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The effects of spatial spillover of good governance and renewable energy on CO_2 emissions

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Abstract

This study examines the relationship between renewable energy, good governance, and CO_2 emissions using the Dynamic Spatial Durbin Model on data from 179 countries between 2002 and 2015. The study confirms the environmental Kuznets hypothesis and finds that while good governance has negative direct and long run effects on CO_2 emissions, its spillover effects on neighboring countries are significantly positive. This supports the pollution haven hypothesis, suggesting that improving governance in a country reduces domestic CO_2 emissions while increasing emissions in neighboring countries. The study emphasizes the need for a global approach to improving governance. The long run effects of renewable energy on CO_2 emissions are negative, indicating that the use of renewable energy in a country reduces CO_2 emissions in neighboring countries due to imitation and learning. These findings reveal the complex interplay between good governance and CO_2 emissions and highlight the importance of considering spillover effe cts in environmental policy decision-making.

Extended author information available on the last page of the article

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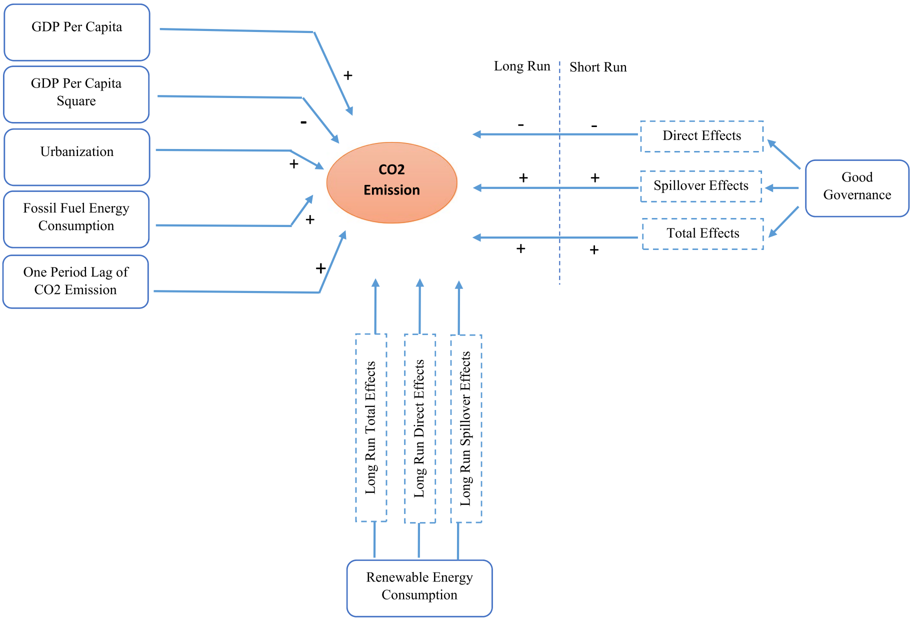
Graphical Abstract



Keywords Good governance · Renewable energy · CO_2 emissions · Pollution haven · Dynamic spatial durbin model

1 Introduction

Carbon dioxide (CO_2) is the most important anthropogenic greenhouse gas. It accounts for the most significant portion of air pollution and is widely accepted as a primary driver of global warming and climate change. Figure 1 illustrates the global trend of CO_2 emissions from 1750–2021. According to this figure, CO_2 emissions have increased six-fold since 1950. However, interregional data implies that CO_2 emissions do not have the same pattern in different regions worldwide. As Fig. 2 depicts, while CO_2 emissions have declined in Europe and the United States in the past decade, they have risen sharply in Asia.

Many studies have inquired about CO_2 emission determinants and regional trends in response to these stylized facts. The majority of studies on this issue concentrate on analyzing the role of GDP per capita in CO_2 emissions within the framework of the environmental Kuznets curve (EKC) (e.g., Al-Mulali et al., 2015; Apergis, 2016; Atici, 2009; Chiu, 2017; Ozturk et al., 2016; Stern, 2004). EKC theory indicates an inverse U-shaped relationship between economic development and environmental quality measured by CO_2 emissions. Many studies have also reported a strong relationship between variations in CO_2 emissions and nonrenewable energy (Long et al., 2015; Salahuddin et al., 2015), renewable energy (Adewuyi & Awodumi, 2017; Dogan & Seker, 2016a, 2016b; Mert et al., 2019), and total energy consumption (Ajmi et al., 2015; Dogan & Aslan, 2017; Heidari et al.,

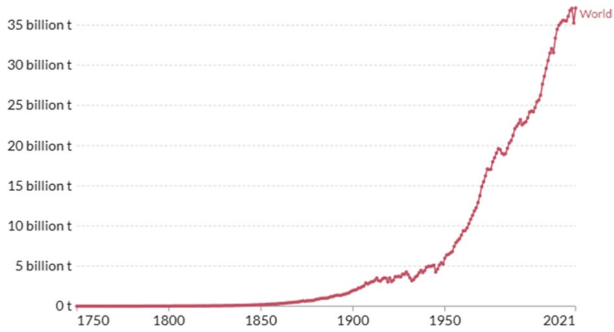


Fig. 1 Annual global CO_2 emissions https://ourworldindata.org/co2-emissions

2015; Shahbaz et al., 2016; Shahnazi & Shabani, 2019). Most of these studies indicated positive (negative) relationships between fossil fuel consumption (renewable energy consumption) and CO_2 emissions, respectively. The present study investigated the impact of renewable and non-renewable energy use on CO_2 emissions.

Recently some research investigated the effects of political institutions on CO_2 emissions (e.g., Lagreid & Povitkina, 2018; Immergut & Orlowski, 2013; Holmberg & Rothstein, 2012) and identified economic freedom as one of the variables that may directly or indirectly affect CO_2 emissions. One of the most significant political and economic institutions is good governance. Good governance refers to the way in which a government or other governing body manages public affairs and resources in a transparent, accountable, and effective manner. It involves a set of principles and practices that ensure the rule of law, participation, responsiveness, equity, inclusiveness, effectiveness, transparency, accountability, and strategic vision. Good governance can be of great importance in controlling CO_2 emissions, an issue that needs to be explored as a research gap. The present study aims to address the extant research gap by exploring the effect of good governance and its spillover effects on CO_2 emissions.

This paper has four main contributions to the literature. Firstly, it examines the effects of good governance on CO_2 emissions. Secondly, this paper investigates the spillover effects of good governance improvement in one country on CO_2 emissions in other countries. Thirdly, we investigate the spillover effects of renewable energy in one country on CO_2 emissions in other countries. Finally, the fourth contribution of this study is related to its econometric technique, the Dynamic Spatial Durbin Model. Since the amount of CO_2 emissions in each period depends on its previous periods, this time dependency should be considered to avoid any possible bias in the model. Elhorst (2014) confirmed that the result of dynamic non-spatial or spatial non-dynamic models in the same situation are likely to

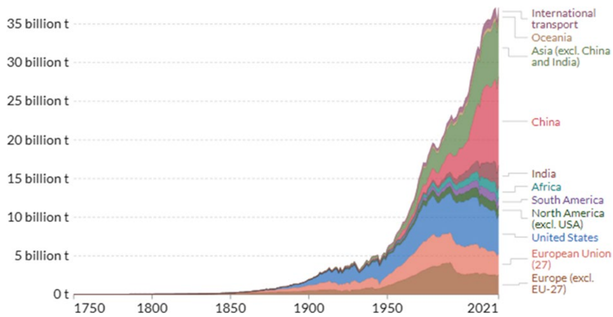


Fig. 2 Annual regional CO_2 emissions https://ourworldindata.org/co2-emissions

be biased. So, this study utilizes the Dynamic Spatial Durbin Model to consider CO_2 emissions dynamics and spillovers.

The remainder of this paper is organized as follows: In Sect. 2, the related literature is reviewed. Section 3 describes the data and methodology. In Sect. 4, empirical results are analyzed. Finally, the article ends with conclusion and policy implications in Sect. 5.

2 Theoretical foundations and hypothesis development

The theoretical foundations of this study are based on the environmental Kuznets curve (EKC) hypothesis, which suggests that economic development initially leads to an increase in pollution levels, but beyond a certain threshold, further economic development leads to a decrease in pollution levels. The EKC hypothesis has been widely studied in the literature, and it has been found that the relationship between economic development and pollution is not linear, but rather an inverted U-shaped curve. Grossman and Krueger (1991) contributed a theoretical framework in support of EKC. According to their research, economic development influences the environment in three ways: First, the scale effect, i.e., the increase in the scale of the economy, leads to more natural resource destruction and more emissions. Second, the composition effect addresses the structural change in production and the transition towards less polluting activities due to economic development. Finally, the technological effect indicates a shift toward new clean technologies due to more expenditure on research and development alongside economic development. So, while economic growth has devastating environmental effects in the short term, it will improve the environmental quality in the long run.

2.1 Good governance on CO_2 emissions

In addition to the EKC hypothesis, this study draws on the literature on good governance and its impact on CO_2 emissions. The governance or visible hand management, in some cases, has been more efficient than the invisible hand and market forces. Thus, the visible hand has replaced the invisible hand in some economic sectors (Chandler, 1993). Good governance refers to legal structures and social institutions supporting economic activities by enhancing the decision-making and implementation process (Weiss, 2000). It can also overcome market failures and alleviate environmental degradation by improving institutional quality, including property rights, contract enforcement, and collective action. Among various measures of governance quality, the Worldwide Governance Indicators (WGI) is the most relevant index with the broadest coverage. It provides information on more than 180 countries biannually since 1996 and annually after 2002. WGI consists of six sub-indicators, including voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law, and control of corruption. These sub-indicators assess different dimensions of a country's institutional framework that are vital to its economic performance. The following paragraphs introduce different dimensions of good governance and theoretically explain how governance quality can diminish environmental degradation within a country.

Various dimensions of good governance, including voice and accountability, political stability, regulatory quality, government effectiveness, rule of law, and control of corruption, also affect CO_2 emissions. The availability of effective mechanisms for citizens to express their voices, access to free media, and an independent press can empower citizens to monitor the government's environmental policies in countries with higher values of voice and accountability. Political instability can lead to neglect of environmental regulations, while a strong legal system and strict implementation of agreements can ensure private companies comply with environmental standards. Effective governance can intensify private sector investment, and strict law enforcement mechanisms can encourage firms to be more compatible with environmental guidelines. Corruption affects not only environmental degradation but also the rate of degradation, as high corruption levels can downplay the government's environmental concerns and postpone enacting and enforcing strict environmental laws.

The association between good governance and CO_2 emissions has been empirically well documented (See Table 2). The literature, however, only examines the consequences of governance within countries. They have completely neglected any spillover effects of governance improvement in one country on environmental performance in other regions. Considering these spillovers seems to rectify the current widely accepted presumptions about the environmental consequences of improved governance. As mentioned earlier, governance amelioration in a particular country would enhance its environmental quality. However, given the relative differences in governance quality among countries, it would be pretty plausible that reducing CO_2 emissions in a country that experienced governance improvement would coincide with pollution transmission to countries with lower governance levels. This transmission is new support for the so-called pollution haven hypothesis. According to the traditional pollution haven hypothesis, industries in developed countries are expected to be relocated to less developed areas with poor environmental regulations. In the governance explanation, however, pollution haven would occur owing to two sources: pollution haven due to poor quality of regulations and pollution haven due to the weak enforcement of environmental laws. Therefore, if the unpleasant spillover effect of a country's governance amelioration on CO_2 emissions in neighboring countries is significantly high, it may outweigh its pleasant domestic environmental impact. It implies the necessity of changing our viewpoints in improving governance from a country level to a global level.

Therefore, based on the effect of good governance and its spillover effects on CO_2 emissions, the following two hypotheses are presented.

Hypothesis 1 The effect of good governance on CO_2 emissions is negative.

Hypothesis 2 Good governance of a country affects the CO_2 emissions of neighboring countries.

2.2 Renewable energy and CO_2 emissions

Renewable energy is another factor that is expected to have an impact on CO_2 emissions. Renewable energy as clean energy has much lower CO_2 emissions than fossil fuels, so one of the most important ways to reduce emissions is to replace fossil fuels with renewable energy. Acording to International Energy Agency (2021) without replacing renewable energy and nuclear energy with fossil fuels, global CO_2 emissions in 2021 would have increased by 220 Mt higher.

Renewable energy production by neighboring countries affects the production of renewable energy and thus the CO_2 emissions. This spillover effect occurs through imitation of knowledge, technology, and the application of similar policies in neighboring countries. The knowledge spillover effect states that the development of new knowledge and technology has a positive external effect. In other words, the invention and exploitation of new technologies in renewable energy positively affect the knowledge of neighboring regions. Knowledge spillover occurs faster in geographical proximity for two reasons. First, knowledge dissemination, particularly innovations associated with a high degree of tacit knowledge, is on the rise in geographical proximity. Transmitting these innovations requires face-to-face interactions, which are more accessible in neighboring countries. Second, the success of technology in a comparable environment, such as neighboring countries, encourages the neighboring country to adopt that technology (Howells, 2002; Shahnazi & Shabani, 2020). Based on this, the other two hypotheses of the article are:

Hypothesis 3 The effect of renewable energy consumption on CO_2 emissions is negative.

Hypothesis 4 Renewable energy in a country affects the CO_2 emissions of neighboring countries.

2.3 CO_2 spillovers

This article also explains the effects of CO_2 spillovers from one country on neighboring countries. These spillover effects occur through three channels. The first channel is related to the distribution of CO_2 emissions along international value chains (Meng et al., 2017). In other words, the effects of spatial spillover occur when the production inputs of one country are produced in another. The more carbon-intensive the intermediate inputs are, the more CO_2 spillovers will exist. Since the CO_2 intensity of factory products is higher than service products, increasing preferences toward the consumption of factory products increases the spillover effect.

Furthermore, due to the positive effect of good governance on economic growth, enhancing the governance quality in a particular country increases production in that country. Subsequently, it raises the demand for related products and services along international value chains. So, governance improvement in a country is probably to increment the emissions of CO_2 in their partners alongside the global value chains.

The second channel is carbon emission spillover related to the pollution haven hypothesis that we re-explained earlier regarding governance theory. The third channel is related to competition and imitation effects. Competition between governments in creating capital and commercial attractions may lead to the choice of similar environmental standards in neighboring countries (Maddison, 2006). On the other hand, following the improvement of energy efficiency in a country, neighboring regions imitate their neighbors' energy-efficient technologies to maintain competitive power. Therefore, this spillover effect can lead to reduced emissions (Balado-Naves et al., 2018). Therefore, the fifth hypothesis of the article is as follows:

Hypothesis 5 CO_2 emissions of a country affect the CO_2 emissions of neighboring countries.

3 Literature review

There are many studies to determine CO_2 emissions factors. Following Kuznets's (1955) seminal work and Grossman and Krueger's influential article (1991), these studies analyze the relationship between GDP and environmental degradation. They have also considered a wide range of control variables, including fossil energy consumption (Jebli et al., 2016; Zhang et al., 2017a, 2017b), renewable energy consumption (Abdulqadir, 2021, 2022; Shahnazi & Shabani, 2021; Zoundi, 2017), trade (Essandoh et al., 2020; Ozatac et al., 2017) foreign direct investment (Tang & Tan, 2015; Zmami & Ben-Salha, 2020) urbanization (Zhu et al., 2017; Lv & Xu, 2019) industrialization (Dong et al., 2019) and human capital (Hao et al., 2021; Khan et al., 2021). Their findings based upon the GDP-CO_2 nexus can be classified into seven groups depending on their methodologies and samples. First: GDP positively affects CO_2 emissions (Apergis et al., 2018; Gill et al., 2018). Second: GDP affects CO_2 emissions negatively (Yaduma et al., 2015). Third: according to Kuznets' hypothesis, there is an inverted U-shaped relation between GDP and CO_2 emissions (Shabani & Shahnazi, 2019; Shahbaz et al., 2016). Fourth, the relationship between the variables mentioned above is U-shaped (Hosseini & Kaneko, 2013; Inglesi-Lotz & Dogan, 2018). Fifth: GDP and CO_2 relationships are N-shaped (Lorente & Álvarez-Herranz, 2016; Sinha & Sen, 2016). Sixth: GDP has an inverted N-shaped relationship with CO_2 emissions (Moghadam & Dehbashi, 2018). Seventh: There is no relationship between GDP and CO_2 emissions (Pal & Mitra, 2017; Rehman & Rashid, 2017).

According to our conceptual framework, in this paper, we evaluate the effects of good governance on CO_2 emissions, taking into account CO_2 emissions spillovers. The previous studies in tune with our article can be classified into two categories. The first category incorporates studies that analyzed the effects of good governance, and more generally institutions, on CO_2 emissions without considering its spillovers. In contrast, research in the second category focused on the above-mentioned relation, applying spatial regressions to analyze CO_2 emissions spillovers. Despite quite rare spatial studies in the latter category, non-spatial studies in the former are tremendous.

So, we can divide the extensive range of non-spatial studies again into two groups. In the first group, scholars based on their aims focused on some specific dimensions of institutions, for instance, political institutions and democracy (Koçak & Kızılkaya, 2020; Lægreid & Povitkina, 2018), economic freedom (Bhattacharya et al., 2017), and corruption (Buitenzorgy & Mol, 2011). As explained in Table 1, studies on the impact of institutional on environmental degradation found differing results. For instance, (Ali et al. 2019; Ali et al., 2020), using ICRG indicators, found adverse effects of institutional quality on CO_2 emissions. Bhattacharya et al. (2017), Koçak and Kızılkaya (2020) reported the same results utilizing the Economic Freedom Index. In contrast, Teng et al. (2021) approved positive relation between institutional quality and CO_2 emissions. The moderating effect of institutional quality on environmental degradation is the canonical point of another line of researches, including (Hassan Shah et al., 2019; Sarkodie et al., 2020; Tang et al., 2021). In a distinctive study, Lægreida and Povitkinac, 2018 found that the elasticity of CO_2 per capita to GDP decreases as GDP per capita rises in societies with non-corrupt democratic governments. Finally, some studies reported a two-way association between institutional quality and environmental quality.

The second group of non-spatial studies concentrates on good governance indicators as comprehensive indexes to measure governance quality. As reported in Table 2, these studies identified the relationship between good governance and CO_2 emissions

Table 1 Summary of studies on the effects of institutions on CO_2 emissions using the non-spatial model

References	Countries	Period	Methodology	Findings
Negative Effects of Institutions				
Ali et al. (2019)	47 DVC	2004–2010	GMM	$INS \overset{-}{\rightarrow} CO_2, EG \overset{+}{\rightarrow} CO_2, TO \overset{+}{\rightarrow} CO_2, UR \overset{+}{\rightarrow} CO_2, EC \overset{+}{\rightarrow} CO_2$
Ali et al. (2020)	OIC Countries	1990–2016	DCCE	$TO \overset{-}{\rightarrow} EQ, FDI \overset{-}{\rightarrow} EQ, UR \overset{-}{\rightarrow} EQ, INS \overset{+}{\rightarrow} EQ$
Bhattacharya et al., (2017)	85 DC and DVC	1991–2012	SYS- GMM	$REC \overset{+}{\rightarrow} EG, REC \overset{-}{\rightarrow} CO_2, INS \overset{+}{\rightarrow} EQ, INS \overset{-}{\rightarrow} CO_2$
Koçak and Kızılkaya (2020)	China		Cointegration	$GDP \overset{N}{\rightarrow} CO_2, IND \overset{+}{\rightarrow} CO_2, TO \overset{+}{\rightarrow} CO_2, PR \overset{-}{\rightarrow} CO_2, CL \overset{-}{\rightarrow} CO_2$
Positive Effects of Institutions				
Teng et al., (2021)	10 Countries	1985–2018	Pooled Mean Group	$REC \overset{-}{\rightarrow} CO_2, FDI \overset{+}{\rightarrow} CO_2, ELC \overset{+}{\rightarrow} CO_2, EG \overset{+}{\rightarrow} CO_2, INS \overset{+}{\rightarrow} CO_2$ $GLO \overset{-}{\rightarrow} CO_{2Longrun}, GLO \overset{+}{\rightarrow} CO_{2Shortrun}$
Moderating Effects of Institutions				
Hassan Shah et al., (2019)	101 Countries	1995–2017	FMOLS	$anFD \overset{+}{\rightarrow} CO_2, INS * FD \overset{-}{\rightarrow} CO_2, GDP \overset{\cap}{\rightarrow} CO_2$
Sarkodie (2020)	47 SSA	1990–2017		$REC \overset{-}{\rightarrow} CO_2, FDI \overset{+}{\rightarrow} CO_2, PGDP \overset{+}{\rightarrow} CO_2, PIQ \overset{+}{\rightarrow} CO_2$ $PGDP * PIQ * REC \overset{+}{\rightarrow} CO_2$
Tang et al., (2021)	114 Countries		GMM	$INS * FDI \overset{-}{\rightarrow} CO_2, INS * REC \overset{-}{\rightarrow} CO_2, GDP \overset{\cap}{\rightarrow} CO_2$ $HC * FDI \overset{-}{\rightarrow} CO_2, HC * REC \overset{-}{\rightarrow} CO_2,$
Two-Way Linkage				
Hassan et al., (2020)	Pakistan	1984–2016	ARDL	$anINS \overset{+}{\rightarrow} CO_2, INS \leftrightarrows CO_2, GDP \overset{\cap}{\rightarrow} CO_2$
Nair et al., (2021)	DVC		Granger Causality Test	$INS \leftrightarrows EG, INS \leftrightarrows CO_2, EG \leftrightarrows CO_2$
Other Findings				
Lægreida and Povitkinac (2018)	156 countries/140 Countries	1972–2014	Panel Data/ Cross Section	$PGDP \overset{-}{\rightarrow} EL.PCO_2.GDP_{DNCG}$
Leitão, 2010	85 countries	1981–2000	Panel Data	$GDP \overset{\cap}{\rightarrow} CO_2, COR \overset{+}{\rightarrow} GDP_{TurningPoint}$
Buitenzorgy and Mol (2011)	177 Countries	1990–2000		$anDEM \overset{\cap}{\rightarrow} DEF, DEF_{DTC} < DEF_{NDC,MDC}$

Table 1 (continued)

Variable: CL = Civil Liberty, CO_2 = CO_2, COR = Corruption, DEF = Deforestation, DEM = Democracy, EC = Energy Consumption, ELC = Electricity Consumption, EL.PCO_2. GDP = Per Capita CO_2 Elasticity of GDP, EG = Economic Growth, EQ = Environmental Quality, FD = Financial Development, FDI = Foreign Direct Investment, GDP = Gross Domestic Product, GDP2 = Square of GDP Emissions, GLO = Globalization, HC = Human Capital, IND = Industrialization, INS = Institutional Quality, KLR = Composition Effect Measured by Capital/Labor Ratio, PGDP = Per capita GDP, PIQ = Political Institutional Quality, PSR = Political Rights, REC = Renewable Energy Consumption, TO = Trade Openness, UR = Urbanization

Groups of Countries: DC = Developed Countries, DNCG = Democratic Non-Corrupt Governments, DTC = Democratic Transition Countries, DVC = Developing Countries, LDC = Less-Developed Countries, MDC = Mature Democratic Countries, NDC = Non-Democratic Countries, OIC = Organization of Islamic Cooperation, SSA = Sub-Saharan African

$\overset{+}{\rightarrow}$ = Positive Relationship, $\overset{-}{\rightarrow}$ = Negative Relationship, $\leftrightarrows$ = Two – Way Linkage, $\overset{Non}{\rightarrow}$ = No Effect, $\overset{U}{\rightarrow}$ = U Shape Relationship, $\overset{\cap}{\rightarrow}$ = U Inverse Relationship, $\overset{N}{\rightarrow}$ = N Shape Relationship, >= Is Grater Than, <= Is Less Than, turning Point = Kuznets Curve Turning Point

Table 2 Summary of studies on the effects of good governance on CO_2 emissions using the non-spatial model

References	Countries	Period	Methodology	Findings
Negative Effects of Good Governance				
Baloch and Wang (2019)	BRICS countries	1996–2017	Westerlund Panel Cointegration	$GG \overset{-}{\to} CO_2, GDP \overset{\cap}{\to} CO_2$
Cansino et al., (2019)	18 Latin American countries	1996–2013	Panel Data	$VA, PS, GE, RQ, RL, and CC \overset{-}{\to} CO_2, TP \overset{-}{\to} CO_2, FDI \overset{-}{\to} CO_2, TO \overset{-}{\to} CO_2$
Gani (2012)	99 Developing countries			$PS, RL, CC \overset{-}{\to} CO_2, GDP \overset{\cap}{\to} CO_2, TO \overset{+}{\to} CO_2, SIS \overset{+}{\to} CO_2$
Karakara and Osabuohien (2021)	12 West African countries		GMM	$GE and RQ \overset{-}{\to} CO_2$
Muhammad and Long, (2021)	65 countries	2000–2016	Panel Data	$PS \overset{-}{\to} CO_2, CC \overset{-}{\to} CO_2, RL \overset{-}{\to} CO_2, FDI \overset{+/-}{\to} CO_2, TO \overset{-}{\to} CO_{2LICandHIC}, TO \overset{+}{\to} CO_{2LMIC}$
Swain (2020)	58 countries	1996–2011	Fixed Effect/ GMM	$ISS \overset{+}{\to} CO_{2DVC}, ISS \overset{-}{\to} CO_{2DC}, CC \overset{-}{\to} CO_{2Non-OECD}$
Yasin et al. (2021)	59 LDC	1996–2016	GMM	$GG \overset{-}{\to} CO_2, FD \overset{+}{\to} CO_2, UR \overset{+}{\to} CO_2, KLR \overset{+}{\to} CO_2, FT \overset{-}{\to} CO_2, EC, GDP \overset{\cap}{\to} CO2$
Positive Effects of Good Governance				
Wu (2017)	167 countries	2000–2013	Panel Data	$VA \overset{+}{\to} PM2.5, PS \overset{+}{\to} PM2.5, GE \overset{+}{\to} PM2.5, CC \overset{+}{\to} PM2.5, EC \overset{+}{\to} PM2.5, POP \overset{+}{\to} PM2.5, GFC \overset{+}{\to} PM2.5, GDP \overset{\cap}{\to} CO_2$
Negative/Positive Effects of Good Governance				
Abid (2016)	25 Sub-Saharan African countries	1996–2010	GMM	$GDP \overset{+}{\to} CO_2, PS \overset{-}{\to} CO_2, GE \overset{-}{\to} CO_2, VA \overset{-}{\to} CO_2, CC \overset{-}{\to} CO_2, RQ \overset{+}{\to} CO_2, RL \overset{+}{\to} CO_2,$
Liu et al., (2020)	China, India, Japan Russia, and the USA	1996–2017	Panel Data	$GDP \overset{N}{\to} CO_2, VA \overset{-}{\to} CO_2, PS \overset{-}{\to} CO_2, GE \overset{-}{\to} CO_2, RQ \overset{+}{\to} CO_2, RL \overset{-}{\to} CO_2, CC \overset{-}{\to} CO_2,$
Sabir et al., (2020)	South Asian Region		Panel ARDL/ Granger Causality Test	$FDI \overset{+}{\to} CO_2, RL \overset{Non}{\to} CO_2, PS \overset{-}{\to} CO_2, CC \overset{+}{\to} CO_2, GDP \overset{\cap}{\to} CO_2$
Moderating Effects of Good Governance				
Afrifa et al., (2020)	29 emerging countries		Panel Data	$IT \overset{-}{\to} CO_2, PS * IT \overset{-}{\to} CO_2, GE * IT \overset{-}{\to} CO_2, RQ * IT \overset{-}{\to} CO_2, RL * IT \overset{-}{\to} CO_2, CC * IT \overset{-}{\to} CO_2$
Bakhsh et al., (2021)	40 Asian countries	1996–2016	GMM	$FDI \overset{+}{\to} CO_2, GG * FDI \overset{-}{\to} CO_2, TI * FDI \overset{-}{\to} CO_2$

Table 2 (continued)

References	Countries	Period	Methodology	Findings
Khan and Rana (2021)	41 Asian economies	1996 to 2015	Panel Cointegration and Panel VECM	$GDP \overset{+}{\to} CO_2, EC \overset{+}{\to} CO_2, TO \overset{+}{\to} CO_2, FDI \overset{+}{\to} CO_2, FD \overset{-}{\to} CO2, GG \overset{-}{\to} CO_2,$ $GG * GDP \overset{-}{\to} CO_2, GG * FDI \overset{-}{\to} CO_2, GG * TO \overset{-}{\to} CO_2$
Nguyen et al., (2018)	36 emerging economies	2002–2015	SYS-GMM	$TO \overset{+}{\to} CO_2, FDI \overset{+}{\to} CO_2, VA, PS, GE, RQ, RL, andCC \overset{+}{\to} CO_2,$ $GE * TO \overset{-}{\to} CO_2, RQ * TO \overset{-}{\to} CO_2, VA * TO \overset{-}{\to} CO_2, RL * TO \overset{-}{\to} CO_2$ $RQ * FDI \overset{-}{\to} CO_2, RL * FDI \overset{-}{\to} CO_2, CC * FDI \overset{-}{\to} CO_2,$
Omri and Bel Hadj (2020)	23 emerging economies	1996–2014	GMM	$FDI \overset{+}{\to} CO_2, PCO_2, CO_2EHandCO_2L, GG \overset{-}{\to} CO_2, PCO_2, CO_2EH, CO_2L,$ $TI \overset{-}{\to} CO_2, PCO_2, CO_2EH, CO_2L$ $FDI * PG \overset{-}{\to} CO_2, PCO_2, CO2EH, CO_2L$ $,FDI * IG \overset{-}{\to} CO_2, PCO_2, CO_2EH, CO_2LFDI * TI \overset{-}{\to} CO_2, PCO_2, CO_2L$
Omri and Bel Hadj (2020)	20 selected MENA economies	1996–2016	DOLS	$FD \overset{+}{\to} CO2, VA, PS, GE, RQ, RL, andCC \overset{-}{\to} CO_2, PGDP \overset{+}{\to} CO_2, EC \overset{+}{\to} CO_2, TO \overset{+}{\to} CO_2,$ $VA * FD \overset{-}{\to} CO_2, PS * FD \overset{-}{\to} CO_2, RL * FD \overset{-}{\to} CO_2, CC * FD \overset{-}{\to} CO_2$
Omri and Ben Mabrouk (2020)	20 selected MENA economies	1996–2014	Simultaneous-Equation Models	$PG \overset{+}{\to} SD, IG \overset{+}{\to} SD, HD \overset{-}{\to} EG,$ $PG * CO_2 \overset{-}{\to} EG, HD, IG * CO_2 \overset{-}{\to} EG, HDPG * EG \overset{-}{\to} CO_2IG * EG \overset{-}{\to} CO_2$
Wang et al., (2018)	BRICS countries	1996–2015	Partial OLS	$CC \overset{-}{\to} CO_2, CC * EG \overset{-}{\to} CO_2, CC * UR \overset{-}{\to} CO_2, CC * TO \overset{-}{\to} CO_2$
Other Findings				
Gok and Sodhi (2021)	115 countries	2000–2015	SYS-GMM	$GG \overset{+}{\to} EQ_{HIC}, GG \overset{-}{\to} EQ_{MIC}, GG \overset{-}{\to} EQ_{LIC},$
Mehmood et al., (2021)	Pakistan, India, and Bangladesh	1996Q1 to 2016Q4	ARDL	$GE * GDP \overset{-}{\to} CO_{2Ind}, GE * GDP \overset{-}{\to} CO_{2Bang}, GE * GDP \overset{+}{\to} CO_{2Pak}$ $GDP \overset{\cap}{\to} CO_{2Pak}, GDP \overset{\cap}{\to} CO_{2Bang}, IQ * GDP \overset{+}{\to} CO_{2Ind}$
Asongu and Odhiambo (2020)	44 Sub-Saharan African countries	2000–2013	GMM	$PG \overset{Non}{\to} CO_2, EG \overset{Non}{\to} CO_2, IG \overset{Non}{\to} CO_2$
Halkos and Tzeremes (2013)	G-20	1996–2010	Nonparametric Estimators	$GG \overset{NLIN}{\to} CO_2$
Wawrzyniak and Doryń (2020)	93 countries	1995–2014	GMM	$Forlowvaluesof GE: PGDP \overset{+}{\to} PCO_2,,$ $Forhighvaluesof GE: PGDP \overset{-}{\to} PCO_2PGDP \overset{\cap}{\to} PCO_2,$

Table 2 (continued)

Variable**:** CC = Control of Corruption, CO = Corruption, CO_2 = CO_2 Emissions, CO_2EH = CO_2 Emissions from Electricity and heat production, CO_2L = CO_2 emissions from the use of Liquid fuel, DEM = Democracy, EC = Energy Consumption, FD = Financial Development, EG = Economic Governance including GE and RQ, EGR = Economic Growth, EQ = Environmental Quality, FDI = Foreign Direct Investment, GDP = Gross Domestic Product, GDP2 = Square of GDP, GE = Government Effectiveness, GG = Good Governance, HD = Human Development, IG = Institutional Governance including RL and CC, INS = Institutional Quality, ISS = Informal Sector Size, IT = Innovative Technologies, PCO_2 = Per capita CO_2 emissions, PG = Political Governance including VA and PS, PGDP = Per capita GDP, PM2.5 = Particulate Matter 2.5, POP = Population Size, PS = Political Stability, RL = Rule of Law, RQ = Regulatory Quality, SD = Sustainable development, SIS = Size of Industrial Sector, TI = Technological Innovation, TO = Trade Openness, TP = Technological Progress, UR = Urbanization, VA = Voice and Accountability

Groups of Countries: LIC = Low Income Countries, HIC = High Income Countries, LMIC = Lower-Middle Income Countries, MIC = Middle Income Countries, OPC = Oil Producing countries, DVC = Developing Countries, DC = Developed Countries, Pak = Pakistan, Ind = India, Bang = Bangladesh

Results: $\overset{+}{\rightarrow}$ = Positive Relationship, $\overline{\rightarrow}$ = Negative Relationship, $\leftrightarrows$ = two – way linkage, $\overset{Non}{\rightarrow}$ = No Effect, $\overset{U}{\rightarrow}$ = U Shape Relationship, $\overset{\cap}{\rightarrow}$ = U Inverse Relationship,

$\overset{N}{\rightarrow}$ = Nshape Relationship $\overset{NLIN}{\rightarrow}$ = Non linear Relationship, S-R = Short Run, L-R = Long Run differently depending on their methodologies and samples. Some studies found positive effects of governance indicators on environmental quality. Notable scholars in this line are (Baloch & Wang, 2019; Cansino et al., 2019; Karakara & Osabuohien, 2021; Muhammad & Long, 2021; Yasin et al., 2021; and Swain, 2020). However, the reverse result has also been reported in the literature. For instance, Wu (2017) observed the inverse effects of good governance indicators on environmental quality in PM2.5 emissions. This distinctive finding would probably be due to the direct association between institutional quality and GDP. Other studies in this group have approved negative impacts on CO_2 emissions for some governance indicators and positive effects for others. In a sample of 25 Sub-Saharan African countries, Abid (2016) realized that CO_2 emissions rise along with improvement in the regulatory quality or the rule of law and fall with other governance indicators amelioration. Liu et al., (2020), for five large world economies, showed that all governance indicators except for regulatory quality are inversely associated with CO_2 emissions. Sabir et al. Reported a negative effect of political stability and a positive effect of controlling corruption and environmental degradation. However, the most frequent finding in inquiring about the governance-CO_2 emission nexus is related to studies considering good governance's moderating effects. They noticed that good governance plays a mediator role in alleviating economic growth's negative side effects using interaction terms. For instance, Bakhsh et al. (2021), Khan and Rana (2021), Nguyen et al. (2018), Omri and Ben Hadj (2020) affirmed the pollution haven hypothesis, they confirmed that good governance could limit foreign direct investment's damaging effects on environmental quality. Other studies explained how governance improvement could lessen other variables' unpleasant environmental effects, including trade openness (Khan and Rana, 2021; Wang et al., 2018), urbanization (Wang et al., 2018), and economic growth (Omri & Ben Mabrouk, 2020; Khan and Rana, 2021). In distinctive research, Gok and Sodhi (2021) found that good governance and CO_2 emissions are positively associated in high-income countries and inversely related in middle-income and low-income countries. Wawrzyniak and Doryń (2020) also realized a direct GDP-CO_2 nexus for low government effectiveness values and an inverse relation for high government effectiveness values.

Contrary to the broad range of non-spatial studies in the first category, spatial research in the second category is relatively scarce. Table 3 reviewed studies that analyzed the effects of institutional quality on environmental contaminants, taking into account CO_2 emissions spillovers. Most of the studies in this category addressed the narrow dimension of institutions. For instance, in Chinese provinces, Chen and Chang (2020) explained the impact of environmental regulation on limiting environmental contaminants, including wastewater, solid waste, and sulfur dioxide. In another study, Galinatoa and Chouinard (2018) focused on two distinctive political institutions, i.e., Policy Consistency (PC) and Government Tenure (GT). A sample of selected European countries approved those countries with more consistent policies and tenure governments with better environmental regulations. Some spatial studies concentrated on the corruption-CO_2 emission nexus in Chinese provinces. Wang et al. (2019) asserted the positive effect of regional corruption on environmental pollution. Wang et al. (2020) found that foreign direct investment and regional corruption interact positively affects environmental pollution. According to their research, this moderating effect in the eastern Chinese provinces is less than in the central and western provinces. However, Yang et al. (2020) identified a negative relationship between regional corruption and CO_2 emissions. Shahnazi and Shabani (2021) focused on economic freedom's effects on environmental quality. They demonstrated an inverted U-shaped association between the effects of economic and CO_2 emissions.

Table 3 Summary of studies on the effects of institutions on CO_2 emissions using the spatial model

References	Countries	Period	Methodology	Institutional Variables	Findings
Chen and Chang (2020)	30 Chinese provinces	2003–2017	SDM	Environmental Regulation	$ER \overset{-}{\to} WW, ER \overset{-}{\to} SW, ER \overset{+}{\to} SO_2, FDC \overset{\cap}{\to} EPI$
Galinatoa and Chouinard (2018)	Selected European Countries	1984–1996	SDM	Political Institutions	$PC \overset{+}{\to} ER_{Neighbor}, GT \overset{+}{\to} ER_{Neighbor}$
Wang et al. (2019)	Chinese provinces	1998–2017	SLM, SEM	Corruption	$RC \overset{+}{\to} EP, HE \overset{+}{\to} EP, RC * HE \overset{+}{\to} EP$
Wang et al. (2020)	30 Chinese provinces	1994–2015	SLM, SEM		$FDI \overset{+}{\to} EP, RC \overset{+}{\to} EP,$ $FDI * RC \overset{+}{\to} EP_{Eastern} < FDI * RC \overset{+}{\to} EP_{CentralandWestern}$
Yang et al. (2020)	30 Chinese provinces	2002–2013	Panel Data		$RLR \overset{-}{\to} CO_2, RC \overset{-}{\to} CO_2, PE \overset{+}{\to} CO_2, GDP \overset{\cap}{\to} CO_2$
Shahnazi and Shabani (2021)	EU countries	2000–2017		Economic Freedom	$REC \overset{-}{\to} CO_2, EF \overset{\cap}{\to} Co_2$
Ronaghi et al. (2020)	OPEC countries	2006–2015	SDM	Good Governance	$GG \overset{-}{\to} CO_2, GDPG \overset{+}{\to} Co_2, EX \overset{+}{\to} Co_2, IM \overset{-}{\to} Co_2,$ $FDI \overset{+}{\to} Co_2, INF \overset{-}{\to} Co_2, EMP \overset{+}{\to} Co_2,$

Variable: CO_2 = CO_2 Emission, EF = Economic Freedom, EMP = Employment, EP = Environmental Pollution, EPI = Environmental Pollution Indicators, ER = Environmental Regulations, EX = Export, FDC = Fiscal Decentralization, FDI = Foreign Direct Investment, GDP = Gross Domestic Product, GDP2 = Square of GDP, GDPG = GDP Growth, GG = Good Governance, GT = Government Tenure, HE = Hidden Economy, IM = Import, INF = Inflation Rate, PC = Policy Consistency, PE = Public Expenditure, SO2 = Sulfur Dioxide, S

W = Solid Waste, RC = Regional Corruption, REC = Renewable Energy Consumption, RLR = Regional Legal Regulation, WW = wastewater

Groups of Countries: Eastern = Eastern Provinces, Western = Western Provinces, Central = Central Provinces, Neighbor = Neighbor Countries, OPEC = Organization of the Petroleum Exporting Countries

To the best of our knowledge, Ronaghi et al. (2020) is the only study that considers good governance as a determinant of CO_2 emissions regarding its spillovers. Using spatial econometric techniques, they realized an inverse relationship between good governance and CO_2 emissions in OPEC countries.

Results: $\overset{+}{\rightarrow}$= PositiveRelationship, $\overset{-}{\rightarrow}$ = NegativeRelationship, $\overset{\cap}{\rightarrow}$= UInverseRelationship, $\overset{+}{\rightarrow}$= PositiveRelationship, $\overset{-}{\rightarrow}$ = NegativeRelationship, $\overset{\cap}{\rightarrow}$= UInverseRelationship,

As the review of previous studies shows, despite the broad range of research on the effects of good governance on CO_2 emissions, research gaps still exist regarding the dynamic effects of good governance on CO_2 emissions and their spillovers among countries. This article covers these research gaps using a dynamic spatial econometrics model. Our study contributes to the literature in 4 ways. The first contribution is to examine the effects of good governance on CO_2 emissions. The second contribution of the paper is to investigate the effects of a good governance spillover in one country on the CO_2 emissions of other countries. The third contribution is investigating the effects of renewable energy spillover in one country on the CO_2 emissions of other countries. So, the fourth contribution of this paper is applying the Dynamic SDM, a well-consistent method with the dynamic nature of CO_2 emissions.

4 The model, data, econometric methodology

4.1 Model

The empirical model investigates the spatial spillovers of good governance on CO_2 emissions and extends the environmental Kuznets curve. Alongside GDP per capita and its squares, two common parts of the environmental Kuznets hypothesis, our model incorporates the good governance index (Asongu & Odhiambo, 2020; Gani, 2012; Sarpong & Bein, 2020). The model also includes urbanization (Abbasi, et al., 2021; Mahmood, et al., 2023; Chen, et al., 2019a, 2019b), the shares of fossil fuel and clean energy in total energy consumption (Abokyi, et al., 2019; Hanif et al., 2019; Shahnazi & Shabani, 2021; Wang & Li, 2019; Zhang et al., 2017a, 2017b) as explanatory variables. The one period lag of the dependent variable is included in the model to control the CO_2 emission dynamism. This time dependency has roots in the prolonged effectiveness of energy policies, e.g., replacing fossil fuels with free carbon fuels, upgrading public transportation, moving toward environmentally friendly technologies, and improving energy transmission systems (Radmehr, et al., 2021; Zhou & Wang, 2018). So, the econometric model of this article is as follows:

$$\begin{aligned} LCO_{it} &= \alpha_0 + \rho LCO_{it-1} + \alpha_1 LGDP_{it} + \alpha_2 LGDP2_{it} + \alpha_3 LFEC_{it} \\ &\quad + \alpha_4 LNFEC_{it} + \alpha_5 LUR_{it} + \alpha_6 GG_{it} + \varepsilon_i + v_t + U_{it} \end{aligned} \tag{1}$$

where LCO_{it} and LCO_{it-1} stand for the logarithms of CO_2 emissions per capita and its one-period lag, respectively. $LGDP$ and $LGDP2$ respectively present the real GDP per capita and its square in logarithm form. $LFEC$ and $LNFEC$ denote logarithms of fossil fuel energy and non-fossil fuel shares of energy consumption, respectively. LUR is the logarithm of urbanization, and GG is the good governance index. ε_i is the spatial fixed effect, while v_t represents pethe riod fixed effect. Finally,U_{it} represents an error term. In the Equation above $\rho, \alpha_1, \dots, \alpha_5$ are the elasticities of CO_2 emissions concerning lagged values of CO_2 emissions, real GDP per capita, the square of real GDP per capita, the share of fossil fuel in energy consumption, the share of non-fossil fuel energy consumption, and urbanization.

α_6 is the coefficient of good governance. The environmental Kuznets hypothesis will be confirmed if $\alpha_1 > 0$ and $\alpha_2 < 0$. We expect the positive sign for α_3 and negative sign for α_4. The signs of α_5 and α_6 can be eighter positive or negative.

4.2 Data

Excluding countries whose data for at least one variable are not available, this study incorporates 179 countries. Appendix A1 presents the list of selected countries. This study covers the period between 2002 and 2015, considering two limitations. First, the Good Governance Index annual data has been available since 2002. Second, fossil and non-fossil energy consumption data are published until 2015. Table 4 describes the variables in detail.

This paper constructs a composite index of good governance from six World Bank good governance sub-indicators and principal components analysis (PCA). The PCA is a mathematical approach that creates new variables as linear combinations of the original variables. It reduces the data dimensions while preserving most of the dataset's variation (Ringnér, 2008).

Figures 3 and 4 compare our composite good governance index worldwide in 2002 and 2015. In 2002, Finland got the highest score in the good governance index while Somalia had the lowest rank. In 2015, New Zealand and Somalia had the highest and lowest governance index, respectively.

Figures 5 and 6 show the world's CO_2 emissions in 2002 and 2015. In 2002, the lowest carbon dioxide emitter country was Niue, and the highest CO_2 emitter country was the United States. In 2015, while the lowest carbon dioxide emission was still in Niue, the highest emissions happened in China.

4.3 Econometric methodology

4.3.1 Cross-sectional dependence

The Pesaran cross-sectional dependence (CD) test is a pre-estimation test to examine cross-sectional dependency among variables. The CD test is a practical way to select the appropriate unit root test in panel data. It relies on the following test statistic:

$$the\ CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{k=i+1}^{N}\hat{\rho}_{ik}\right) \tag{2}$$

where $\hat{\rho}_{ik}$ represents the estimate of the pairwise correlation of the residuals. N and T are the number of countries and years, respectively. The null hypothesis (H0) of the CD test implies cross-sectional independence (Pesaran, 2004).

4.3.2 Unit root

Some panel unit root tests do not consider cross-sectional dependence [e.g., such as Hadri (2000), Levin et al. (2002), and Im et al. (2003)]. So, they are not appropriate in the presence of cross-sectional dependency. In this case, augmented cross-sectional Im, Pesaran, and Shin (CIPS) and Hadri and Rao (2008) can be used. Considering the structural breaks in data is the advantage of the Hadri and Rao test over CIPS. This study comprises the

Table 4 Descriptions of variables

Variables	symbol	Unit	Data source	Obs	Mean	Std. Dev
CO_2 emissions	CO_2	CO_2 per capita	globalcarbonatlas.org	2506	45,658.67	394,027.3
Gross domestic product	GDP	constant 2010, US$ per capita	data.worldbank.org	2506	12,842.14	18,207.04
Share of fossil fuel energy consumption	FEC	Percent	data.worldbank.org	2506	66.027	29.885
Share of non-fossil fuel energy consumption (as proxy for renewable energy)	NFEC	Percent (NFEC = 100- FEC)	Calculation	2506	32.235	30.226
Urbanization	UR	Percent	data.worldbank.org	2506	55.532	23.154
Good governance	GG	This index was constructed using PCA method	info.worldbank.org	2506	-0.030	0.893

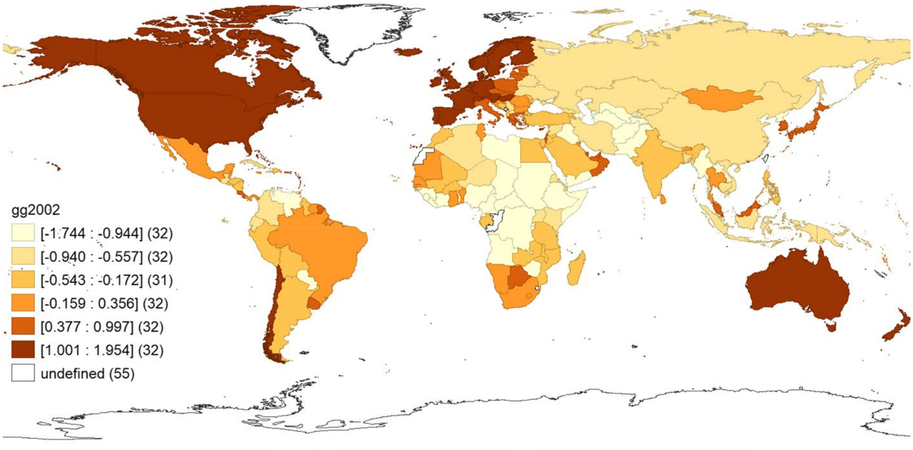


Fig. 3 Good governance index map, 2002

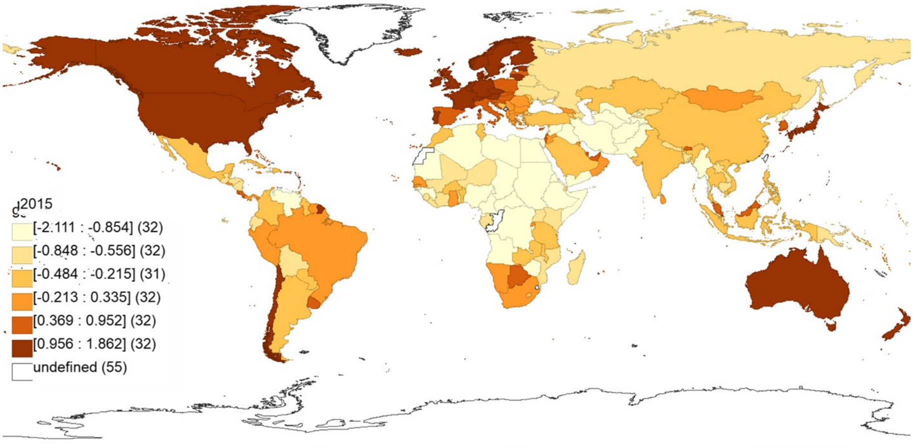


Fig. 4 Good governance index map, 2015

years between 2002 and 2015 and covers two shocks, the 2007–2008 financial crisis and the 2014 oil shock. So, the Hadri and Rao test is the most consistent test with our data. The following equation indicates Hadri and Rao's test statistic:

$$LM_{T,N,K}(w) = \frac{1}{N}\sum_{i=1}^{N}\frac{\sum_{t=1}^{T} S_{it}^{2}}{T^{2}\widehat{\sigma}_{\varepsilon,i}^{2}} \tag{3}$$

where S_{it} is the partial sum of residuals and $\widehat{\sigma}_{\varepsilon,i}^{2}$ is the long-run variance of ε_{it}. In the unit root test of Hadri and Rao, the H0 alludes to stationary (Hadri & Rao, 2008; Ranjbar et al., 2015).

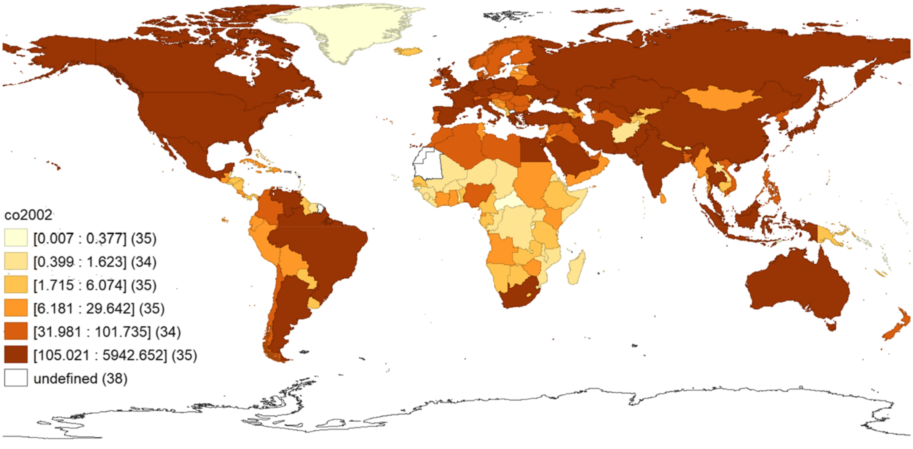


Fig. 5 CO_2 emissions map, 2002

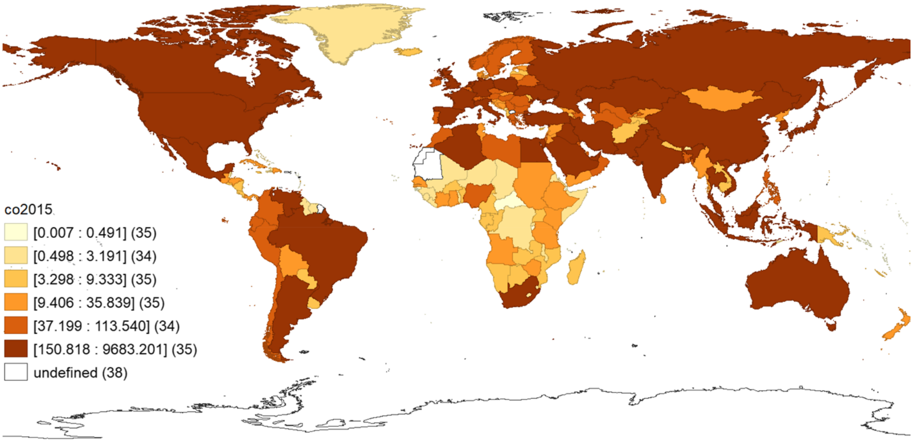


Fig. 6 CO_2 emissions map, 2015

4.3.3 Spatial correlation test

The existence of spatial correlation in data violates the assumption that observations are independent of one another. Various tests, including Getis-Ord General G, Global Moran's I, Global Geary GC, and Local Moran's are designed to test spatial correlation. However, the Global Moran's I and Local Moran's I are the most widely-used test. The Global Moran's I test relies on the following test statistic:

$$\text{the}I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(Y_i - \overline{Y})(Y_j - \overline{Y})}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(Y_i - \overline{Y})^2} \tag{4}$$

In the Equation above, Y_i stands for the variable in country $i,\overline{Y}$ indicates the average amount of variable, W_{ij} denotes the ith and jth elements of the spatial weights matrix (W), and n is the number of countries.W is a diagonal nonnegative matrix that describes the spatial arrangement of the neighboring countries. In this study, we apply the inverse-distance spatial weight matrix.

The Global Moran's I positive (or negative) value indicates the positive (or negative) spatial autocorrelation. The zero value of Moran's I statistic implies the random distribution of underlying variables among countries (Messner et al., 2000). The Local Moran's I test with the following test statistic is designed to determine local spatial correlations (Anselin, 1995);

$$I_i = \frac{n(Y_i - \overline{Y}) \sum_{i \neq j} W_{i,j}(Y_i - \overline{Y})}{\sum_{i=1}^{n} (Y_i - \overline{Y})^2} \tag{5}$$

4.3.4 Dynamic spatial model

The primarily spatial model was introduced by Cliff and Ord (1981), and then various theoretical extensions were developed by Anselin et al. (2006), Elhorst (2003), and Lee and Yu (2010). Equation (6) expresses the most general specification of spatial regression in vector form. Other specifications that are more straightforward can be derived from this general form. For a cross-section of countries at time t we can specify a spatial dynamic panel data model as follows:

$$Y_t = \tau Y_{t-1} + \delta WY_t + \eta WY_{t-1} + X_t\beta + WX_t\theta + v_t \tag{6}$$

$v_t = \gamma v_{t-1} + \rho W v_t + \mu + \lambda_t \iota_N + \varepsilon_t, \mu = \kappa W \mu + \xi$

In Eq. (6), Y_t represents an $N \times 1$ vector constituted of observations of dependent variables for every spatial unit for $i = 1, \ldots, N$ and$t = 1, \ldots, T$. The exogenous explanatory variables vector of the model is shown byX_t, which is an $N \times K$ matrix. The subscripts $(t-1)$ in all vectors and matrixes show the serially lagged values multiplied by$W$, representing the spatial weight matrix for the spatially lagged values. Defining a spatial weight matrix denoted by W can be a sound instrument to illustrate the spatial linkages between spatial units $i = 1, \ldots, N$. In Eq. (6), W denotes the spatial weight matrix. The coefficient of the lagged values of the dependent variable in time (Y_{t-1}), the coefficient of the lagged values of the dependent variable in space (WY_t), and the lagged value of the dependent variable in time and space (WY_{t-1}) are denoted byτ, andη, respectively. β, θ indicate the coefficients of the exogenous independent variables. Finally,v_t,ρ, and γ uusedfor the disturbance term, serial and spatial autocorrelation coefficients, respectively. The disturbance term is assumed to be serially and spatially correlated in the model (Elhorst, 2012). Moreover, spatial dynamic panel data models were classified into four main categories, including dynamic spatial autocorrelation (SAC) model$(\theta = 0)$, dynamic spatial Durbin model (SDM)$(\rho = \kappa = \gamma = 0)$, dynamic spatial lag model (SAR)$(\rho = \kappa = \theta = \gamma = 0)$, and dynamic spatial error model (SEM)$(\eta = \delta = \theta = 0)$. (Belotti et al., 2017).

To select the appropriate model, Wald test spatial lag and Wald test spatial error was used. The H0 of the Wald test spatial lag is $\theta = 0$; if the H0 is rejected, the SAR model is an appropriate model. In Wald test spatial error, the H0 is $\theta + \eta\delta = 0$. If the H0 of this test is rejected, the SEM model is appropriate. If the H0 of both tests is not rejected, the appropriate model is SAC, and if the H0 of both models is rejected, the appropriate model is the

SDM model. In this paper, the appropriate model is the dynamic SDM model, which is as follows:

$$Y_t = \tau Y_{t-1} + \delta W Y_t + \eta W Y_{t-1} + X_t \beta + W X_t \theta + \nu_t \tag{7}$$

As it was shown in Eq. 7, X_t and WX_t are in the model, and the coefficients include spatial interaction effects (Tong et al., 2013). We used LeSage and Pace (2009) method to decompose total effect into direct and indirect effects. To show direct, indirect, and total effect, Eq. 7 can be rewritten as follow:

$$\begin{aligned} ((1-\tau)I - (\delta+\eta)W)Y_t &= \alpha I + \left[X1_t \ X2_t \ X3_t \ \ldots Xn_t\right]\begin{bmatrix}\beta_1\\ \beta_2\\ \beta_3\\ \cdots\\ \beta_n\end{bmatrix} \\ &+ W\left[X1_t \ X2_t \ X3_t \ \ldots Xn_t\right]\begin{bmatrix}\theta_1\\ \theta_2\\ \theta_3\\ \theta_4\\ \theta_5\end{bmatrix} + \mu + \lambda_t I + u_t \end{aligned} \tag{8}$$

So,

$$\begin{aligned} Y_t &= ((1-\tau)I - (\delta+\eta)W)^{-1}\alpha I + ((1-\tau)I - (\delta+\eta)W)^{-1} \\ &\times\left(\left[X1_t \ X2_t \ X3_t \ \ldots Xn_t\right]\begin{bmatrix}\beta_1\\ \beta_2\\ \beta_3\\ \cdots\\ \beta_n\end{bmatrix} + W\left[X1_t \ X2_t \ X3_t \ \ldots Xn_t\right]\begin{bmatrix}\theta_1\\ \theta_2\\ \theta_3\\ \theta_4\\ \theta_5\end{bmatrix}\right) \\ &+((1-\tau)I - (\rho+\vartheta)W)^{-1}[\mu + \lambda_{tt} I + u_t] \end{aligned} \tag{9}$$

The partial derivatives of the dependent variable concerning X1 in countries $i = 1, \ldots, N$ can be expressed as follow:

$$\left[\frac{\partial Y}{\partial X1_1} \cdots \frac{\partial Y}{\partial X1_N}\right] = ((1-\tau)I - (\delta+\eta)W)^{-1}\begin{bmatrix}\beta_1 \ W_{1,2}\,\theta_1 \cdots W_{1,N-1}\theta_1 \ W_{1,N}\theta_1\\ W_{2,1}\theta_1 \ \beta_1 \cdots W_{2,N-1}\theta_1 \ W_{2,M}\theta_1\\ \cdots\cdots\cdots\cdots\\ W_{N,1}\theta_1 \ W_{N,2}\theta_1 \ \ldots \ W_{N,N-1}\theta_1 \ \beta_1\end{bmatrix} \tag{10}$$

The short-run and long-run direct, indirect (or spillover) effects of X1 are presented in Table 5.

5 Empirical results

In this study, we used Pesaran's CD test (2004) to check cross-sectional dependence. The H0 of this test represents cross-section independence. Table 6 shows the variables are cross-sectional dependent as the p-values are less than 1%.

Table 5 Direct and indirect effect of dynamic SDM model

Short-run			Long-run		
Direct effect	Indirect effect	Total effect	Direct effect	Indirect effect	Total effect
$\{(I-\delta W)^{-1} * (\beta_1 I+\theta_1 W)\}^{\overline{A}}$	$\{(I-\delta W)^{-1} * (\beta_1 I+\theta_1 W)\}^{\overline{offA}}$	$\{(I-\delta W)^{-1} * (\beta_1 I+\theta_1 W)\}^{\overline{sumA}}$	$\{((1-\tau)I-(\delta+\eta)W)^{-1} * (\beta_1 I+\theta_1 W)\}^{\overline{A}}$	$\{((1-\tau)I-(\delta+\eta)W)^{-1} * (\beta_1 I+\theta_1 W)\}^{\overline{offA}}$	$\{((1-\tau)I-(\delta+\eta)W)^{-1} * (\beta_1 I+\theta_1 W)\}^{\overline{sumA}}$

The superscript $\overline{A}$ is the operator that calculates the average of the diagonal elements of matrix A

The superscript $\overline{off\,A}$ is the operator that calculates the average of either the row or the column sums of the off-diagonal elements of matrix A

The superscript $\overline{sum\,A}$ is the operator that calculates the average of all elements of matrix A

Table 6 The results of Pesaran's CD test

Variable	Statistic	*p*-values
LCO_2	31.84	0.000
LGDP	246.49	0.000
GG	6.75	0.000
LFEC	51.38	0.000
LNFEC	52.43	0.000
LUR	270.03	0.000

Table 7 Hadri and Rao's (2008) unit root tests

Variable	statistics	*p*-values	critical value		
			90%	95%	99%
LCO_2	0.223	1.000	3.678	4.571	6.598
LGDP	0.296	1.000	6.864	10.232	15.854
GG	0.208	1.000	6.334	7.713	11.003
LFEC	0.292	1.000	8.157	10.016	15.825
LNFEC	0.282	1.000	5.200	6.121	7.102
LUR	0.195	1.000	4.678	5.963	6.975

Table 8 Global Moran's I statistics for corruption

Year	Moran's I value	*p*-value
2002	0.166	0.014
2003	0.168	0.010
2004	0.162	0.016
2005	0.153	0.020
2006	0.161	0.016
2007	0.153	0.020
2008	0.150	0.024
2009	0.151	0.022
2010	0.149	0.024
2011	0.161	0.016
2012	0.170	0.010
2013	0.170	0.010
2014	0.167	0.010
2015	0.144	0.028

The H0 is no spatial dependence

Table 7 reports the results of the Hadri and Rao (2008) unit root test. In this test, the H0 indicates the stationary of the variables. As Table 7 illustrates, there is no ground to reject the H0, and all the variables are stationary.

To investigate the spatial autocorrelation of the dependent variable, i.e., CO_2 emissions, we applied the Global and Local Moran's I statistic tests. According to Global Moran's I statistic (1950), presented in Table 8, there is a positive and significant correlation

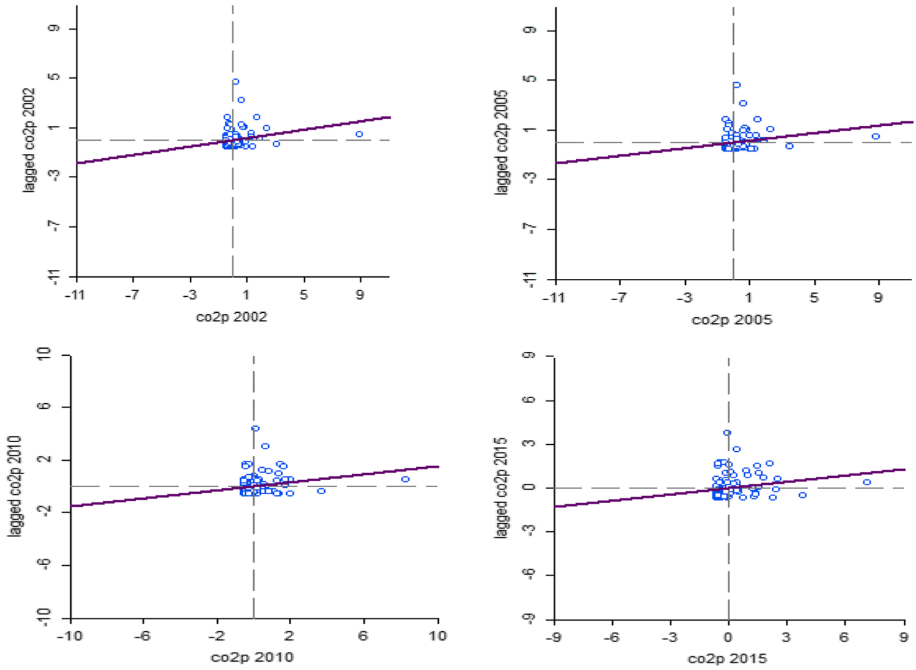


Fig. 7 Scatter plots of Moran's I values for 2002, 2005, 2010, and 2015

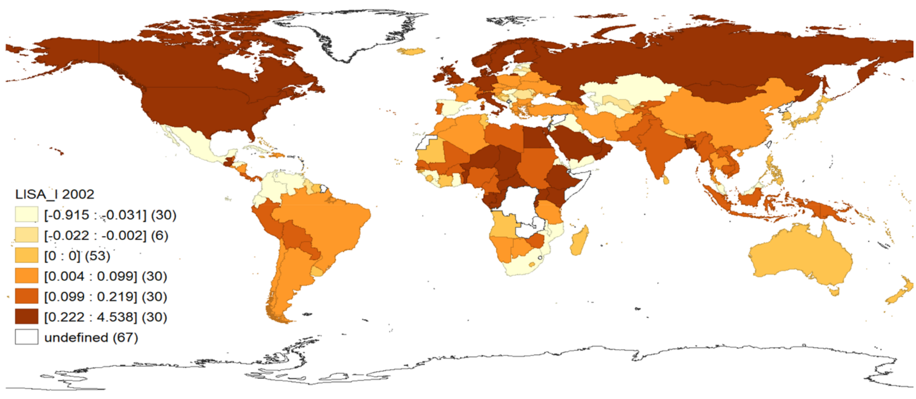


Fig. 8 Local Moran's I statistic of CO_2 emissions in 2002

between countries' CO_2 emissions. Therefore, countries with high (low) CO_2 emissions are neighbors.

Figure 7 compares Moran's I values scatter plots for 2002, 2005, 2010, and 2015. As depicted in all four panels, the majority of countries are located in Quarters I and III, implying a positive spatial correlation. We also apply the Local Moran's I statistic test presented by Anselin (1995) to examine the dependence of each country's CO_2 emissions on its neighbors. Figures 8 and 9 display the results of the Local Moran's I statistic test for

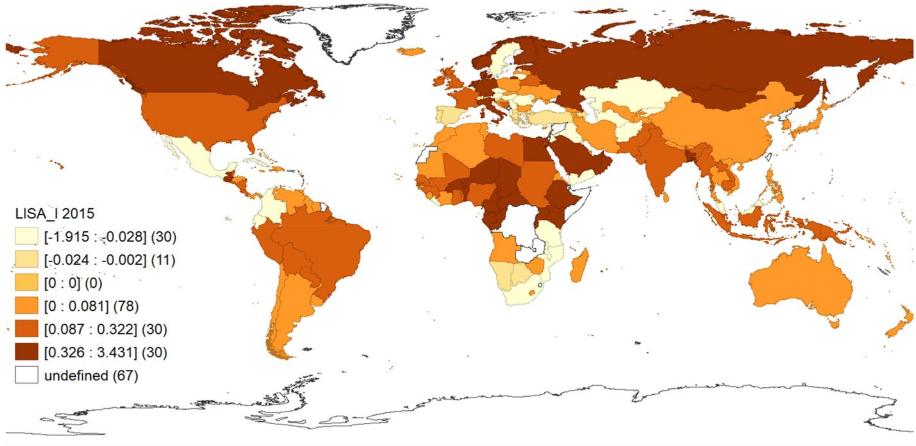


Fig. 9 Local Moran's I statistic of CO_2 emissions in 2015

the years 2002 and 2015. According to the results, 90 countries out of 179 had a positive CO_2 emissions correlation in 2002. The between neighbors' dependencies were even more intense in 2015, so that 138 countries of the 179 experienced a positive correlation in CO_2 emissions. Therefore, the high CO_2 emitter countries are located alongside each other, and the nations with low CO_2 emissions are also neighbors. This finding is consistent with (Lv & Li, 2021; Ning & Wang, 2018; Shahnazi & Shabani, 2021).

In order to identify the appropriate model, with a similar methodology to Elhorst's (2014), we estimated three different non-spatial regressions, including pooled estimation, spatial fixed effects, and time-period fixed effects. Table 9 reports the results of these estimations as well as the likelihood ratio (LR) test results. The LR test rejects the H0, implying non-significance of spatial fixed effects, at 1% (42.87, $p<0.01$). However, it does not reject the equivalent hypothesis, of non-significance of time-fixed effects (23.76, $p=1.00$). So, the appropriate model for estimation have to include spatial fixed effects.

Table 9 also incorporates the Lagrange multiplier (LM) test and robust LM test results. These two tests determine whether spatial lag or error should be considered in the model. The H0 of the LM test suggests a non-spatial model. As shown in Table 9, the H0 of LM-lag, LM-error, robust LM-lag, and robust LM-error are rejected in the pooled and spatial fixed effect models. Also, the H0 of LM-lag, robust LM-lag, and robust LM-error are also rejected in the time-period fixed effects model. So, the LM tests approve that spatial models are more suitable in comparison with non-spatial ones. In the Hausman test, summarized in Table 9, the H0 of random effects is also rejected.

Table 10 presents the results of SEM, SAR, SDM, Dynamic SAR, and Dynamic SDM models. We utilized Wald spatial lag and Wald spatial error tests to identify the most suitable model among SAR, SEM, and SDM. The H0 of the Wald test spatial lag is that SDM can be reduced to SAR. According to the results presented in Table 10, SDM is a more proper model than SAR, as the H0 is rejected at 1%. The results also reflect the rejection of the H0 of the Wald test spatial error, implying that the SDM can be summarized as the SEM. Therefore, the proper model both in static and dynamic estimation is the SDM.

Pollution control policies often confront some resistance to approval and long delays in implementation. Furthermore, these policies can only be effective in the long run, even if

Table 9 Estimation results without spatial interaction

Varibale	Pooled estimation		Spatial fixed effects		Time-period fixed effects	
	Coefficient	*t*-stat	coefficient	*t*-stat	coefficient	*t*-stat
LGDP	4.204***	13.51	1.371***	8.02	4.212***	13.49
LGDP2	−0.530***	−12.32	−0.145***	−6.18	−0.530***	−12.30
GG	0.228***	6.67	−0.004*	−1.64	0.227***	6.60
LFEC	0.318***	4.17	0.441***	12.58	0.318***	4.16
LNFEC	0.062**	2.05	−0.061***	−6.34	0.062**	2.06
LUR	0.805***	8.33	0.849***	8.53	0.807***	8.31
Constant	−6.816***	-11.98	−2.397***	-8.26	−6.830***	-11.91
R^2	0.274		0.994		0.274	
F-statistic	157.34***		2244.13***		49.47***	
Hausman test			957.11***		17.04*	
LR test			1680.16***		0.04	
LM spatial lag (LM lag)	133.590***		130.288***		137.726***	
LM spatial error (LM error)	5.095**		4.017***		2.384	
Robust LM spatial lag	140.705***		137.412***		157.522***	
Robust LM spatial error	26.921***		25. 301***		22.181***	

***,** and * denote statistical significance at the 0.01, 0.05 and 0.10 levels, respectively

implemented. Therefore, CO_2 emissions are lag-dependent variables, and neglecting this time dependency can lead to inaccurate estimations. In this paper, we applied Dynamic SDM to avoid any possible bias.

According to the results of dynamic SDM estimation presented in Table 10, the CO_2 emission has a significant positive association with its one-period lag. This result is consistent with (Shahnazi & Shabani, 2019, 2021; Zhou & Wang, 2018). So, CO_2 emissions in each country will rise by 1.39% in reflection to one percent increase in the previous period CO_2 emissions. The spatial lag (W * LCO_2) also has statistically significant positive effects on CO_2 emissions, implying that the amount of CO_2 pollution in a particular country is influenced positively by its neighbors' CO_2 emissions. Based on the estimation results, CO_2 emissions in each country will increase by 0.299% due to a one percent CO_2 emission increment in neighboring countries. These spillovers, as mentioned in the introduction, can be explained based on three channels. The first channel is related to countries' linkages along international value chains. The second channel focus on the pollution haven theory argues that businesses tend to reduce their costs through investing in countries with lower environmental standards. As a result, investments shift from developed countries with high environmental governance to developing countries with poor environmental governance. Finally, the third channel is associated with competition and imitation effects. These findings are consistent with You and Lv (2018), Kacprzyk and Kuchta (2020), Dong et al. (2018)

The GDP and GDP square coefficients, both in logarithm forms, are positive and negative, respectively, and significant at 1%. Therefore, CO_2 emissions and GDP are inverted U-shaped. This finding confirms the Kuznets environmental curve hypothesis. As Kuznets declared, while in the early stages of economic development, CO_2 emissions will increase due to rapid urbanization and industrialization, it will fall in the following stages as a result

Table 10 The estimation results of spatial models

Variables	Static Model						Dynamic Model			
	SEM		SAR		SDM		Dynamic-SAR		Dynamic-SDM	
	coefficient	*t*-stat	coefficient	*t*-stat	coefficient	*t*-stat	coefficient	*t*-stat	coefficient	*t*-stat
$LCO_2(-1)$							0.756***	5.64	1.390***	5.73
W* LCO_2			0.073	1.12	0.346***	4.05	0.385***	4.56	0.299***	3.18
LGDP	1.398***	8.31	1.333***	7.94	1.473***	7.88	1.634***	8.61	1.589***	7.65
LGDP2	-0.148***	-6.42	-0.143***	-6.28	-0.160***	-6.29	-0.172***	-6.78	-0.171***	-6.11
LFEC	0.438***	13.00	0.441***	13.08	0.439***	13.05	0.454***	12.51	0.455***	12.52
LNFEC	-0.061***	-6.59	-0.062***	-6.64	-0.059***	-6.36	-0.057***	-5.88	-0.058***	-5.98
LUR	0.865***	8.89	0.819***	8.25	0.864***	8.31	0.990***	8.78	0.921***	7.87
GG	-0.008	-0.66	-0.002*	-1.64	-0.015*	-1.71	-0.017*	-1.82	-0.016*	-1.84
W*LGDP					-0.456	-0.48			0.522	0.48
W*LGDP2					0.089	0.73			-0.003	0.97
W*LFEC					0.198	0.69			0.598*	1.85
W*LNFEC					0.075	0.74			-0.153*	-1.79
W*LUR					-1.279**	-1.96			-0.350	0.63
W*GG					0.330***	4.08			0.244***	2.74
Spatial lambda	0.225**	2.48								
R^2	0.312		0.311		0.318		0.296		0.298	
Log-likelihood	2774.598		2744.571		2774.598		2744.571		2755.903	
								Wald test spatial lag	25.67***	26.17***
								Wald test spatial lag	20.90***	40.47***

***,** and * denote statistical significance at the 0.01, 0.05 and 0.10 levels, respectively

Table 11 Direct, indirect, and total effect

	Short-run			Short-run		
	Direct effect	Indirect effect	Total effect	Indirect effect	Indirect effect	Total effect
GG	−0.0158*	0.334***	0.318**	0.127***	0.127***	0.106**
NFEC	−0.059***	−0.244	−0.304*	−0.043*	−0.043*	−0.101*

of structural changes toward knowledge-based industries and the service sector. This result is consistent with You and Lv 2018, Kacprzyk & Kuchta, 2020, and Dong et al., 2018.

The elasticity of CO_2 emissions concerning urbanization is statistically significant and equals 0.921. This positive association indicates the upward trend of CO_2 emissions as energy consumption rises due to the growth of commercial and industrial activities in cities (Sadorsky, 2013). As expected, fossil and non-fossil fuel consumptions have respectively positive and negative impacts on emissions of CO_2. These effects are statistically significant at 1%. The results show that a one percent increase in the share of fossil fuel consumption will lead to a 0.455% increment in CO_2 emissions. This finding is consistent with Kang et al. (2019) and Ito (2017) and Chen et al. (2019a, 2019b). Furthermore, the estimation results indicate that the fossil fuel consumption spatial lag coefficient is positive and significant at 1%.

The elasticity of CO_2 to the share of renewable energy consumption is -0.058, representing that with a one percent growth in renewable energy share, the emissions of CO_2 fall by 0.058%. This result conforms to (Zaman et al., 2021; Saidi & Omri, 2020; Namahoro et al., 2021). Also, the results indicate that renewable energy consumption spatial lag has a negative and statistically significant at 10%.

According to the estimation results, the good governance index has negative and statistically significant effects on CO_2 emissions. While, its spatial lag has positive and significant impacts. In this study, we intend to investigate the effects of good governance and renewable energy and their spillovers on the CO_2 emissions. So, we employed the LeSage and Pace (2009) method to decompose direct, indirect (spillover), and the total effect of good governance and renewable energy on CO_2 emissions. Table 11 shows the short run and long run direct, indirect and total effects of good governance and renewable energy on CO_2.

Table 11 shows that the direct effects of good governance on CO_2 emissions, both in the short-run and long-run, are negative and significant at 10%. These results are compatible with the theory that it is more plausible that industries and economic entities obey environmental rules and regulations in countries with high governance quality (Acemoglu et al., 2005). Therefore, in the presence of effective laws, private firms try to fully comply with the standards and regulations related to CO_2 emissions to avoid being punished for non-compliance with the rules. As the results demonstrate, the long run effect of good governance on CO_2 emissions is greater than the short-run impact. Because, in countries with more robust governance, in the long run, the public sector has more significant achievements in terms of macroeconomic stability and enhancing economic infrastructures (Varoudakis et al., 2007). The government will also be more successful in implementing effective and transparent regulation in the long run. Furthermore, as it takes time for the private sector to believe in the government's commitment to enforcing the law, it is more likely that the private sector entities adapt their businesses to implement environmental rules in countries with a higher quality of governance in the long run.

The effect of good governance spillover on CO_2 emissions in the short and long run is positive and significant at 1%. Therefore, with the improvement of governance quality in a particular country, the CO_2 emissions in its neighboring countries will rise. The pollution-haven hypothesis can explain this result. In countries with a higher level of governance, as corruption is more limited, the possibility of improper use of the environment and natural resources by private firms is disrupted (Candau & Dienesch, 2017). According to good governance theory, pollution havens originate from two sources: the poor quality of regulation and the weak enforcement of environmental laws. The results also show that the short-run spillover of good governance is greater than in the long-run. Finally, the total effect of good governance on CO_2 emissions, both in the short and long run, is positive and significant at 5%. The sum of the direct and indirect effects is less in the short run than in the long run due to the greater impact of short-run spillover.

Furthermore, Table 11 indicates the direct effect of renewable energy on CO_2 emissions is negative and statistically significant in the short-run and long-run. The effect of spatial spillover of renewable energy on CO_2 emissions is negative and significant in the long-run. The theoretical foundations state that renewable energy spillover effects are based on the mechanism of knowledge spillover. The knowledge spillover mechanism, including based on the transfer of tacit knowledge as well as imitation of neighboring countries, in the long run, justifies the effects of renewable energy spillover on reducing CO_2 emissions. Also, the results indicate total effect of renewable on CO_2 emissions is negative and significant in the short and long-run.

6 Conclusion and policy implication

This paper examines the impact of good governance on CO_2 emissions, both directly and indirectly, using data from multiple countries. The study confirms the environmental Kuznets hypothesis, which suggests that there is an inverted U-shaped relationship between GDP and CO_2 emissions. The results show that urbanization has a positive effect on CO_2 emissions, while fossil fuel consumption has a negative effect, and non-fossil fuel consumption has a positive effect. The study also finds that the impact of good governance on CO_2 emissions is complex, with negative direct effects in the short and long term, but significantly positive spillover effects in both the short and long term. This suggests that improving governance may reduce CO_2 emissions domestically while increasing them in neighboring countries, supporting the pollution haven hypothesis. Overall, the study highlights the importance of considering spillover effects and the need for a global approach to environmental policy-making.

As shown in Table 12, none of the five hypotheses are rejected. This means that the results suggest that the hypotheses are valid and that further research is needed to confirm them.

Following the empirical results, this study provides a set of policies to alleviate emissions of CO_2 and remedy the climate change problem.

(a) Due to CO_2 emission spillovers, it is necessary to change the concentration of environmental policies from domestic to regional and global policies. Sharing environmentally-friendly technologies and transferring successful governance experiences in subtracting CO_2 emissions to other countries effectively decrease the global amounts of CO_2.

Table 12 The result of hypothesis

Hypothesis	Result	What does that mean	Reasons
Hypothesis 1: *The effect of good governance on CO2 emissions is negative*	✓	As the quality of governance improves, the level of CO_2 emissions tends to decrease	Good governance can create an enabling environment for the adoption of policies and practices that reduce CO_2 emissions
Hypothesis 2: *Good governance of a country affects the CO2 emissions of neighboring countries*	✓	Good governance has a spillover effect on CO_2 emissions	By promoting regional cooperation, attracting foreign investment and trade
Hypothesis 3: *The effect of renewable energy consumption on CO2 emissions is negative*	✓	As the use of renewable energy increases, the level of CO_2 emissions tends to decrease	Reduced dependence on fossil fuels, More efficient energy use and Increased energy security and resilience
Hypothesis 4: *Renewable energy in a country affects the CO2 emissions of neighboring countries*	✓	Renewable energy has a spillover effect on CO_2 emissions	Imitation of knowledge, the success of technology encourages the neighboring country to adopt that technology
Hypothesis 5: *CO2 emissions of a country affect the CO2 emissions of neighboring countries*	✓	CO_2 emissions has a spillover effect on CO_2 emissions	Along international value chains Related to the pollution haven hypothesis Competition between governments

(b) Considering the environmental Kuznets hypothesis and the CO_2 emission spillovers, it is recommended that developed countries that have passed the environmental Kuznets turning point facilitate developing countries' transition through the Kuznets turning point by transferring them clean technologies. So, developing countries will enter the downward part of the Kuznets curve sooner, and consequently, the worldwide CO_2 emissions will decrease.

(c) Given the positive impact of fossil fuels on emissions and the negative effect of non-fossil fuels, shifting from fossil to non-fossil energy is necessary. Appropriate policies in this regard are investment subsidies, favorable financing for the investment, feed-in tariffs, green certificates, indirect support through taxation of carbon or fossil fuels, additional support for small-scale facilities, the incentive for using manure, and gate-fee income for the handling of waste.

(d) Since the positive effects of good governance improvements on CO_2 emissions outweigh its direct negative effects, good governance amelioration increases total CO_2 emissions. This result reminds us of the necessity to focus on promoting international and global governance policies instead of local governance. Although the pollution haven hypothesis can explain the positive spillover effects of governance on CO_2 emissions, according to good governance theory, the pollution haven comes from two sources: the poor quality of regulation and the weak enforcement of environmental laws. Thus, unbalanced environmental policies in neighboring countries cause negative spillover effects. These imbalances must be addressed through balanced regional and global policies. Therefore, it is necessary to pay attention to the balanced policies and support of countries with lower protection technologies in international treaties, including the Paris Agreement. Also, the rapid transfer of low-carbon technologies to developing countries and the provision of sufficient international loans to these countries to improve infrastructure and upgrade polluting industries to low-carbon industries is a local necessity and a regional and global necessity.

(e) Addressing the complex relationship between good governance and CO_2 emissions: The study finds that good governance has a complex relationship with CO_2 emissions, with negative direct effects in the short and long term, but positive spillover effects. Policymakers should aim to improve governance while also considering the potential spillover effects on neighboring countries, and work towards a global approach to environmental policy-making.

(f) Promoting international cooperation: The study highlights the need for a global approach to environmental policy-making, as policies implemented in one country can have spillover effects on neighboring countries. Policymakers should promote international cooperation and coordination to address global environmental challenges, such as climate change. This can be achieved through international agreements, partnerships, and initiatives.

According to Article 1 of the Paris Agreement, "Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development." Fiscal compatibility to declining emissions has been addressed, and Article 3 emphasizes the need to support developing countries "while recognizing the need to support developing country Parties for the effective implementation of this Agreement." Implementation of these clauses is essential to success in reducing direct emissions and spillover. Also, according to the results, the short-run effect of good governance is more significant than the long-run, which requires attention to short-run policies to improve global environmental governance balance.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare the following financial interests/personal relationships which may be considered as potential competing interests.

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