a small open economy. *Ecological Economics, 45*(1), 133–148. https://doi.org/10.1016/S0921-8009(03)00008-9

Galinato, G., & Islam, F. (2017). The challenge of addressing consumption pollutants with fiscal policy. *Environment and Development Economics, 22*(5), 624–647.

Gholipour, H. F., & Farzanegan, M. R. (2018). Institutions and the effectiveness of expenditures on environmental protection: Evidence from Middle Eastern countries. *Constitutional Political Economy, 29*, 20–39. https://doi.org/10.1007/s10602-017-9246-x

Giovanis, E. (2013). Environmental Kuznets curve: Evidence from the British household panel survey. *Economic Modelling, 30*, 602–611. https://doi.org/10.1016/j.econmod.2012.10.013

Girma, M. (1992). Macropolicy and the environment: A framework for analysis. *World Development, 20*, 531–540.

Godil, D. I., Sharif, A., Agha, H., & Jermsittiparsert, K. (2020). The dynamic nonlinear influence of ICT, financial development, and institutional quality on CO2 emission in Pakistan: New insights from QARDL approach. *Environmental Science and Pollution Research, 27*(19), 24190–24200.

Gok, A. (2020). The role of financial development on carbon emissions: A meta regression analysis. *Environmental Science and Pollution Research, 27*(11), 11618–11636. https://doi.org/10.1007/s11356-020-07641-7

Grabel, I. (1996). The contradictions of portfolio investment in the global economy. *World Development, 24*(11), 1761–1776. https://doi.org/10.1016/0305-750X(96)00068-X

Graff Zivin, J., & Neidell, M. (2012). The impact of pollution on worker productivity. *American Economic Review, 102*(7), 3652–3673.

Graff Zivin, J., & Neidell, M. (2013). Environment, health, and human capital. *Journal of Economic Literature, 51*(3), 689–730.

Grossman G, Krueger, A. (1991). "Environmental Impacts of a North American Free Trade Agreement". National Bureau of Economic Research Working Papers, https://doi.org/10.3386/w3914 accessed on 05 June 2020.

Halicioglu, F. (2009). An econometric study of CO2 emissions, energy consumption, income and foreign trade in Turkey. *Energy Policy, 37*(3), 1156–1164. https://doi.org/10.1016/j.enpol.2008.11.012

Halkos, G. E., & Gkampoura, E. C. (2021). Examining the linkages among carbon dioxide emissions, electricity production and economic growth in different income levels. *Energies*. https://doi.org/10.3390/en14061682

Halkos, G. E., & Paizanos, E. A. (2013). The effect of government expenditure on the environment: An empirical investigation. *Ecological Economics, 91*, 48–56. https://doi.org/10.1016/j.ecolecon.2013.04.002

Hall, P., & Soskice, D. (2001). *Varieties of capitalism: Institutional foundations of comparative advantage*. Oxford University Press.

Hamit-Haggar, M. (2012). Greenhouse gas emissions, energy consumption and economic growth: A panel cointegration analysis from Canadian industrial sector perspective. *Energy Economics, 34*(1), 358–364. https://doi.org/10.1016/j.eneco.2011.06.005

Hamilton, K., & Clemens, M. (1999). Genuine savings rates in developing countries. *World Bank Economic Review, 13*(2), 333–356.

Hansen, A. C., & Selte, H. K. (2000). Air pollution and sick-leaves. *Environmental and Resource Economics, 16*(1), 31–50.

He, F., Chang, K. C., Li, M., Li, X., & Li, F. (2020). Bootstrap ARDL test on the relationship among trade, FDI, and CO2 emissions: Based on the experience of BRICS countries. *Sustainability, 12*(3), 1060. https://doi.org/10.3390/su12031060

Heijdra, B. J., & Heijnen, P. (2013). Environmental Abatement and the Macroeconomy in the Presence of Ecological Thresholds. *Environmental and Resource Economics, 55*, 47–70.

Holden, S. T., Shiferaw, B., & Wik, M. (1998). Poverty, market imperfections and time preferences: Of relevance for environmental policy? *Environment and Development Economics*. https://doi.org/10.1017/S1355770X98000060

Hu, H., Xie, N., Fang, D. B., & Zhang, X. L. (2018). The role of renewable energy consumption and commercial services trade in carbon dioxide reduction: Evidence from 25 developing countries. *Applied Energy, 211*, 1229–1244. https://doi.org/10.1016/j.apenergy.2017.12.019

Hunjra, A. I., Tayachi, T., Chani, M. I., Verhoeven, P., & Mehmood, A. (2020). The moderating effect of institutional quality on the financial development and environmental quality nexus. *Sustainability, 12*(9), 3805. https://doi.org/10.3390/su12093805

Ibrahim, M., & Vo, X. V. (2021). Exploring the relationships among innovation, financial sector development and environmental pollution in selected industrialized countries. *Journal of Environmental Management*. https://doi.org/10.1016/j.jenvman.2021.112057

Im, K. S., Pesaran, M. H., & Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics, 115*(1), 53–74. https://doi.org/10.1016/S0304-4076(03)00092-7

IMF (2020a). "Global Debt Database", https://www.imf.org/en/Publications/WP/Issues/2018/05/14/Global-Debt-Database-Methodology-and-Sources-45838, accessed on 15 September 2020a.

IMF (2020b). "IMF Financial Development Index Database", https://data.imf.org/?sk=F8032E80-B36C-43B1-AC26-493C5B1CD33B, accessed on 10 December 2020b.

Islam, A. M., & López, R. E. (2015). Government Spending and Air Pollution in the US. *International Review of Environmental and Resource Economics, 8*(2), 139–189. https://doi.org/10.1561/101.00000068

Javid, M., & Sharif, F. (2016). Environmental Kuznets curve and financial development in Pakistan. *Renewable and Sustainable Energy Reviews, 54*, 406–414. https://doi.org/10.1016/j.rser.2015.10.019

Jayanthakumaran, K., Verma, R., & Liu, Y. (2012). CO2 emissions, energy consumption, trade and income: A comparative analysis of China and India. *Energy Policy, 42*, 450–460.

Jiang, M., Kim, E., & Woo, Y. (2020). The relationship between economic growth and air pollution—a regional comparison between China and South Korea. *International Journal of Environmental Research and Public Health, 17*(8), 2761.

Kampa, M., & Castanas, E. (2008). Human health effects of air pollution. *Environmental Pollution, 151*(2), 362–367.

Kao, C. (1999). Spurious regression and residual-based tests for cointegration in panel data. *Journal of Econometrics, 90*(1), 1–44. https://doi.org/10.1016/S0304-4076(98)00023-2

Khalil, S., & Inam, Z. (2006). Is trade good for environment? A unit root cointegration analysis. *The Pakistan Development Review, 45*(4), 1187–1196.

Khan, M., & Ozturk, I. (2021). Examining the direct and indirect effects of financial development on CO2 emissions for 88 developing countries. *Journal of Environmental Management, 293*, 112812.

Khaskheli, A., et al. (2021). Financial development, international trade, and environmental degradation: A nonlinear threshold model based on panel smooth transition regression. *Environmental Science and Pollution Research, 28*(21), 26449–26460. https://doi.org/10.1007/s11356-020-11912-8

Kivyiro, P., & Arminen, H. (2014). Carbon dioxide emissions, energy consumption, economic growth, and foreign direct investment: Causality analysis for Sub-Saharan Africa. *Energy, 74*, 595–606.

Klein, M., & Olivei, G. (1999). Capital account liberalisation, financial depth and economic growth. *Journal of International Money and Finance, 27*(6), 861–875. https://doi.org/10.1016/j.jimonfin.2008.05.002

Kuznets, S. (1955). Economic growth and income inequality. *The American Economic Review, 45*, 1–58.

Lanzi, E. (2016). The Economic Consequences of Outdoor Air Pollution. *Organization for Economic Cooperation and Development. Retrieved from* https://www.oecd.org/environment/indicators-modelling-outlooks/Policy-Highlights-Economic-consequences-of-outdoor-air-pollution-web.pdf.

Lau, L. S., et al. (2018). Role of institutional quality on environmental Kuznets Curve: A comparative study in developed and developing countries. *Advances in Pacific Basin Business, Economics and Finance, 6*, 223–247. https://doi.org/10.1108/S2514-465020180000006007

Lazăr, D., Minea, A., & Purcel, A. A. (2019). Pollution and economic growth: Evidence from Central and Eastern European countries. *Energy Economics, 81*, 1121–1131.

Levin, A., Lin, C.-F., & Chu, C.-S.J. (2002). Unit root tests in panel data: Asymptotic and finite-sample properties. *Journal of Econometrics, 108*(1), 1–24. https://doi.org/10.1016/S0304-4076(01)00098-7

Lieb, C. M. (2004). The environmental Kuznets curve and flow versus stock pollution: The neglect of future damages. *Environmental and Resource Economics, 29*(4), 483–506.

Liu, D. H. F., & Lipták, B. G. (2000). *Air pollution*. Boca Raton, Florida: Lewis publishers.

Liu, H., Liu, S., Xue, B., Lv, Z., Meng, Z., Yang, X., Xue, T., Yu, Q., & He, K. (2018). Ground-level ozone pollution and its health impacts in China. *Atmospheric Environment, 173*, 223–230.

López, R., & Palacios, A. (2014). Why has Europe become environmentally cleaner? Decomposing the roles of fiscal, trade and environmental policies. *Environmental and Resource Economics, 58*(1), 91–108.

Lv, Z. K., & Xu, T. (2019). Trade openness, urbanization and Co2 emissions: Dynamic panel data analysis of middle-income Countries. *Journal of International Trade and Economic Development, 28*(3), 317–330.

Maddala, G. S., & Wu, S. (1999). A comparative study of unit root tests with panel data and a new simple test. *Oxford Bulletin of Economics and Statistics, 61*, 631–652. https://doi.org/10.1111/1468-0084.0610S1631

Managi, S., & Jena, P. R. (2008). Environmental productivity and Kuznets Curve in India. *Ecological Economics, 65*(2), 432–440. https://doi.org/10.1016/j.ecolecon.2007.07.011

Marques, A. C., & Caetano, R. (2020). The impact of foreign direct investment on emission reduction targets: Evidence from high-and middle-income countries. *Structural Change and Economic Dynamics, 55*, 107–118. https://doi.org/10.1016/j.strueco.2020.08.005

Minlah, M. K., & Zhang, X. (2021). Testing for the existence of the environmental Kuznets Curve (EKC) for CO 2 emissions in Ghana: Evidence from the bootstrap rolling window Granger causality test. *Environmental Science and Pollution Research, 28*(2), 2119–2131.

Mitić, P., Kostic, A., Petrovic, E., & Cvetanovic, S. (2020). The Relationship between CO2 emissions, industry, services and gross fixed capital formation in the Balkan Countries. *Inzinerine Ekonomika-Engineering Economics, 31*(4), 425–436. https://doi.org/10.5755/j01.ee.31.4.24833

Moore, F. C. (2009). Climate change and air pollution: Exploring the synergies and potential for mitigation in industrializing countries. *Sustainability, 1*(1), 43–54.

Muhammad, B. (2019). Energy consumption, CO2 emissions and economic growth in developed, emerging and Middle East and North Africa countries. *Energy, 179*, 232–245. https://doi.org/10.1016/j.energy.2019.03.126

Mujtaba, A., Jena, P. K., & Mukhopadhyay, D. (2020). Determinants of Co(2)emissions in upper middle-income group countries: An empirical investigation. *Environmental Science and Pollution Research, 27*(30), 37745–37759. https://doi.org/10.1007/s11356-020-09803-z

Nasir, M. A., et al. (2021). Environmental degradation & role of financialisation, economic development, industrialisation and trade liberalisation. *Journal of Environmental Management, 277*, 111471. https://doi.org/10.1016/j.jenvman.2020.111471

Nasir, M. A., Huynh, T. L. D., & Tram, H. T. X. (2019). Role of financial development, economic growth and foreign direct investment in driving climate change: A case of emerging Asean. *Journal of Environmental Management, 242*, 131–141. https://doi.org/10.1016/j.jenvman.2019.03.112

Neog, Y., & Yadava, A. K. (2020). Nexus among CO2 emissions, remittances, and financial development: A NARDL approach for India. *Environmental Science and Pollution Research, 27*(35), 44470–44481.

Nguyen, T. T., et al. (2020). Role of information and communication technologies and innovation in driving carbon emissions and economic growth in selected G-20 countries. *Journal of Environmental Management, 261*, 110162. https://doi.org/10.1016/j.jenvman.2020.110162

Nugraha, A. T., & Osman, N. H. (2018). The environmental study on causality relationship among energy consumption, CO2 emissions, the value added of development sectors and household final consumption expenditure in Indonesia. *Ekoloji, 27*(106), 837–852.

Omri, A. (2013). CO2 emissions, energy consumption and economic growth nexus in MENA countries: Evidence from simultaneous equations models. *Energy Economics, 40*, 657–664.

Omri, A., Daly, S., Rault, C., & Chaibi, A. (2015). Financial development, environmental quality, trade and economic growth: What causes What in Mena Countries. *Energy Economics, 48*, 242–252.

Ongan, S., Isik, C., & Ozdemir, D. (2021). Economic growth and environmental degradation: Evidence from the US case environmental Kuznets curve hypothesis with application of decomposition. *Journal of Environmental Economics and Policy, 10*(1), 14–21. https://doi.org/10.1080/21606544.2020.1756419

Ozturk, I., & Acaravci, A. (2013). The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey. *Energy Economics, 36*, 262–267.

Palley, T. (2013). *Financialization: The economics of finance-capital domination*. Palgrave Macmillan.

Pata, U. K., & Aydin, M. (2020). Testing the EKC hypothesis for the top six hydropower energy-consuming countries: Evidence from Fourier Bootstrap ARDL procedure. *Journal of Cleaner Production, 264*, 121699.

Pedroni, P. (1999). Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and Statistics, 61*(S1), 653–670. https://doi.org/10.1111/1468-0084.0610s1653

Pedroni, P. (2004). Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. *Econometric Theory, 20*(3), 597–625.

Pesaran, M. H. (2004). "General diagnostic tests for cross-sectional dependence in panels. *Empirical Economics, 60*, 13–50. https://doi.org/10.17863/CAM.5113

Pesaran, M. H., Shin, Y., & Smith, R. P. (1999). Pooled mean group estimation of dynamic heterogeneous panels. *Journal of the American Statistical Association, 94*(446), 621–634. https://doi.org/10.2307/2670182

Pesaran, M. H., & Smith, R. (1995). Estimating long-run relationships from dynamic heterogenous panels. *Journal of Econometrics, 68*, 79–113. https://doi.org/10.1016/0304-4076(94)01644-F

Pesaran, M. H., Ullah, A., & Yamagata, T. (2008). A bias-adjusted lm test of error cross-section independence. *The Econometrics Journal, 11*(1), 105–127. https://doi.org/10.1111/j.1368-423X.2007.00227.x

Pham, N. T., et al. (2020). The impact of international trade on environmental quality: Implications for Law. *Asian Journal of Law and Economics*. https://doi.org/10.1515/ajle-2020-0001

Pozzer, A., Dominici, F., Haines, A., Witt, C., Münzel, T., & Lelieveld, J. (2020). Regional and global contributions of air pollution to risk of death from COVID-19. *Cardiovascular Research, 116*, 2247–2253.

Pradhan, A. K., Sachan, A., Sahu, U. K., & Mohindra, V. (2021). Do foreign direct investment inflows affect environmental degradation in BRICS nations? *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-021-15678-5

Rafaj, P., Kiesewetter, G., Gül, T., Schöpp, W., Cofala, J., Klimont, Z., Purohit, P., Heyes, C., Amann, M., & Borken-Kleefeld, J. (2018). Outlook for clean air in the context of sustainable development goals. *Global Environmental Change, 53*, 1–11.

Rahman, Z. U., & Ahmad, M. (2019). Modeling the relationship between gross capital formation and CO2 (a) symmetrically in the case of Pakistan: An empirical analysis through NARDL approach. *Environmental Science and Pollution Research, 26*(8), 8111–8124. https://doi.org/10.1007/s11356-019-04254-7

Reinhart, C. and Reinhart, V. (2009). "Capital flow bonanzas: an encompassing view of the past and present". NBER Macroeconomics Annual. Chicago: University of Chicago Press

Sadorsky, P. (2010). The impact of financial development on energy consumption in emerging economies. *Energy Policy, 38*(5), 2528–2535.

Salari, M., et al. (2021). The nexus between CO2 emissions, energy consumption, and economic growth in the US. *Economic Analysis and Policy, 69*, 182–194. https://doi.org/10.1016/j.eap.2020.12.007

Sarkodie, S. A., & Strezov, V. (2018). Empirical study of the environmental Kuznets curve and environmental sustainability curve hypothesis for Australia, China, Ghana and USA. *Journal of Cleaner Production, 201*, 98–110. https://doi.org/10.1016/j.jclepro.2018.08.039

Saxena, P., & Srivastava, A. (2020). *Air pollution and environmental health*. Springer.

Sephton, P., & Mann, J. (2016). Compelling evidence of an environmental Kuznets curve in the United Kingdom. *Environmental and Resource Economics, 64*(2), 301–315. https://doi.org/10.1007/s10640-014-9871-z

Sephton, P., & Mann, J. (2018). Gold and crude oil prices after the great moderation. *Energy Economics, 71*, 273–281. https://doi.org/10.1016/j.eneco.2018.02.022

Shafik, N. (1994). Economic development and environmental quality: An econometric analysis. *Oxford Economic Papers, 46*, 757–773. https://doi.org/10.1093/oep/46.Supplement_1.757

Shahbaz, M., et al. (2016). Financial development and environmental quality: The way forward. *Energy Policy, 98*, 353–364. https://doi.org/10.1016/j.enpol.2016.09.002

Shahbaz, M., & Lean, H. H. (2012). Does financial development increase energy consumption? The role of industrialization and urbanization in Tunisia. *Energy Policy, 40*, 473–479.

Shahbaz, M., Raghutla, C., Song, M., Zameer, H., & Jiao, Z. (2020). Public-private partnerships investment in energy as new determinant of CO2 emissions: The role of technological innovations in China. *Energy Economics, 86*, 104664. https://doi.org/10.1016/j.eneco.2020.104664

Shahbaz, M., Tiwari, A. K., & Nasir, M. (2013). The effects of financial development, economic growth, coal consumption and trade openness on CO2 emissions in South Africa. *Energy Policy, 61*, 1452–1459. https://doi.org/10.1016/j.enpol.2013.07.006

Shi, H., et al. (2020). Global difference in the relationships between tourism, economic growth, CO2 emissions, and primary energy consumption. *Current Issues in Tourism, 23*(9), 1122–1137. https://doi.org/10.1080/13683500.2019.1588864

Shikwambana, L., Mhangara, P., & Kganyago, M. (2021). Assessing the relationship between economic growth and emissions levels in South Africa between 1994 and 2019. *Sustainability, 13*(5), 2645.

Shoaib, H. M., et al. (2020). Impact of financial development on CO 2 emissions: A comparative analysis of developing countries (D 8) and developed countries (G 8). *Environmental Science and Pollution Research, 27*(11), 12461–12475. https://doi.org/10.1007/s11356-019-06680-z

Smulders, S. (2004). Economic growth, liberalization and the environment. *Encyclopedia of Energy, 2*, 53–64.

Solarin, S. A., Al-Mulali, U., Musah, I., & Ozturk, I. (2017). Investigating the pollution haven hypothesis in Ghana: An empirical investigation. *Energy, 124*, 706–719. https://doi.org/10.1016/j.energy.2017.02.089

Song, Y., Li, Z., Liu, J., Yang, T., Zhang, M., & Pang, J. (2021). The effect of environmental regulation on air quality in China: A natural experiment during the COVID-19 pandemic. *Atmospheric Pollution Research, 12*(4), 21–30.

Song, Y., Zhang, X., & Zhang, M. (2021). The influence of environmental regulation on industrial structure upgrading: Based on the strategic interaction behavior of environmental regulation among local governments. *Technological Forecasting and Social Change, 170*, 120930.

Soytas, U., & Sari, R. (2009). Energy consumption, economic growth, and carbon emissions: Challenges faced by an EU candidate member. *Ecological Economics, 68*, 1667–1675. https://doi.org/10.1016/j.ecolecon.2007.06.014

Stern, D. I. (2004). The rise and fall of the environmental Kuznets curve. *World Development, 32*, 1419–1439.

Tamazian, A., Chousa, J. P., & Vadlamannati, K. C. (2009). Does higher economic and financial development lead to environmental degradation: Evidence from Bric Countries. *Energy Policy, 37*, 246–253. https://doi.org/10.1016/j.enpol.2008.08.025

Tamazian, A., & Rao, B. B. (2010). Do economic, financial and institutional developments matter for environmental degradation? Evidence from transitional economies. *Energy Economics, 32*, 137–145. https://doi.org/10.1016/j.eneco.2009.04.004

Thampanya, N., et al. (2021). Carbon neutrality targets, optimal environmental management strategies and the role of financial development: New evidence incorporating non-linear effects and different income levels. *Journal of Environmental Management, 297*, 113352. https://doi.org/10.1016/j.jenvman.2021.113352

Ukaogo, P. O., Ewuzie, U., & Onwuka, C. V. (2020). Environmental pollution: causes, effects, and the remedies. In *Microorganisms for sustainable environment and health* (Vol. 21, pp. 419–429). Elsevier.

Ummalla, M., & Goyari, P. (2020). The impact of clean energy consumption on economic growth and CO2 emissions in BRICS countries: Does the environmental Kuznets curve exist? *Journal of Public Affairs*. https://doi.org/10.1002/pa.2126

UN (2021a). 'Why does air matter'. https://www.unep.org/explore-topics/air/why-does-air-matter

UN (2021b). 'Sustainable development goals'. https://sdgs.un.org/topics

UN (2021c). 'Actions on air quality'. https://wedocs.unep.org/bitstream/handle/20.500.11822/36694/AAQ_GSP_PRAP.pdf

UNEP (2018). UN environment assembly 3 implementation plan "Towards a Pollution-Free Planet". https://wedocs.unep.org/. Accessed 10 Sept 2021

UNEP (2021a). ‘Types of environmental pollution: Air’. https://www.unep.org/beatpollution/forms-pollution/air

UNEP (2021b). ‘Pollution action note’. https://www.unep.org/interactive/air-pollution-note/

Valodka, I., et al. (2020). Impact of the international trade on the EU clothing industry carbon emissions. *Engineering Economics, 31*(3), 314–322. https://doi.org/10.5755/j01.ee.31.3.25012

Vo, D. H., & Le, Q. T. T. (2019). CO2 emissions, energy consumption, and economic growth: New evidence in the ASEAN countries. *Journal of Risk and Financial Management, 12*(3), 145–159. https://doi.org/10.3390/jrfm12030145

Wang, S., Wang, H., & Sun, Q. (2020). The impact of foreign direct investment on environmental pollution in china: Corruption matters. *International Journal of Environmental Research and Public Health, 17*(18), 6477. https://doi.org/10.3390/ijerph17186477

Warford, J., Munasinghe, M, Cruz, W. (1997). *The Greening of Economic Policy Reforms Volume 1: Principles*. World Bank, Washington. https://doi.org/10.1596/0-8213-3477-8.

WHO (World Health Organization) (2020). “Coronavirus disease (COVID-19) outbreak situation. Coronavirus Dis outbreak Situat”. https://www.who.int/emergencies/diseases/novel-coronavirus-2019, accessed on 16 November 2020

WHO (2021). ‘Climate change and health’. https://www.who.int/teams/environment-climate-change-and-health/air-quality-and-health/health-impacts

World Economic Forum (2020). *Challenges and Opportunities in the Post-COVOC-19 World*. Geneva.

World Bank (2020). “World Development Indicators”, https://databank.worldbank.org/source/sustainable-energy-for-all/Type/TABLE/preview/on# , accessed on 27 March 2020.

Wu, R., Ma, T., Chen, D., & Zhang, W. (2021b). International trade, CO2 emissions, and re-examination of “Pollution Haven Hypothesis” in China. Environmental Science and Pollution Research, 1–15.

Wu, J. Y., et al. (2021a). Exploring the relationships among CO2 emissions, urbanization, economic growth, economic structure, energy consumption, and trade along the BRI based on income classification. *Energy Ecology and Environment, 6*(3), 213–231. https://doi.org/10.1007/s40974-020-00176-0

Wu, Y., Zhu, Q., & Zhu, B. (2018). Decoupling analysis of world economic growth and Co2 emissions: A study comparing developed and developing countries. *Journal of Cleaner Production, 190*, 94–103. https://doi.org/10.1016/j.jclepro.2018.04.139

Xie, Q., Wang, X., & Cong, X. (2020). How does foreign direct investment affect CO2 emissions in emerging countries? New findings from a nonlinear panel analysis. *Journal of Cleaner Production, 249*, 119422. https://doi.org/10.1016/j.jclepro.2019.119422

Xu, B., & Lin, B. (2016). Regional differences of pollution emissions in China: Contributing factors and mitigation strategies. *Journal of Cleaner Production, 112*, 1454–1463.

Yang, H., He, J., & Chen, S. (2015). The fragility of the environmental Kuznets curve: Revisiting the hypothesis with Chinese data via an “extreme bound analysis. *Ecological Economics, 109*, 41–58.

Zaman, K., & Moemen, M. A. E. (2017). Energy consumption, carbon dioxide emissions and economic development: Evaluating alternative and plausible environmental hypothesis for sustainable growth. *Renewable and Sustainable Energy Reviews, 74*, 1119–1130. https://doi.org/10.1016/j.rser.2017.02.072

Zhang, J. and Gangopadhyay, P. (2012). "The Janus-faced view of China’s economy: implications of trade for environment." Indian Journal of Asian Affairs: 99–107.

Zhang, C., & Zhao, W. (2014). Panel estimation for income inequality and CO2 emissions: A regional analysis in China. *Applied Energy, 136*, 382–392.

Zhang, L., & Gao, J. (2016). Exploring the effects of international tourism on China’s economic growth, energy consumption and environmental pollution: Evidence from a regional panel analysis. *Renewable and Sustainable Energy Reviews, 53*, 225–234.

Zhang, L., Wang, Q., & Zhang, M. (2021). Environmental regulation and CO2 emissions: based on strategic interaction of environmental governance. *Ecological Complexity, 45*, 100893.

Zhang, X. P., Zhang, H. N., & Yuan, J. H. (2019). Economic growth, energy consumption, and carbon emission Nexus: Fresh evidence from developing countries. *Environmental Science and Pollution Research, 26*(25), 26367–26380. https://doi.org/10.1007/s11356-019-05878-5

Zhang, Y. J. (2011). The impact of financial development on carbon emissions: An empirical analysis in China. *Energy Policy, 39*, 2197–2203. https://doi.org/10.1016/j.enpol.2011.02.026

Zhao, B., & Yang, W. (2020a). Does financial development influence CO2 emissions? A Chinese province-level study. *Energy, 200*, 117523.

Zhao, B., & Yang, W. (2020b). Does financial development influence CO2 emissions? A Chinese province-level study. *Energy, 200*, 117523. https://doi.org/10.1016/j.energy.2020.117523

Zhao, X., Zhang, X., & Shao, S. (2016). Decoupling CO2 emissions and industrial growth in China over 1993–2013: The role of investment. *Energy Economics, 60*, 275–292. https://doi.org/10.1016/j.eneco.2016.10.008

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