



The Influencing Factors of CO₂ Emissions and the Role of Biomass Energy Consumption: Statistical Experience from G-7 Countries

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Abstract

This paper examines the impact of biomass energy consumption on CO₂ emissions and the environmental Kuznets curve (EKC) hypothesis in G-7 countries. We also incorporate capitalization, financial development, and globalization measures (economic, social, and political) as additional determinants of CO₂ emissions. This study covers the period of 1980–2014. We apply the generalized method of moments (GMM) for empirical analysis. The empirical results reveal that biomass energy consumption contributes to CO₂ emissions. The EKC hypothesis is valid in G-7 countries. Capitalization is inversely linked with CO₂ emissions. Financial development deteriorates environmental quality. Foreign direct investment (FDI) and trade openness improve environmental quality. Globalization increases CO₂ emissions. Institutional quality improves environmental quality through effective economic and environmental policies. Urbanization impedes environmental quality. These results provide new insights for policy makers in designing comprehensive environmental policy by considering biomass energy as an economic tool for sustainable economic development and to improve environmental quality.

Keywords Biomass energy · EKC · G-7 countries · GMM

1 Introduction

In the last few decades, industrialization and population growth have led to a rapid increase in world energy demand. This trend has also been followed in recent years by developing countries. However, the need to meet a growing energy demand to sustain

economic growth has seriously affected environmental quality (e.g., deforestation, climate change, water pollution, and a loss of biodiversity). The rising level of energy consumption worldwide has led to a need for research on how to mitigate the negative effects of climate change that are caused by CO₂ emissions because the way in which we consume energy determines society's environmental impacts [123]. Therefore, research in energy economics that aims to determine optimal and efficient energy sources is one of the most fundamental ways to support sustainable economic development. Today, the awareness of climate change and its repercussions is widespread; however, it was not until the early 1990s that environmental pollution problems began to be more frequently described in energy economics literature. Since Grossman and Krueger [60], many studies have considered the connection between economic growth and environmental degradation [114, 122, 125]. Various studies have shown that environmental degradation generates global economic recession [135, 142]. Therefore, in the coming decades, it will be necessary to assume energy challenges at global levels to reduce or at least control the ascending trend of environmental degradation [73, 142]. In doing so, the way to mitigate this problem must be linked with the promotion of structural reforms, mainly in terms of energy usage and environmental regulations [20].

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Numerous studies have explored the important role that is played by the energy sector in economic activity for developed nations [28, 112, 115]¹. Since the pioneering study of Kraft and Kraft [88], many studies have investigated the relationship between energy consumption and economic growth and have defined different relationships between energy use and economic growth. This has motivated interest among economists and policy analysts to investigate the direction of causality between energy consumption and economic variables as well as between energy consumption and trade variables, i.e., exports, imports, trade, trade liberalization, foreign capital inflows, and globalization (economic, social, and political). Additionally, the existence of improvements in economic development will increase environmental pressure because of an ascending economic cycle (high rates of economic growth), which increases energy demand to drive long-run economic growth. Consequently, energy use can be considered a fundamental cause of high carbon dioxide (CO₂) emissions, and environmental policies and improvements in institutional quality become a global concern in the reduction of the negative consequences that energy consumption and economic growth have for environmental quality [22, 28, 44].

Higher economic growth and better environmental quality have conventionally been considered a trade-off scenario [102]. Grossman and Krueger [60] empirically reported a positive relationship between economic growth and environmental degradation². Furthermore, they noted that economic growth is initially positively aligned with carbon emissions and that environmental quality begins to improve after a certain level of per capita income at later stages of economic development, which is referred to as an Environmental Kuznets curve, i.e., the EKC hypothesis.

The EKC hypothesis reveals that at a certain level, the positive relationship between economic growth and environmental degradation changes to a negative one. This action can be considered justified by the improvements in income levels, which, as a result, increase the demand for better environmental quality [111]. In its original version, the EKC embodies an inverted U-shaped relationship between economic growth and environmental pollution. To confirm the inverted U-shaped relationship, many studies have used gross domestic product (GDP) in real and per capita terms as an indicator of economic

growth and CO₂ emissions as an indicator of environmental degradation [2, 8, 12–14, 76, 85, 91, 110, 119, 127].

Figure 1 shows an inverted U-shaped relationship between economic growth and environmental degradation [19, 27, 32, 38, 40, 114, 122, 136]. Figure 1 illustrates that in the early stages of economic growth, environmental pollution levels rise up to a certain turning point, beyond which economies experience a reduction in pollution levels. This advance also supposes dynamic structural changes that are connected with economic growth [46]. Economic development implies modifications in environmental quality through three channels: scale, composition, and technique effects. In the first stage of economic growth, an increase in income, which is achieved by industrialization, is positively linked with environmental pollution (scale effect). The scale effect suggests that even if the structure and technology of an economy does not change, an increase in output level will decrease environmental quality. Therefore, in the developing stage, the relationship between economic growth and environmental quality becomes positive [46, 116, 140]. In the early stage of economic growth (developing stage), a rise in economic growth will worsen environmental quality until it reaches a certain turning point at which the relationship between economic growth and environmental pollution becomes negative. The composition effect suggests a positive impact on environment quality due to changes in economic structure as societies experience a transition from agriculture and heavy manufacturing industries to cleaner industries and a growing service sector.

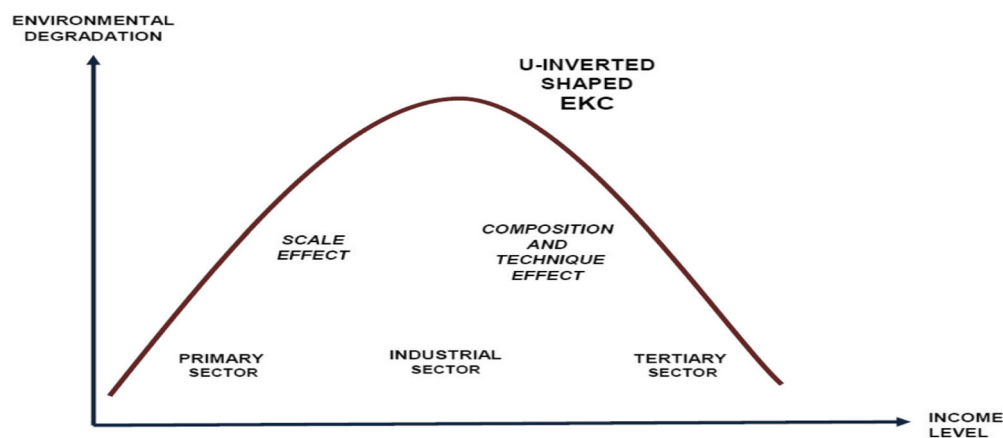
Therefore, as the economic structure transits to a tertiary sector, clean industry will reduce environmental degradation by adopting energy-efficient technology. Finally, the technique effect implies that as economies achieve a developed stage (high-income level, low economic growth), energy innovations and improvements in institutional quality will reduce energy intensity [20, 95, 106]. In such circumstances, the level of environmental pollution declines (composition and technique effects) as countries that experience an increase in environmental consciousness achieve sustainable economic development.

The described relationship between economic growth and environmental pollution has been well discussed in the existing energy economics literature [60, 65, 122, 125]. For example, Martínez-Zarzoso and Bengochea-Morancho [101] reported that economic growth and CO₂ emissions are negatively correlated in developing countries, but the relationship is positive in high-income countries. However, a high-income level does not necessarily ensure greater efforts to maintain environmental quality. Shafik [124] and Holtz-Eakin and Selden [66] demonstrated that emissions monotonically increase with income levels. Therefore, the empirical findings of the existing empirical studies are inconclusive for design policy recommendations that can be helpful across countries. Various studies have also tested the nexus of income-energy and income-environmental pollution under the

¹ Payne [115] examines, through the Toda-Yamamoto causality test, the relationship between biomass energy consumption and income in the USA. The results support a positive unidirectional causality that runs from biomass energy consumption to real GDP. Bildirici [28] examines the short- and long-run causality between biomass energy consumption and income for selected emerging countries. Ozturk and Bilgili [112] find a significant but positive effect of biomass consumption on economic growth.

² Although, Panayotou [113] first coined the term Environmental Kuznets Curve, Grossman and Krueger [60] established the EKC relationship using cross-sectional data for 42 countries' urban areas and 3 pollutants to study the relationship between air quality and economic growth.

The Environmental Kuznets Curve: Scale, Composition and Technique Effects



Source: Prepared by authors

Fig. 1 The Environmental Kuznets Curve: scale, composition, and technique effects. Source: Prepared by authors

same integrated framework, given that energy consumption has a direct effect on environmental pollution [8, 13, 28, 34, 110, 115, 131]. This highlights the significance of linking these two standards of literature to avoid problems of misspecification [123].

Many studies in the existing energy literature apply diverse methodologies and additional variables to confirm the presence of the EKC relationship between economic growth and environmental degradation. These variables are *energy consumption* [8, 13, 22, 34, 110, 126], *capitalization* [13, 58, 68, 104], *FDI* [42, 106, 128], *trade openness* [6, 76, 80, 110, 111, 127], *financial development* [6, 47, 52, 110, 128, 133], *urbanization* [6, 80, 111, 129], *institutional quality* [111], and *globalization* [130, 132]. This study examines, within the EKC modeling framework, the role that biomass energy consumption exerts on environmental pollution in G-7 countries over the period 1980–2014.

The Group of Seven (G-7) contains the world's leading industrialized countries (Canada, France, Germany, Italy, Japan, the UK, and the USA). Although G-7 represents 11% of the worldwide population, its share of the world's economic output—which is 33% when adjusted for purchasing power—underscores its importance for the global economy [145]. In other words, these seven countries are responsible for one-third of the global economic output. Despite the financial crisis, in recent years, most of the G-7 states have managed to increase their economic output in real terms, with the USA and Canada achieving the largest increase in GDP. The only exception is Italy, which was more or less unchanged (−1.2%) compared to the year 2000. Furthermore, approximately one-third of all exports worldwide come from one of G-7 states, and 35% of all goods and services imported have a G-7 destination. Germany is a leading export nation, with an export volume of 1744 billion US\$ (goods and services) in 2013. Otherwise, most G-7 countries depend on imports to cover their energy demand. This circumstance is especially significant in Japan, which imports

approximately 96% of its total primary energy supply. The other G-7 countries also have a high percentage of energy dependency levels: Italy (84%), Germany (64%), France (49%), the UK (45%), and the USA (18%). On the other hand, in 2013, Canada produced more energy than it needed for inland consumption (−67%), being the only net energy exporter among the G-7 states [71]. Concerning the levels of energy intensity, for G-7 countries, the rates differ considerably. In 2013, while Italy and the UK required, respectively, 0.1 and 0.09 kg oil equivalent (koe) of energy for every 1 int. US\$ of GDP, Germany and Japan required approximately 0.11 kop. In contrast, the highest rates of energy intensity were found in Canada (0.19), the USA (0.15) and France (0.13).

Since 1990, many countries have succeeded in reducing their carbon dioxide emissions. However, this positive progress has remained a regional phenomenon because, from a global perspective, the total emissions of carbon dioxide and greenhouse gases have continued to increase [71]. Between 1990 and 2013, the G-7 reduced its per capita CO₂ emissions levels: Germany (21.24%), France (21.32%), Italy (22.24%), the UK (26.53%), the USA (15.18%), Canada (13.58%), and Japan (10.04%). These results are correlated with the CCPI ranking³. In 2016, the UK rose to fifth place in the CCPI, with a score of 70.13 points, followed by France (position 8, score 65.97), Italy (position 11, score 62.98), and Germany

³ The Climate Change Performance Index (CCPI) is an instrument that was designed to enhance transparency in international climate politics. On the basis of standardized criteria, the index evaluates and compares the climate protection performance of 58 countries that together are responsible for more than 90% of global energy-related CO₂ emissions. Therefore, 80% of the evaluation is based on indicators of emissions (30% for emissions levels and 30% for recent development of emissions), efficiency (5% level of efficiency and 5% recent development in efficiency), and renewable energy (8% recent development and 2% share of total primary energy supply). The remaining 20% of the CCPI evaluation is based on national and international climate policy assessments by approximately 300 experts from the respective countries.

(position 22, score 58.39). Germany's position is supported by the efforts of the renewable energy sector, where it performs relatively well. However, the USA ranks at position 34 with a score of 54.91; but despite that the USA is still the second-largest CO₂ emitter, recent positive developments, such as the rejected construction of a large oil-sands pipeline and efforts to push international climate negotiations, are sending positive signals [141]. A slightly positive trend can be seen in Canada (position 56 and score 38.74). Japan has the poorest CCPI score position among G-7 countries. This country is positioned at 58 with a 37.23 score. This position is associated with the dominant use and promotion of coal-fired power plants and the lack of an effective and binding emission trading scheme in Japan [72].

In 2014, the total primary energy supply (TPES) in the G-7 rose to 43,898.05 Tw/h [71]. The USA had the highest share (58%), followed by Japan (12%), Germany (8%), Canada (7%), and France (6%). The lowest percentages were from the UK (5%) and Italy (4%). By source (from TPES), Italy showed the highest contribution in renewable energy at 18.5% (314.6 Tw/h) (18.5%), followed by Canada at 18.1% (542.2 Tw/h), and Germany at 12.6% (443.2 Tw/h). The lowest shares of participation of renewable sources in primary energy supply were from the UK at 6.9% (142.7 Tw/h), the USA at 6.7% (1719.0 Tw/h), and Japan at 5.3% (271.9 Tw/h). In 2014, crude oil and natural gas continued to be the main energy sources in the G7 countries (Fig. 2). Otherwise, the total primary energy supply of renewable energy sources is mostly covered by energy from biofuel and waste at 56% (mean value from G-7 countries), followed by hydropower at 24%. In 2014, solar and wind energy represented 14% and geothermal 6% (Fig. 3).

By country, most of the renewable energy consumed comes from biofuel and waste: Germany (73%), the UK (70%), the USA (66%), France (65.5%), Italy (50%), Japan (39%), and Canada (29%). Figure 4 illustrates the annual TPES (including industry) per unit population in 2014. In the USA, the share of biogenetic energy (solid biomass, gas biofuel, and liquid biofuel) from the TPES (81.1 Gw/h) was 4.2% (3.38 Gw/h per capita). In Canada in 2014, the share of biogenetics was 5.3% (4.49 Gw/h per capita), and in Japan, the biogenetic share was 2.1% of the TPES (40.3 Gw/h per capita). In France, the biogenetic share accounted for 5.5% (2.33 Gw/h) of the annual TPES (42.5 Gw/h per capita). In 2014, Italy showed a biogenetic share of 8.4% (2.3 Gw/h per capita) of the annual TPES. Finally, in the UK, the biogenetic share was 3.7% (1.2 Gw/h per capita) of the annual TPES (31.9 Gw/h per capita) in 2014 [71]. Figure 5 also shows the evolution of CO₂ emissions (metric tons). This evolution reveals that G-7 countries present a net correction in CO₂ emissions (21.92%). The highest reduction in CO₂ emissions appears in Germany (42.70%). Within the G-7 countries, France presented the minimum value of CO₂ emissions in 2012, followed by Italy. Both

countries presented a high score in their CCPI rankings. Between 1980 and 2014, the G-7 countries reduced biomass consumption (Fig. 5). This use has stabilized in recent decades. The UK offered the highest reduction in biomass energy use (63.34%), followed by Japan (48.37%), Germany (45.87%), Italy (30%), and France (26.8%). The lowest percentages of reduction in biomass consumption between 1980 and 2013 were in the USA (11.8%) and Canada (3%).

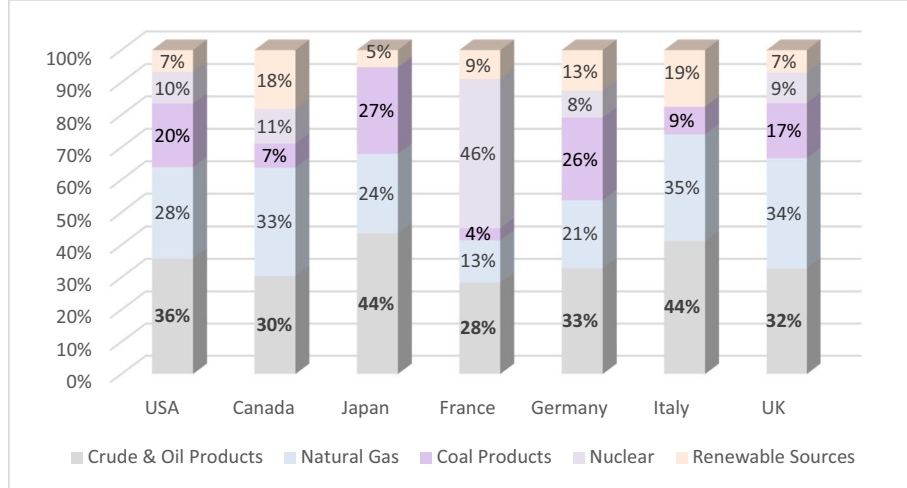
Few studies have examined the association between biomass energy consumption and carbon emissions using various empirical methodologies or have supported the presence of a direct relationship between biomass energy consumption and CO₂ emissions (for instance, see [23, 54, 78, 98, 113, 143]). Additionally, a few studies have shown that *biomass fuel* forms the highest percentage in household energy portfolios in some developing countries, where the energy transition is common in the urban areas. The use of biomass fuel is strongly dependent on urban populations and household incomes [51, 64, 90, 109].

Furthermore, few studies have demonstrated that biomass as the primary form of energy consumption decreases with increasing economic growth [143]. Foster et al. [54] tested the existence of the energy transition process with a model of household energy utility as a function of net energy consumption and efficiency factors. They found that at high levels of net energy consumption, increasing gross energy consumption is associated with a decrease in utility. In other words, households that can afford to do so will reduce their gross consumption by switching to more efficient energy sources under an inverted U scenario in, for example, Guatemala. The IEA [71] shows that the majority of biomass energy consumption remains in developing countries where there is low GDP per capita, while cleaner fuel dominates the households of the developed world. This result supports the EKC hypothesis, in which economies would reduce their biomass energy consumption with an increase in their income levels. Manomet [100] concluded that generating a given amount of energy using biomass would emit 20 tons of carbon, and generating the same amount of energy from fossil fuels would emit only 11 tons of carbon⁴. Higher rates of biomass energy development are typically not a function of any single factor but are instead the result of the combined effects of a variety of policy instruments. Within the context of a single country, there

⁴ The atmospheric greenhouse gas implications of burning forest biomass for energy vary depending on the characteristics of bio-energy combustion technology, the fossil fuel technology that it replaces, and the biophysical and forest management characteristics of the forests from which the biomass is harvested. For the biomass replacement of coal-fired power plants, the net cumulative emissions in 2050 are approximately equal to what they would have been burning coal; and for the replacement of natural gas, the cumulative total emissions are substantially higher with biomass electricity generation [100].

Fig. 2 Total primary energy supply in G-7 (2014). Source: Renewables Information OECD/IEA [71]

Total Primary Energy Supply in G-7 (2014)



Source: Renewables Information OECD/IEA (2016)

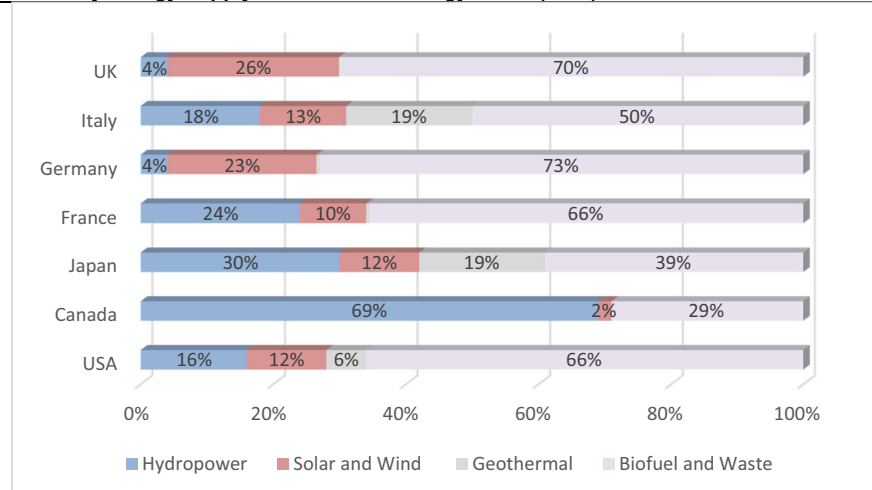
tends to be a combination of energy sources, determined to some extent by the degree of development of its forestry sector [79]. However, the existing biomass energy consumption literature has focused on the positive impacts of biomass on carbon emission reduction [4]. Ahmed et al. [4] examine the causal relationship among CO₂ emissions, biomass energy consumption, and GDP per capita by including technology innovations in the carbon emissions function. Their results validate a negative relationship between biomass energy consumption and CO₂ emissions, where energy efficiency innovations help correct environmental degradation.

This study contributes to the existing energy literature in four ways: (i) an augmented carbon emissions function is

utilized to validate whether the EKC exists in the presence of biomass energy consumption. (ii) To avoid specification bias, other determinants of CO₂ emissions, such as capital, trade openness, financial development, urbanization, and institutional quality, are included in the carbon emissions function. (iii) Globalization (economic, social, and political) is also included in the carbon emissions function. (iv) The generalized method of moments (GMM) developed by Arellano and Bover [17] is employed for empirical analysis. Our empirical analysis confirms the presence of an EKC relationship between economic growth and carbon emissions. Financial development and urbanization worsen environmental quality by adding CO₂ emissions. Capital, FDI, and trade openness lower CO₂ emissions. Institutional quality improves

Fig. 3 Total primary energy supply of renewable energy in G-7 (2014). Source: OECD/IEA [71]

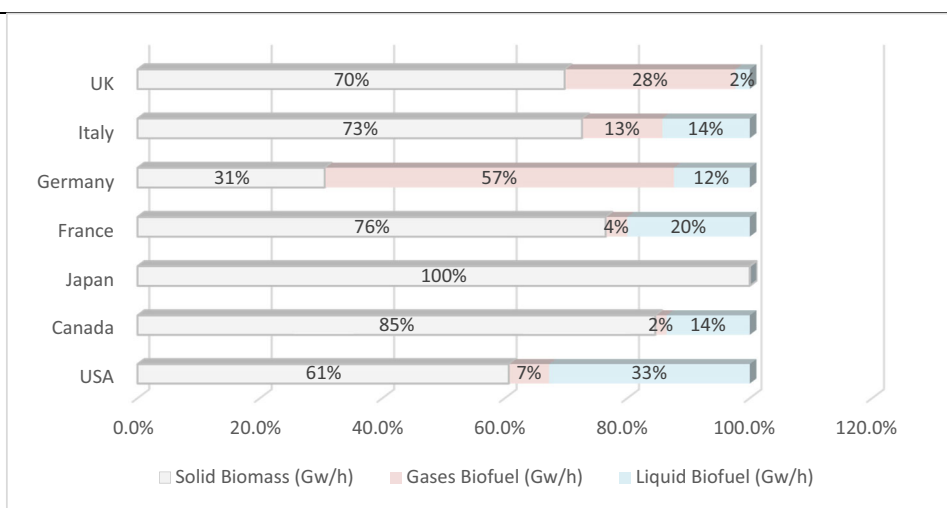
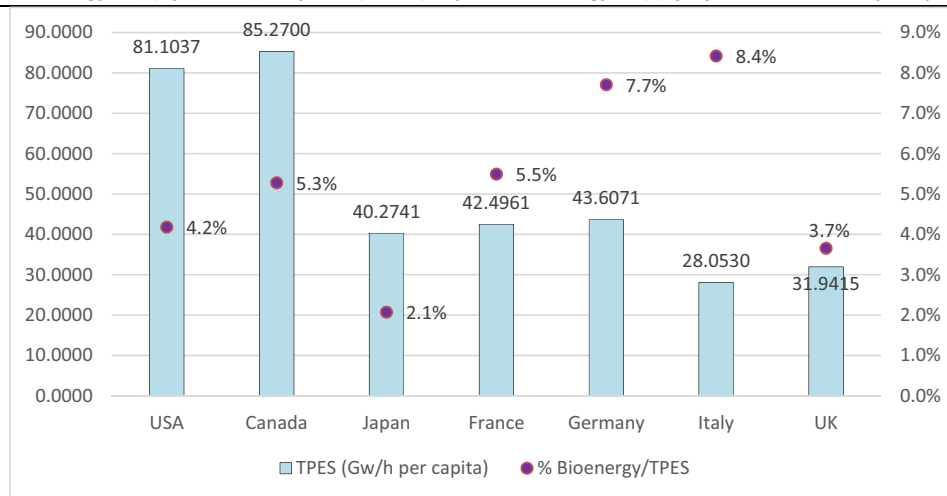
Total Primary Energy Supply of Renewable Energy in G-7 (2014)



Source: OECD/IEA (2016)

Fig. 4 Bioenergy supply per capita (Gw/h per capita) and bioenergy supply by sources in G-7 (2014). Notes: main axis: annual final total primary energy supply (TPES) (including industry) per unit population (Gw/h per capita). Secondary Axis: percentage of bioenergy. Source: IEA [71]

Bioenergy Supply per Capita (Gw/h per capita) and Bioenergy Supply by Sources in G-7 (2014)



Notes: Main axis: annual final total primary energy supply (TPES) (including industry) per unit population (Gw/h per capita). Secondary Axis: Percentage of Bioenergy. Source: IEA (2016).

environmental quality through effective economic and environmental policies.

2 Modeling and Data Collection

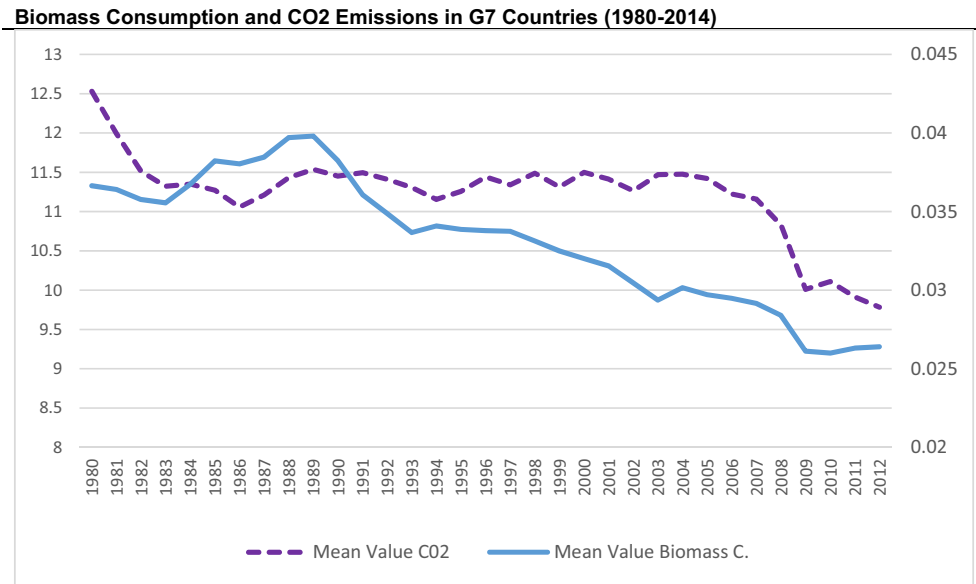
Environmental quality improvement depends on the level of economic growth, type of energy use, efforts in energy innovation, financial development, institutional quality, foreign divestment, trade openness, urbanization, and globalization (economic, social, and political). Following Grossman and Krueger [60], who showed that the relationship between economic growth and CO₂ emissions is nonlinear, we compose our empirical equation as follows:

$$\ln C_t = a_0 + a_1 \ln Y_t + a_2 \ln Y_t^2 + a_z \ln Z_t + \varepsilon_i \quad (1)$$

In Eq. 1, if the signs a_1 and a_2 are positive and negative (Fig. 1), respectively, and significant, an inverted U or EKC hypothesis will be supported, as was proposed by Grossman and Krueger [60]. Stern [134] suggested that the EKC model was excessively simplistic and/or generally inadequate and that alternative approaches might be more productive. Therefore, the EKC analysis might determine factors that are important in driving changes in emissions and may indicate where there might be policy levers. In addition, a_z is expected to adopt different significant effects to validate the assumption that is proposed in the empirical model.

This study employed annual data for the period 1980–2014 to examine an inverted U-shaped linkage between economic growth and environmental degradation for G-7 countries, including additional determinants of carbon emissions. These variables have been included in different studies by various researchers as determinants of

Fig. 5 Biomass consumption and CO₂ emissions in G7 countries (1980–2014). Notes: main axis mean values CO₂ emissions. Second axis mean value biomass consumption (ktoe). Source: www.materiaflow.com. IEA (2015)



Notes: Main axis mean values CO₂ emissions. Second axis mean value biomass consumption (ktoe). Source: www.materiaflow.com. IEA (2015).

environmental degradation. Additionally, this study includes the interaction of institutional quality with FDI, trade openness, and globalization (economic, social, and political) to explore moderation under the EKC framework. Institutional quality plays a fundamental role in the establishment of an inverted U relationship between economic growth and carbon emissions. Ozturk and Al-Mulali [111] find a negative relationship between governance and CO₂ emissions. This negative relationship validates that better governance reinforces environmental regulations and reduces pollution levels and/or that improvements in the quality of governance increase the demand for environmental quality by stimulating environmental regulation [22, 111].

To estimate the impact of different variables on environmental degradation, we employ different models based on the carbon emissions function for G-7 countries. The empirical models are specified as follows:

$$\ln C_t = a_0 + a_1 \ln Y_t + a_2 \ln Y_t^2 + a_E \ln E_t + a_K \ln K_t + a_{FD} \ln FD_t + a_F \ln F_t + a_I \ln I_t + a_U \ln U_t + \varepsilon_i \quad (2)$$

$$\ln C_t = a_0 + a_1 \ln Y_t + a_2 \ln Y_t^2 + a_E \ln E_t + a_K \ln K_t + a_{FD} \ln FD_t + a_U \ln U_t + a_2 \ln I_t * \ln F_t + \varepsilon_i \quad (3)$$

$$\ln C_t = a_0 + a_1 \ln Y_t + a_2 \ln Y_t^2 + a_E \ln E_t + a_K \ln K_t + a_{FD} \ln FD_t + a_U \ln U_t + a_I \ln I_t + a_F \ln F_t + \varepsilon_i \quad (4)$$

$$\ln C_t = a_0 + a_1 \ln Y_t + a_2 \ln Y_t^2 + a_E \ln E_t + a_K \ln K_t + a_{FD} \ln FD_t + a_3 \ln I_t * \ln O_t + \varepsilon_i \quad (5)$$

$$\ln C_t = a_0 + a_1 \ln Y_t + a_2 \ln Y_t^2 + a_E \ln E_t + a_K \ln K_t + a_{FD} \ln FD_t + a_F \ln F_t + a_I \ln I_t + a_U \ln U_t + a_{EG} \ln EG_t + \varepsilon_i \quad (6)$$

$$\ln C_t = a_0 + a_1 \ln Y_t + a_2 \ln Y_t^2 + a_E \ln E_t + a_K \ln K_t + a_{FD} \ln FD_t + a_F \ln F_t + a_U \ln U_t + a_4 \ln I_t * EG_t + \varepsilon_i \quad (7)$$

$$\ln C_t = a_0 + a_1 \ln Y_t + a_2 \ln Y_t^2 + a_E \ln E_t + a_K \ln K_t + a_{FD} \ln FD_t + a_F \ln F_t + a_I \ln I_t + a_U \ln U_t + a_{SG} \ln SG_t + \varepsilon_i \quad (8)$$

$$\ln C_t = a_0 + a_1 \ln Y_t + a_2 \ln Y_t^2 + a_E \ln E_t + a_K \ln K_t + a_{FD} \ln FD_t + a_F \ln F_t + a_U \ln U_t + a_5 \ln I_t * \ln SG_t + \varepsilon_i \quad (9)$$

$$\ln C_t = a_0 + a_1 \ln Y_t + a_2 \ln Y_t^2 + a_E \ln E_t + a_K \ln K_t + a_{FD} \ln FD_t + a_F \ln F_t + a_I \ln I_t + a_U \ln U_t + a_{PG} \ln PG_t + \varepsilon_i \quad (10)$$

$$\ln C_t = a_0 + a_1 \ln Y_t + a_2 \ln Y_t^2 + a_E \ln E_t + a_K \ln K_t + a_{FD} \ln FD_t + a_F \ln F_t + a_U \ln U_t + a_6 \ln I_t * \ln PG_t + \varepsilon_i \quad (11)$$

$$\begin{aligned} \ln C_t = & a_0 + a_1 \ln Y_t + a_2 \ln Y_t^2 + a_E \ln E_t + a_K \ln K_t \\ & + a_{FD} \ln FD_t + a_F \ln F_t + a_I \ln I_t + a_U \ln U_t \\ & + a_G \ln G_t + \varepsilon_i \end{aligned} \quad (12)$$

$$\begin{aligned} \ln C_t = & a_0 + a_1 \ln Y_t + a_2 \ln Y_t^2 + a_E \ln E_t + a_K \ln K_t \\ & + a_{FD} \ln FD_t + a_F \ln F_t + a_U \ln U_t + a_7 \ln I_t * \ln G_t \\ & + \varepsilon_i \end{aligned} \quad (13)$$

where $\ln C_t$, $\ln Y_t$, $\ln K_t$, $\ln E_t$, $\ln FD_t$, $\ln F_t$, $\ln O_t$, $\ln I_t$, $\ln U_t$, $\ln EG_t$, $\ln SG_t$, $\ln PG_t$ and $\ln G_t$ are respectively the natural logs of CO₂ emissions per capita proxy for environmental degradation, a real GDP per capita measure of economic growth, a real gross fixed capital formation per capita proxy for capitalization, biomass energy consumption, real domestic credit to private sector per capita measuring financial development, real foreign direct investment per capita, a real trade per capita proxy for trade openness, an institutional quality index, urbanization (urban population/total population), economic globalization, social globalization, political globalization, and overall globalization. ε_i is an error term.

The data for CO₂ emissions (metric tons), real GDP (constant 2010 US dollars), and real gross fixed capital formation (constant 2010 US dollars) measure capitalization, while real domestic credit to private sector (constant 2010 US dollars) proxies for financial development. The real FDI (constant 2010 US dollars), real exports (constant 2010 US dollars), and real imports (constant 2010 US dollars) were collected from world development indicators (CD-ROM 2015). Biomass energy consumption (domestic material consumption) was retrieved from net material flows⁵. Total population is used to transform all the variables into per capita units except for globalization⁶. We borrowed the globalization index from Dreher [50], who separates the overall globalization index into three sub-indices: economic globalization, social globalization, and political globalization. Economic globalization is a composite of actual economic flows that include trade, foreign direct investment, and portfolio investment and restrictions to trade and capital flows (e.g., restrictions on trade and capital using hidden import barriers, mean tariff rates, taxes on international trade as a share of current revenue, and an index of capital controls). Social globalization is composed of personal contacts, telephone contacts, tourism, the migration of people among countries, information flows (internet usage, televisions per 1000 people, trade in newspapers), and data on cultural proximity (number of

McDonald's restaurants, number of IKEA stores, trade in books). Political globalization includes the number of embassies in a country, membership in international organizations, participation in UN secretary council membership, and international treaties to generate an index of political globalization. Taken together, the relative share in the overall globalization index that is contributed by economic globalization is 36%, by social globalization 38%, and by political globalization 26%. The overall globalization index and its sub-indices are available at <http://globalization.kof.ethz.ch/>. The trend of sampled variables is shown in Fig. 6⁷.

3 Methodological Framework

This study examines the influencing factors that affect CO₂ emissions using data for G-7 countries. In doing so, we apply the generalized method of moments (GMM) for empirical analysis. The panel GMM technique is used because it efficiently estimates linear and nonlinear regressions with endogenous regressors and non-spherical disturbances. The GMM estimation model was developed by Arellano and Bond [16], who argued that additional instruments could be obtained in a dynamic model from panel data if the orthogonality conditions between the lagged values of the dependent variable and the disturbances were utilized. The GMM estimator eliminates country effects through first-differencing and controls for the possible endogeneity of the explanatory variables.

This study treats economic growth variable as endogenous, while biomass energy consumption, capital, financial development, urbanization, and institutional quality variables are treated as exogenous. The endogenous variables and disturbances are jointly correlated in simultaneous equation models that create the problem of simultaneity and/or endogeneity bias. Furthermore, inconsistent and biased parameter estimates are obtained by using ordinary least squares (OLS) regressions, which lead to the infringement of one of the assumptions of the classical linear regression model. The GMM model employs first-differences in the equation to control for unobserved country-specific effects. The GMM estimation consequently reduces the error term to "white noise" and thereby eliminates endogeneity due to a correlation between the error term and the independent variables [62]. The GMM estimation thus works under the supposition that all independent variables in addition to the lagged-dependent variable are exogenous and operate as valid instruments.

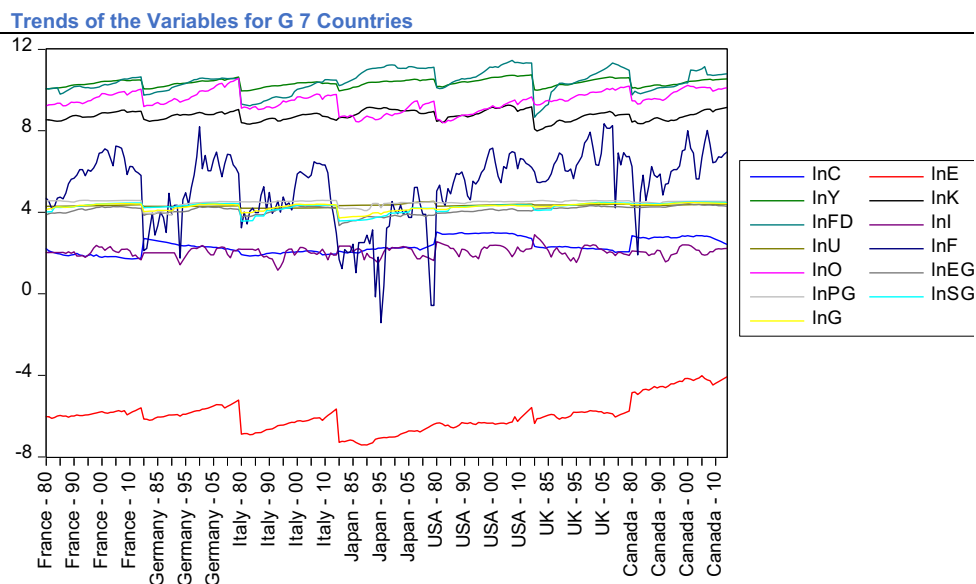
The use of instrumental variables provides a set of variables that are correlated with the independent variables of the equation; however, they are uncorrelated with disturbances. Therefore, the instruments remove the correlation between

⁵ Many of the biomass fuels that are used today come in the form of wood products, dried vegetation, crop residue, and aquatic plants. Biomass must be considered in the search for an alternative source of energy that is abundant in a wide-scale yet non-disruptive manner because it is capable of being implemented at all levels of society.

⁶ We have also transformed all of the variables into natural-log before empirical analysis for reliable and efficient empirical evidence.

⁷ G 7 countries such as France, Germany, Italy, Japan, the USA, and the UK and Canada are shown by 1, 2, 3, 4, 5, 6, and 7, respectively.

Fig. 6 Trends of the variables for G 7 countries. Source: Prepared by authors



Source: Prepared by authors

the independent variables and the disturbances. By eliminating endogeneity, we restore the orthogonality conditions of the independent variables to attain “unbiased and consistent estimates” [62]. Consequently, the estimates that are obtained are reliable and consistent. Arellano and Bond [16] and Arellano [15] proposed the GMM estimator, which is both a single-equation and a system estimator. GMM was chosen for the current study over other estimators of its class for the following reasons:

- The GMM offers a simple substitute for other estimators, particularly when it is problematic to write a maximum likelihood estimator.
- The GMM covers many standard estimators and thereby offers a valuable framework for their evaluation and comparison.
- The GMM is a robust estimator because it does not require information about the accurate distribution of error terms.
- The GMM is an asymptotically unbiased and consistent estimator, regardless of the weighting matrix that is used.

In conclusion, the GMM estimation technique corrects for heteroskedasticity and creates efficient as well as unbiased results. The GMM model helps to solve for heteroscedasticity and corrects for the endogeneity of independent variables [62]. It therefore produces efficient and unbiased results⁸.

⁸ For a more detailed explanation, see [16, 17, 30, 62].

4 Empirical Results and Discussion

The descriptive statistics analysis reported in Table 1 reveals that urbanization is less volatile compared to economic growth and political globalization (overall globalization). The volatility in CO₂ emissions is higher than volatility in capitalization, industrialization, and economic globalization (social globalization). Trade openness has less volatility compared to volatility in biomass energy consumption and financial development. Foreign direct investment is found to be highly volatile. We explore a linkage among carbon emissions, income, biomass energy consumption, capitalization, and other additional explanatory variables (Table 2). The econometric results that were estimated by the GMM (Table 2) of Eqs. 2 to 13 verify the existence of an inverted U-shaped relationship between economic growth and environmental pollution.⁹ The signs $\ln Y_t$ and $\ln Y_t^2$ are positive and negative, respectively ($a_1 > 0$, $a_2 < 0$), and both are statistically significant for Eqs. 2 to 13. The $\ln Y_t^2$ result confirms the delinking of CO₂ emissions and a higher per capita GDP. This result validates the existence of an inverted U-shaped relationship between economic growth and CO₂ emissions. This relationship considers that CO₂

⁹ To determine whether the EKC hypothesis does exist, the significance of the slope coefficient Y and Y square must be examined. If the slope coefficients of Y are positive and significant ($\beta_1 > 0$) and the Y square is negative and significant ($\beta_2 < 0$), an inverted U-shaped relationship can be determined between income and environmental pollution (Table 4). The behavior of the remaining coefficients also helps to explain the relationship between income level and environmental pollution levels. The result of the regression implies that in an initial stage, increases in income levels lead to increases in CO₂ emission levels until the first turning point is reached. Beyond this point, higher income levels are inversely related to environmental pollution levels (CO₂ levels start to decrease).

Table 1 Descriptive statistic of the variables

Variable	lnC _t	lnE _t	lnY _t	lnK _t	lnFD _t	lnI _t	lnU _t	lnF _t	lnO _t	lnEG _t	lnPG _t	lnSG _t	lnG _t
Mean	2.3362	-5.9555	10.3498	8.7515	10.4203	2.0673	4.3309	5.2841	9.4663	4.1051	4.4777	4.2544	4.2749
Median	2.2603	-6.0019	10.3681	8.7809	10.4352	2.0689	4.3386	5.7909	9.4734	4.1675	4.5262	4.3451	4.3329
Maximum	3.0338	-4.0107	10.7383	9.2521	11.4478	2.8995	4.5359	8.3427	10.573	4.4270	4.5865	4.5044	4.4862
Minimum	1.7077	-7.4170	9.9504	7.9906	8.6579	1.1526	4.1993	-1.4150	8.3985	3.3463	3.8643	3.5698	3.7172
Std. Dev.	0.3785	0.7790	0.1861	0.2454	0.5589	0.2427	0.0668	1.7021	0.4767	0.2031	0.1474	0.2450	0.1718
Skewness	0.3661	0.6888	-0.1353	-0.3276	-0.3745	-0.3302	-0.0389	-1.1134	-0.2231	-0.9824	-2.5133	-1.5046	-1.3171
Kurtosis	1.8902	3.2978	2.3153	2.8152	2.8926	4.0310	3.6595	4.5397	2.4937	3.6608	8.7963	4.4172	4.2276
Sum	572.386	-1459.115	2535.708	2144.136	2552.976	506.502	1061.095	1294.628	2319.268	1005.771	1097.043	1042.334	1047.357
Sum Sq. Dev.	34.963	148.074	8.453	14.699	76.240	14.380	1.091	706.903	55.451	10.070	5.306	14.647	7.204
Observations	245	245	245	245	245	245	245	245	245	245	245	245	245

emissions will increase with economic growth until a certain turning point in a developing stage; after that, emissions will begin to decline under a sustainable level of economic growth. This empirical evidence is consistent with Galeotti et al. [57], Cho et al. [36], Yusuf and Erginbay [146], Nabaee et al. [105], and Apergis [11], who reported the validity of an environmental Kuznets curve in G-7 economies.

Biomass energy consumption exerts a positive and significant effect on environmental quality, i.e., $a_E > 0$. Biomass energy consumption is increased by 1%, and it is aligned with a 0.307–0.636% increase in carbon emissions. This indicates that biomass energy consumption is positively linked with carbon emissions and that it deteriorates environmental quality. This empirical evidence is consistent with Ma and Stern [98] and Manomet [100], who noted that biomass energy consumption produces CO₂ emissions as a fossil fuel source. However, Ahmed et al. [4] conclude that biomass energy consumption reduces CO₂ emissions in newly industrialized countries. The effect of capitalization on environmental degradation is negative and significant. It shows that capitalization is environmentally friendly, i.e., $a_K < 0$. The empirical results are consistent with Mugablech [104], Saidi and Hammami [121], and Kasperowicz [81], who noted that an improvement in capitalization leads to a decline in carbon emissions and improves environmental quality.

Financial development significantly increases energy pollutants, i.e., $a_{FD} > 0$. A 1% increase in financial development increases carbon emissions by 0.175–0.466%. This implies that financial development worsens environmental quality by increasing carbon emissions. Existing studies, such as Shahbaz et al. [127, 128], Al-Mulali et al. [6, 7], Jalil and Feridun [75], and Tang and Tan [138], have argued that financial development may attract FDI and higher degrees of economic growth and energy consumption [55]. This process will enhance the level of economic growth and energy consumption, leading to carbon emissions. This empirical evidence is consistent with Sadorsky [120] and Zhang [147], who noted the positive relationship between financial development and carbon emissions. Similarly, Dasgupta et al. [45] and Tamazian and Rao [137] conclude that financial development deteriorates environmental quality by increasing carbon emissions.

FDI negatively and significantly affects CO₂ emissions. This implies that FDI is environmentally friendly in G-7 countries, i.e., $a_F < 0$. We note that a 1% increase in FDI leads to a decline in CO₂ emissions by 0.007%. This empirical evidence is not consistent with Frankel and Romer [55], who considered that the attraction of FDI would attract economic growth and energy consumption (scale effect), which leads to CO₂ emissions. This negative effect of FDI reveals that as the level of manufacturing in G-7 countries increases, CO₂ emissions in these countries decrease due to the adoption of energy-efficient technology. This negative effect of FDI on CO₂

Table 2 GMM regression analysis

Variable	1	2	3	4	5	6	7	8	9	10	11	12
Constant	-122.010* [-7.146]	-75.213* [-4.446]	-58.177* [-5.196]	-28.144* [-5.601]	-12.074* [-3.171]	-17.712* [-10.964]	-7.185* [-4.796]	-24.932* [-8.179]	-11.403* [-6.983]	-8.798* [-6.126]	-9.770* [-5.833]	-4.602* [-3.488]
lnY _t	22.866* [7.286]	14.624* [4.667]	11.621* [5.828]	52.581* [5.695]	25.867* [3.344]	32.683* [19.963]	12.295* [4.487]	27.289* [7.574]	21.245* [7.037]	16.561* [6.094]	16.615* [5.454]	7.959* [3.441]
lnY _t ²	-1.082* [-7.530]	-0.708* [-4.980]	-0.537* [-5.688]	-2.486* [-5.732]	-1.217* [-3.294]	-1.542* [11.180]	-0.577* [-4.621]	-1.240* [-7.486]	-1.008* [-7.218]	-0.781* [-6.234]	-0.793* [-5.631]	-0.377* [-4.323]
lnE _t	0.406* [10.231]	0.307* [5.202]	0.455* [11.434]	0.531* [10.582]	0.444* [6.099]	0.462* [10.536]	0.387* [8.976]	0.540* [9.823]	0.436* [8.921]	0.390* [9.158]	0.466* [9.836]	0.636* [7.264]
lnK _t	-0.328* [-4.503]	-0.346* [-2.747]	-0.630* [-7.086]	-0.493* [-7.721]	-0.327* [-9.983]	-0.463* [-7.056]	-0.228* [-2.586]	-0.566* [-9.078]	-0.402* [-4.987]	-0.429* [-4.981]	-0.146* [-2.018]	-0.570* [-5.438]
lnFD _t	0.175* [6.644]	0.116*** [1.686]	0.236* [7.325]	0.262* [5.939]	0.446* [10.164]	0.255* [6.917]	0.222* [6.397]	0.237* [5.353]	0.218* [6.383]	0.216* [6.757]	0.278* [7.055]	0.234* [4.502]
lnF _t	-0.007*** [-1.792]	-	-	-	-	-	-	-	-	-	-	-
lnI _t	-0.119*** [-2.202]	-	-0.195* [-3.103]	-	-0.181* [-2.298]	-	0.009 [0.143]	-	-0.180* [-2.761]	-	0.017 [0.140]	-
lnU _t	1.964* [6.454]	1.289* [4.276]	1.399* [4.748]	-	0.872* [4.143]	1.227* [7.531]	1.255* [7.209]	1.634* [4.100]	1.767* [5.720]	1.774* [6.276]	2.300* [7.139]	2.017* [5.770]
lnO _t	-	-	-0.321* [-6.843]	-	-	-	-	-	-	-	-	-
lnEG _t	-	-	-	-	-0.846* [-11.959]	-	-	-	-	-	-	-
lnSG _t	-	-	-	-	-	-	0.334* [8.240]	-	-	-	-	-
lnPG _t	-	-	-	-	-	-	-	-	0.023 [0.498]	-	-	-
lnG _t	-	-	-	-	-	-	-	-	-	-	0.754* [5.913]	-
lnI _t × lnF _t	-	-0.046* [-3.700]	-	-	-	-	-	-	-	-	-	-
lnI _t × lnO _t	-	-	-	-0.003 [-0.315]	-	-	-	-	-	-	-	-
lnI _t × lnEG _t	-	-	-	-	-	-0.009 [-0.665]	-	-	-	-	-	-
lnI _t × lnSG _t	-	-	-	-	-	-	-	-0.34 [-1.230]	-	-	-	-
lnI _t × lnPG _t	-	-	-	-	-	-	-	-	-	-0.031* [-2.840]	-	-
lnI _t × lnG _t	-	-	-	-	-	-	-	-	-	-	-	-0.029 [-1.223]
Observations	231	231	231	231	231	231	231	231	231	231	231	231

Table 2 (continued)

Dependent variable = $\ln C_t$												
Variable	1	2	3	4	5	6	7	8	9	10	11	12
Countries	7	7	7	7	7	7	7	7	7	7	7	7
R ²	0.8276	0.8346	0.8248	0.8430	0.8596	0.8326	0.8005	0.8370	0.8510	0.8274	0.8014	0.8332
Adj-R ²	0.7974	0.7911	0.7818	0.8045	0.5760	0.7915	0.7375	0.7970	0.8313	0.7850	0.7512	0.7922
F-statistic	10.639*	3.140**	6.713*	9.851*	17.962*	9.642*	10.532*	9.328*	9.090*	10.236*	8.441*	11.940*
Hansen-J test (J statistic)	0.0935 [0.7627]	1.0794 [0.2988]	1.3062 [0.2530]	1.4953 [0.2215]	0.1768 [0.6758]	1.3719 [0.2414]	1.1216 [0.2627]	1.3892 [0.2385]	1.6096 [0.1817]	1.3078 [0.2527]	1.1328 [0.2523]	1.3727 [0.2413]

Note: *, **, and *** represent significance at 1, 5, and 10% levels, respectively. *P* values of the Hansen-J test are in squared brackets

emissions can be justified by the existence of strong or sufficient composition and technique effects. The empirical evidence that FDI improves environmental quality is contradictory to Kim and Beak [84], Wang et al. [144], Lau et al. [89], Kiviyiro and Arminen [86], and Shahbaz et al. [130]; however, Al-Mulali and Tang [5] reported a neutral impact of FDI on environmental quality. This empirical evidence is similar to Blanco et al. [29] and Zhang and Zhou [148], who reported that FDI improves environmental quality by lowering CO₂ emissions.

The association between institutional quality and carbon emissions is negative and statistically significant. This implies that institutional quality significantly saves the environment from degradation. We note that a 1% increase in institutional quality leads to a decline in CO₂ emissions of 0.119–0.195%. The existing literature reveals that institutions determine our choices and provide incentives for the sustainable use of natural resources, which enhances environmental quality [44, 107]. Moreover, Panayotou [114] revealed that “countries with the same level of per capita income may consciously adopt more or less stringent environmental policies based on differences in educational level, quality of policy making institutions and bureaucracy, rule of law, etc.”. This empirical evidence is similar to that of Ibrahim and Law [70].

Urbanization has a positive and significant effect on CO₂ emissions, i.e., $a_{U} > 0$. We note that a 1% increase in urbanization leads to an increase in CO₂ emissions of 0.82–2.3%. The positive effect of urbanization on carbon emissions is similar to Lin et al. [97], Liddle [96], Iwata and Okada [74], Hou et al. [67], and Shahbaz et al. [131]. For instance, Lin et al. [97] examined the relationship among population, urbanization, and atmospheric pollution in China. They concluded that population is the main factor to influence CO₂ emissions and that the level of urbanization plays a significant role. The reason for this phenomenon is that immigration flows have been internally generated in recent years in China as a result of the process of industrial growth. Liddle [96] applied a population-based framework, i.e., a STIRPAT model, to examine the association between urban density and CO₂ emissions. He noted that population size and urban density are determining factors that affect environmental quality. Iwata and Okada [74] analyzed the effect of population and urbanization on carbon emissions in 119 countries. Their empirical analysis indicated that population leads to urbanization that positively and significantly affects CO₂, CH₄, and NO₂ emissions. Hou et al. [67] find that population and the degree of urbanization affect emissions. Similarly, Shahbaz et al. [131] reported that urbanization was initially accompanied by low carbon emissions; however, after a certain level, it impedes environmental quality, i.e., it has a U-shaped effect. We may conclude that urbanization exerts a negative effect on environmental quality.

Trade openness is negatively and significantly linked with carbon emissions. This reveals that trade openness is environmentally friendly. We note that a 1% increase in trade openness leads to a decrease in CO₂ emissions by 0.321%. This empirical finding is consistent with Jayanthakumaran et al. [77], Shahbaz et al. [128], Dogan and Turkecul [48], and Al-Mulali et al. [6]. This result can be justified by the view that trade openness improves environmental quality, as the technique effect dominates the scale effect [53, 127, 128]. We may argue that in the transition from a developing to developed stage, the scale effect implies trade liberalization, which increases exports and, by extension, economic growth. Otherwise, the composition effect changes the industrial structure of an economy through trade liberalization, and the technique effect boosts economies to use more efficient and cleaner technologies. Consequently, the net effect of a reduction of CO₂ emissions can be justified by the existence of comparative advances in environmentally clean industries and improvements in energy efficiency [20, 21, 128]. Recently, Shahbaz et al. [132] examined the association between trade openness and carbon emissions using data for low-, middle-, and high-income countries for the period 1980–2014. They found that trade openness was initially positively aligned with carbon, and after a certain level of trade openness, CO₂ emissions begin to decline, i.e., the EKC effect.

The relationship between economic globalization and CO₂ emissions is negative and statistically significant at a 1% level. We note that a 1% increase in economic globalization leads to a decrease in CO₂ emissions of 0.846%. This implies that economic globalization is environmentally friendly. This result is linked with the empirical literature that considers the economic globalization process in terms of instruments of efficiency and technical progress. Cavlovic et al. [33] establish the existence of a direct relationship between low levels of economic globalization and high pollution intensity levels. They suggest that in the long-term, globalization might be expected to have a positive impact on economic efficiency (technique effect) and improve environment quality. Therefore, increased competition, which is shaped by economic globalization, will reduce technical inefficiency and pollution [139]. This empirical evidence is similar to that of Shahbaz et al. [131].

Similarly, the social globalization process is understood in terms of increasing access to education and information about the negative side effects of consumption and production, and environmental awareness increases with the demand for “cleaner” products [103]. The impact of social globalization is positive and significant at a 1% level. We note that a 1% increase in social globalization leads to an increase in CO₂ emissions of 0.334%. This result is in opposition to the “global environmental awareness” hypothesis, which suggests that globalization decreases environmental pressures [46]. Our results support the “socio-cultural distancing hypothesis,”

which assumes that social globalization will increase ecological pressures [43, 108, 118]. Thus, the critical drivers of social globalization (e.g., dairy consumption, mobility, international tourism, and especially the air transport system¹⁰) will increase environmental damage [108]. Shahbaz et al. [131] also reported that social globalization impedes environmental quality.

The effect of overall globalization is positive and significant on carbon emissions. It shows that globalization is not environmentally friendly. We note that a 1% increase in overall globalization leads to an increase in CO₂ emissions of 0.754%.¹¹ Our study supports Dinda’s [46] “global environmental awareness” hypothesis for economic globalization, and social and overall globalization implies a direct negative effect on CO₂ emissions. The effect of social globalization on CO₂ emissions is mainly due to an increase in the air transport process [43, 108].¹² Our results suggest the existence of a negative relationship between overall globalization and CO₂ emissions under the “global environmental governance failure” hypothesis, which supports a positive correlation between political globalization and environmental pollution [108]. These results are consistent with Shahbaz et al. [130, 131]. However, Shahbaz et al. [132] noted that overall globalization has a positive and significant effect on carbon emissions.

We have also included interactions of institutional quality with FDI, trade openness, and globalization (economic, social, and political) in the carbon emissions function for the G7 countries.¹³ The results, reported in Table 1, reveal that interaction between institutional quality and FDI has a negative but significant impact on carbon emissions. This empirical evidence confirms the presence of a dampening effect. It indicates that the intent of strict environmental regulations coupled with high punitive penalties for contaminators is that foreign manufacture companies implement cleaner, more efficient, and more environmentally friendly means of

¹⁰ Over the period from 1975 through 2004, the annualized growth rate for ocean transport was 3.8%, while for air transport, the growth rate was 8.4% [69]. Consistent with the disparity between the growth rates of aviation and other modes of transport, the Stern report (2007) projects that—between 2005 and 2050—emissions are expected to grow fastest from aviation (tripling over the period, compared to a doubling of road transport emissions) (Stern 2007).

¹¹ The impact of political globalization on CO₂ emissions is positive but statistically insignificant.

¹² The overall globalization disclosures inform nations and people about how to improve institutions and structures. In many cases when there is suffering from a lack of democracy, accountability and transparency, globalization may contribute to power abuses (and potential damages over environmental processes) [59]. This abuse is shaped more by increased consideration about investment objectives than by environmentally sustainable consumption, production and trade.

¹³ The hypothesis of interaction effects seeks to determine under what conditions a relationship becomes stronger or weaker, disappears or changes direction. The moderator variable may be qualitative or quantitative, and it affects the magnitude and/or direction of a relationship between an independent variable (predictor) and dependent variable (criterion) [37].

production [95, 106].¹⁴ Under the correct institutional quality, the globalization process can also help lessen and prevent environmental damage [108]. For example, international trade can help spread the most-sophisticated environmental solutions far and wide, particularly with regard to global warming, and it applies innovations to green technologies.

The impact of the interaction between institutional quality and trade openness has a negative but insignificant effect on carbon emissions. Kaufmann et al. [82] indicate that institutions do indeed improve as a result of trade openness in countries that can expect to capture institutionally intensive sectors after trade opening. Meanwhile, Levchenko [94] considers that institutions play dual roles: they generate rents for some parties within the economy, and they are a source of comparative advantage in trade openness. In addition, this dual role implies that the increasing openness for institutional quality will depend on technological development similarity between the trading countries. The results of our study are compatible with Frankel and Rose [56], who consider both income and trade openness to be endogenous variables through the use of a gravity model of bilateral trade and endogenous growth. This study shows that air pollution is an externality, and society must engage both an adequate level of income and effective institutional quality to reduce environmental pollution. Therefore, and in accordance with this fact, institutional instruments are necessary to restrain the damaging effects of trade and economic growth on environmental quality. These results are similar to those obtained by Chintrakarn and Millimet [35] and Kellenberg [83]. Moreover, Cole and Elliott [39] establish that trade openness would increase the production share in countries with comparative advantages. Instead, trade openness would reduce the comparative advantage of capital-intensive goods in high-income countries with relatively strict environmental policies. However, capital-intensive industries present the comparative advantage of having such goods in countries with less stringent environmental regulations. Therefore, the production of capital-intensive goods¹⁵ will decrease under more stringent regulation (institutional quality), and, by extension, this will reduce environmental pollution [99].

The interaction terms between institutional quality and economic globalization and between institutional quality and social globalization negatively but insignificantly affect environmental degradation. These results are in line with the

theoretical framework of endogenous growth theory, where globalization is understood as a driving force for global economic growth [31]. Consequently, the globalization process can be considered an opportunity to make more efficient use of available resources [43]. Globalization enables the transfer of advanced technology (technique effect), and political decisions will promote the division of labor and increase the comparative advantage with beneficial environmental consequences [24, 25]. In contrast, an inadequate property rights protection system with a low level of institutional quality will increase uncertainty and volatility, with pernicious influences on investments and research in clean production processes [18, 61].

The joint (interaction) effect of institutional quality and political globalization on CO₂ emissions is negative and significant at a 1% level. An extensive literature search has empirically confirmed that the quality of institutions is a significant element of economic growth and the political integration process ([1, 49, 87, 93, 117], among others). In addition, the “global environmental governance” hypothesis suggests that under a high institutional capacity, the political globalization process will lower ecological pressures [118]. In addition, the globalization literature establishes that the association between globalization and institutional quality depends both on the level of economic development and on the presence of natural resources¹⁶ [26]. Antweiler et al. [10] describe the “factor endowments hypothesis” (FEH), in which globalization leads to an increase in emissions in capital-abundant countries and to a reduction in capital-scarce countries.

Overall, the coefficient of R^2 shows that the carbon emissions function is well explained, i.e., more than 80%, by its determinants. This is an indication of the goodness-of-fit of the empirical model(s). The overall significance of the carbon emissions function(s) is confirmed by the F-statistic, which is highly significant at the 1 and 5% levels.¹⁷ Lastly, we applied the Hansen-J test of overidentification. The F-statistic (p values are in brackets) of the Hansen-J test indicates confirmation of the null hypothesis. The null hypothesis of the Hansen-J test assumes that the instruments used in the model are appropriate, i.e., the empirical model is well specified. These empirical findings show that the model is valid for empirical analysis by applying the GMM approach.

Figure 7 shows the empirical results of the interaction between institutional quality and globalization indicators on

¹⁴ It is argued by Neequaye and Oladi [106] that the relationship between FDI and carbon emissions is linked with a wide number of factors. These are factors such as technology usage for domestic production. The adoption of energy-efficient technology for production lessens carbon emissions (technique effect) and institutional quality, whereas environmental regulations and corruption can affect emissions directly by increasing the cost of production [20, 41] and indirectly through FDI, i.e., the pollution haven hypothesis [63].

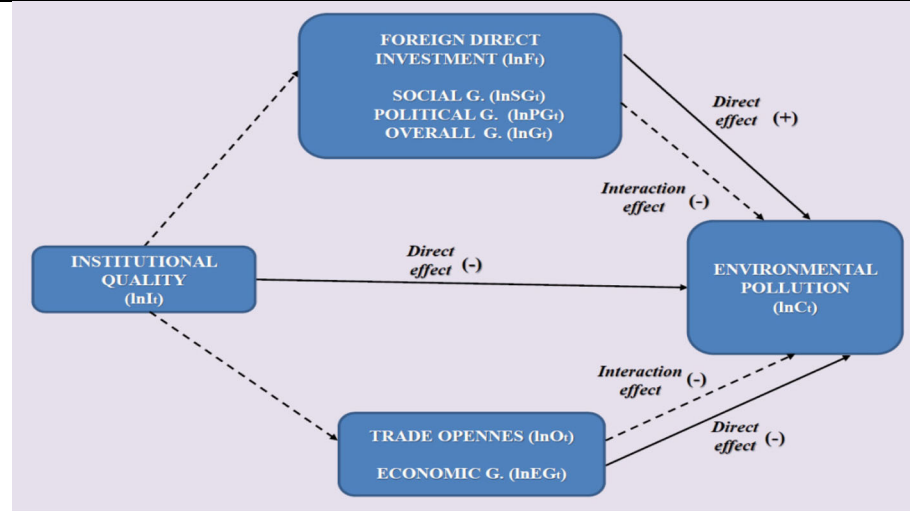
¹⁵ Cole and Elliott (2003) establish a strong correlation between a sector's capital intensity and its pollution intensity, where the capital-intensive goods can be considered pollution goods.

¹⁶ In societies, when there is a tendency toward decreasing institutional quality, this tendency should be particularly strong when there is an abundance of valuable natural resources. In other words, resource abundance correlates with a lower quality of government in general [9]. Therefore, some studies support a correlation between resource abundance and institutional quality ([3]; Treisman 2000; [92]).

¹⁷ The adjusted- R^2 indicates the percentage of variation explained by determinants of CO₂ emissions. Comparatively, a moderate value of adjusted- R^2 also corroborates R^2 , which is used for the goodness-of-fit of empirical model(s).

Fig. 7 Interaction effects between institutional quality and globalization. Source: Prepared by authors

Interaction Effects between Institutional Quality and Globalization



Source: Prepared by authors

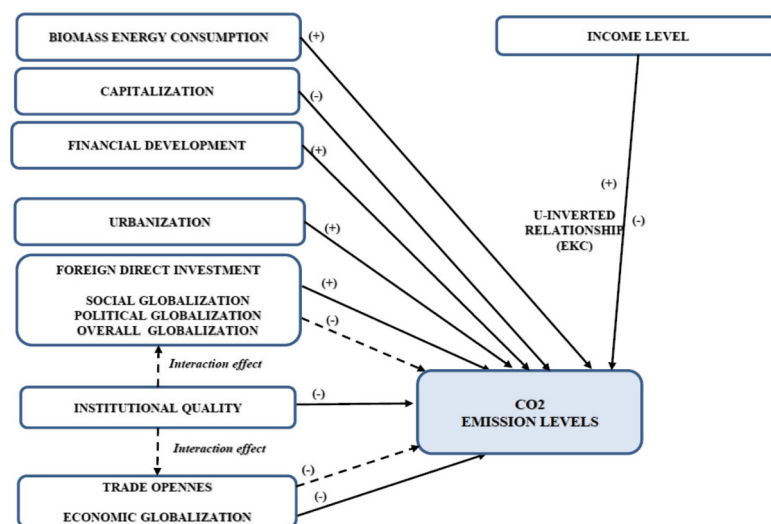
carbon emissions. The impact of the influencing factors of CO₂ emissions is described in Fig. 8. The empirical analysis confirms the presence of an inverted U relationship between economic growth and environmental degradation, i.e., EKC for G-7 countries. An increase in biomass energy consumption stimulates CO₂ emissions. The elasticity of CO₂ emissions with respect to capital formation, trade openness, overall globalization, and institutional quality is negative and significant. However, financial development, urbanization, and globalization (social and political) exert positive effects on carbon emissions. The impact of economic globalization on CO₂ emissions is positive and significant.

5 Conclusions and Policy Implications

This study has examined the validity of the environmental Kuznets curve hypothesis in G-7 countries in the presence of biomass energy use and other explanatory variables, such as capitalization, financial development, FDI, urbanization, trade openness, institutional quality, and globalization. The empirical results from the generalized method of moments (GMM) confirm the existence of an inverted U-shaped relationship (i.e., the EKC) between economic growth and CO₂ emissions in G-7 countries for the period 1980–2014. The EKC hypothesis is detected, which indicates that an increase in GDP per

Fig. 8 Conceptual scheme of empirical analysis. Source: Prepared by authors

Conceptual Scheme of Empirical Analysis



Source: Prepared by authors

capita leads to environmental improvements after the threshold income level. Countries should project boosts to their income levels. Biomass energy consumption increases CO₂ emissions. Administrations might implement policies to replace this source with other renewable sources by controlling air pollution levels. Improvements in governance are important for the improvement in the quality of the environment. Otherwise, it is assumed that countries that produce biomass energy should support other renewable sources, because the empirical evidence has proven a negative relationship with the environmental pollution process.

To improve environmental quality, administrations should continue to improve their capitalization amenities and reduce the rate of urban population expansion with new local strategies of suburban development. Given the positive role that trade openness and institutional quality exert over economic globalization, these factors can support the adoption of clean technologies, and administrations should increase public efforts in environmental protection. The results also show that improvements in institutional quality will reduce environmental pollution. Therefore, it would be effective to increase efforts to improve environmental policies and institutions rather than limit FDI and globalization activities that reduce environmental quality. In addition, institutional quality helps increase positive effects on the environmental correction process more so than trade openness and economic globalization. Therefore, to correct the negative effect of FDI on carbon emissions, administrations might promote energy efficiency and energy R&D policies under strong environmental regulations coupled with high punitive consequences for contaminators to reduce energy intensity and carbon emissions.

Finally, we have outlined some options that encompass a wide range of non-regulatory and regulatory approaches that the state may wish to consider if it determines that further actions are needed to protect environmental quality. One of the greatest concerns about biomass energy consumption is indoor air pollution, which has been found to cause serious health problems. Smoke from incomplete combustion during the burning of biomass contains a large number of pollutants, such as CO₂ emissions and suspended particulate matter (SPM), which have been associated with public health risks. Therefore, future studies might explore the control of endogenous SPM within the EKC model to estimate the income levels that are necessary to reduce environmental damage.

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