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Biofuel energy consumption-economic growth relationship: an empirical investigation of Brazil

Usama Al-Mulali, Sakiru Adebola Solarin, Multimedia University, Melaka, Malaysia
Ilhan Ozturk, Cag University, Mersin, Turkey

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Abstract: This study investigates the influence of biofuel energy consumption on Brazil's economic growth during the period 1980–2012 by employing the Autoregressive Distributed Lag (ARDL) approach and the vector error correction model (VECM) Granger causality. The results revealed two structural breaks during the early 1980s due to the Latin American debt crisis as well as the early 2000s due to the worries related to the increasing global spreads. Moreover, it was found that economic growth, biofuel energy consumption, capital, urbanization, and globalization are co-integrated. Additionally, it was found that biofuel energy consumption, capital, urbanization, and globalization increase Brazil's economic growth in the short run and in the long run. However, the two structural breaks have a significant negative influence on economic growth. The vector error correction model Granger causality revealed a feedback causal relationship between all the variables (with the exception of capital). However, a unidirectional causality was concluded from capital to economic growth, biofuel energy consumption, urbanization, and globalization. From the results of this study, a number of policy implications were provided. © 2016 Society of Chemical Industry and John Wiley & Sons, Ltd

Keywords: biofuel energy consumption; Brazil economic growth; ARDL approach; VECM Granger causality

Introduction

It is well known that Brazil is one of the major emerging economies in the world which witnessed a remarkable boost in its economic growth and development during the last three decades. Brazil is the seventh biggest economy in the world based on the gross domestic product (GDP) in 2014.[1] This impressive economic growth and development is fueled by the consumption of energy. During the last three decades, Brazil's primary energy consumption increased over 66%.[2] Moreover, a sizable amount of Brazil's primary energy consumption comes from imported fossil fuels which can threaten Brazil's energy security. Therefore, the Brazilian government undertook different programs and policies to reduce the country's dependency on fossil fuels by promoting renewable energy. Consequently, the country's renewable energy consumption is increasing, especially the consumption of biofuel. The level of biofuel ethanol energy consumption increased from only 63 900 barrels per day in 1980 to

Correspondence to: Ilhan Ozturk, Faculty of Economics and Administrative Sciences, Cag University, 33800 Mersin, Turkey.
E-mail: ilhanozturk@cag.edu.tr

359 000 barrels per day in 2012. Thus, exploring the influence of biofuel ethanol energy consumption on Brazil's economic growth is essential.

Investigating the relationship between energy consumption and economic growth has been well established by different scholars who examined different countries and regions. Most of the energy-GDP growth nexus literature utilized total energy consumption.[3–38] Another group of scholars disaggregated energy consumption in two different types from fossil fuels energy sources[9, 29,39–45] and renewable energy sources[32, 39, 46, 55] Most of the studies found that there is a long-run relationship between energy consumption and GDP growth.[4–7, 9, 10, 12–16, 18–21, 23, 27,30, 33, 34, 37–42, 44–46, 48, 50, 53, 56–58]

The causality between energy consumption and GDP growth is well examined in the literature. A group of studies found a bi-directional causality between the two components,[3,4,13,15,18,19,21,23, 25, 30–34,36, 38–40,42,44–47,49,50,53,54,57–59] which is called feedback hypothesis. The feedback hypothesis means that both energy consumption and economic growth are jointly determined and influence each other in the same time. In addition, a number of studies found a unidirectional causal relationship from energy consumption to GDP growth[3,4,5,12–14,16,17,20,23,25,27,29,31–33,36,37,47,49, 51,54,56,58–60] and from GDP growth to energy consumptionm[3,6,7,10,18,25,29,31,32,36,38,41,46,47,49,52] these relationships are called growth hypothesis and conservation hypothesis. The growth hypothesis explains that energy consumption plays an important role on economic growth and any energy conservation policies will have an adverse effect on economic growth. On the other hand, the conservation hypothesis implies that any conservation policies will have no or only a small impact on economic growth.

However, few studies found no causality between the two variables[10,17,21,25,31,33,36,49,54,59] this relationship is called neutrality hypothesis.* This hypothesis explains that energy consumption is not connected with economic growth and any energy conservation policies will have no effect on economic growth.

From the outcome of the energy consumption-GDP growth nexus literature (Table 1), it is clear that the significance of energy consumption-GDP growth relationship is present in most of the investigated countries despite their differences in the level of income and economic development.

Despite the substantial literature review, there are only a few studies that have examined the biofuel energy consumption-GDP nexus relationship. A number of scholars such as Yildirim *et al*.,[25] Bildirici,[61] Ohler and Fetters,[62] Ozturk and Bilgili,[63] Al-mulali,[64] and Qiao *et al.*[65] have investigated the biofuel energy consumption- GDP growth relationship in the United States, 10 developing and emerging countries, 20 OECD countries, sub-Sahara African countries, G7 countries, 16 major biofuel consuming countries, and China, respectively. The outcome of these studies reached the conclusion that biofuel energy consumption has a long-run significant effect on the investigated countries' GDP growth.[61–65] Moreover, biofuel energy consumption has a positive influence on GDP growth in the long run.[61–64] The causality between biofuel energy consumption and GDP growth has also been investigated by these scholars. Feedback causality was found between the two components by Ohler and Fetters[62] and Al-mulali[64] while a unidirectional causality was found from biofuel energy consumption to GDP growth by Yildirim *et al.*[25] and Bildirici.[61] Recently, Ozturk[66] examined the interrelationship between biofuel consumption and production as well as several national-scale indicators of socioeconomic and environmental sustainability by using the functional form of the Solow growth model. Panel data from 2000 to 2013 was used to examine 12 distinct countries by employing the Panel Generalized Method of Moments (PGMM) technique. The results show that growth factors have a positive impact on biofuel consumption while environmental indicators increase along with the increasing use of biofuels.

From the empirical literature it is clear that most of the scholars reached inconsistent conclusions due to the different methodologies and variables that they utilized in their studies. However, most of the studies were consistent in one important conclusion: energy consumption, whether it is from renewable or non-renewable sources, is still an important determinant of economic growth and development in the long run which contains important consequences for policy implications. However, in terms of the causality relationships, the outcomes of the previous studies were inconsistent with each other. The Granger causality outcome reveals that the conservation hypothesis is present in developed nations.[10,25,28,32,36,46,47,49,54] However, the growth hypothesis[3,16,23,31] and the feedback hypothesis[3,7,15,19,25,31,40,42,53,57] are more present in emerging countries. This outcome shows that for any country in the initial stage of economic development, energy consumption is an important source of economic growth. In the initial stage of economic development, the country's economic growth will increase much faster than that of developed countries. Therefore, this rapid

*To fully understand these hypotheses, please refer to Ozturk I, A literature survey on energy–growth nexus. *Energy Policy,* **38**:340–349 (2010).

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Table 1: Summary of literature on GDP growth-energy nexus

Author(s)	Time period	Country/region	Methodology	Variables	cointe-gration	long run relationship between GDP and energy consumption	Causality between GDP and energy consumption
Studies on total energy and economic growth							
Soytas & Sari[6]	1950–1994	Developed and emerging countries.	VECM Granger causality.	GDP and total electricity consumption	Na	Na	Bi-directional in Argentina. Unidirectional from GDP to electricity consumption in Italy and South Korea. Unidirectional from electricity consumption to GDP in Turkey, France, Germany and Japan.
Oh & Lee[4]	1970–1999	South Korea.	Johansen cointegration and VECM Granger causality.	GDP, total energy consumption, capital and labor.	Yes	Na	Bi-directional.
Lee[5]	1975–2001	18 developing Asian countries.	Pedroni cointegration, fully modified ordinary least square (FMOLS) and vector error correction model (VECM) Granger causality.	GDP and total energy consumption.	Yes	Yes +	Unidirectional from energy consumption to GDP.
Lise & Montfort[6]	1970–2003	Turkey.	VECM Granger causality.	GDP and total energy consumption.	Yes	Na	Unidirectional from GDP to total energy consumption.
Mozumder & Marathe[7]	1971–1999	Bangladesh	Johansen cointegration and Pair-wise Granger causality.	GDP and total electricity consumption.	Yes	Na	Unidirectional from GDP to total electricity consumption.
Narayan & Smyth[37]	1972–2002	G7 countries.	Pedroni contegration, Westerlund cointegration, FMOLS, dynamic OLS (DOLS) and VECM Granger causality.	GDP, total energy consumption and capital.	Yes	Yes+	Unidirectional from total energy consumption to GDP.
Hu & Lin[9]	1982–2006	Taiwan	Threshold cointegration and VECM model.	GDP and total energy and electricity consumption, oil consumption, coal consumption and natural gas consumption.	Yes excluding oil consumption.	Na	Na

Table 1. (Continues)

Narayan & Prasad[36]	1965–2002	OECD	Bootstrapped causality.	GDP and total electricity consumption.	Na	Na	Bi-directional between total electricity consumption and GDP in UK, South Korea and Iceland. Unidirectional from total electricity consumption to GDP in Australia, Italy, the Slovak Republic, the Czech Republic, Portugal. Unidirectional from GDP to electricity consumption in Finland, Hungary and Netherlands. No causality between total electricity consumption and GDP in Belgium, Canada, Denmark, France, Germany, Greece, Ireland, Japan, Luxembourg, New Zealand, Norway, Poland, Spain, Sweden, Switzerland, Turkey, Mexico, and the USA.
Huang *et al*[10]	1972–2002	82 countries based on income level.	System GMM.	GDP and total energy consumption.	Na	Na	Unidirectional from GDP to total energy consumption positively in middle-income countries and negatively in high-income countries. No causality between total energy consumption and GDP in low-income countries.
Apergis & Payne[12]	1980–2004	Central American countries.	Pedroni cointegration, FMOLS and VECM Granger causality.	GDP, total energy consumption, labor and capital.	Yes	Yes+	Unidirectional from total energy consumption and GDP.
Apergis & Payne[13]	1991–2005	Commonwealth of Independent States.	Pedroni cointegration, FMOLS and VECM Granger causality.	GDP, total energy consumption, labor and capital.	Yes	Yes+	Unidirectional from total energy consumption and GDP.
Odhiambo[14]	1971–2006	Tanzania	ARDL and VECM Granger causality.	GDP, total energy and electricity consumption.	Yes	Na	Unidirectional from energy and electricity consumption to GDP.
Belloumi[15]	1971–2004	Tunisia	Johansen cointegration and VEC, Granger causality.	GDP and total electricity consumption.	Yes	Na	Bi-directional between total electricity consumption and GDP.

Tsani [59]	1960–2006	Greece	Toda and Yamamoto Granger causality.	GDP, total energy consumption and energy consumption from industrial, residential and transportation.	Na	Na	Unidirectional from total energy consumption to GDP. Bi-directional between residential, industrial and GDP. No causality between transport energy consumption and GDP.
Apergis & Payne[16]	1980–2005	South American countries.	Pedroni cointegration, FMOLS and VECM Granger causality.	GDP, total energy consumption, capital and labor.	Yes	Yes+	Unidirectional from total energy consumption to GDP.
Balcilar *et al*.[17]	1960–2006	G7 countries.	Bootstrap Granger non-causality.	GDP and total energy consumption.	Na	Na	Unidirectional from total energy consumption to GDP in Canada. No causality between total energy consumption and GDP for the rest of the countries.
Ozturk *et al*.[18]	1971–2005	Low and middle-income countries.	Pedroni cointegration and VECM Granger causality.	GDP and total energy consumption.	Yes	Na	Unidirectional from GDP to total energy consumption for low-income countries. Bi-directional between total energy consumption and GDP for the middle-income countries.
Ozturk & Acaravci[19]	1980–2006	Albania, Bulgaria, Hungary and Romania.	ARDL and VECM Granger causality.	GDP and total energy consumption.	Yes for Hungary only	Na	Bi-directional between total energy consumption and GDP in Hungary.
Narayan & Popp[38]	1980–2006	93 countries by region.	Pedroni cointegration and long run panel causality.	GDP and total electricity consumption.	Yes	Na	Bi-directional between total electricity consumption and GDP in all regions except for Middle East unidirectional from GDP to total electricity consumption.
Wang *et al*.[20]	1972–2006	China	ARDL and VECM Granger causality.	GDP, total energy consumption, capital and labor.	Yes	Yes+	Unidirectional from energy consumption and GDP.
Eggoh *et al*.[21]	1970–2006	African countries.	Pedroni and Westerlund cointegration tests, OLS, FMOLS, DOLS , pooled mean group, VECM Granger causality.	GDP, total energy consumption, capital, labor and consumer price index.	Yes	Yes+	Bi-directional between total energy consumption and GDP.
Kahsai *et al*.[23]	1980–2007	Sub-Saharan African countries.	Pedroni cointegration, FMOLS and VECM Granger causality.	GDP, total energy consumption and consumer price index.	Yes	Yes+	Bi-directional between total energy consumption and GDP for the full sample and the low-income countries. Unidirectional from total energy consumption to GDP for middle-income countries.

Table 1. (Continues)

Dagher & Yacoubian[24]	1980–2009	Lebanon	Johansen cointegration, Hsiao,Toda-Yamamoto,and VECM Granger causality.	GDP and total energy consumption.	Yes	Na	Bi-directional between energy consumption and GDP.
Yildirim & Aslan[25]	1960–2009	17 highly developed OECD countries.	Toda–Yamamoto and bootstrap-corrected Granger causality.	GDP and total energy consumption.	Na	Na	Bi-directional between total energy consumption and GDP in Italy, New Zealand, Norway and Spain. Unidirectional from GDP to total energy consumption in directional causality from GDP to energy is found for Australia, Canada and Ireland. Unidirectional from total energy consumption to GDP in Japan. No causality between total energy consumption and GDP in for the rest of the countries.
Ouedraogo[26]	1980–2008	West African countries.	Pedroni, Kao and fisher type cointegration, FMOLS, DOLS and VECM Granger causality.	GDP, total electricity and energy consumption and energy prices.	Yes	Yes+	Bi-directional between total energy consumption and GDP. Unidirectional from electricity consumption to GDP.
Dergiades *et al.*[27]	1980–2008	Greece.	Johansen cointegration, vector autoregression (VAR) Granger causality and Non-parametric causality.	GDP and total energy consumption.	Yes	Na	Unidirectional from total energy consumption to GDP.
Salamaliki & Venetis[28]	1970–2010	G7 countries.	Multiple horizon causality testing, sequential causality testing and Toda and Yamamoto Granger causality.	GDP, total energy consumption, capital stock and labor.	Na	Na	Unidirectional from GDP to energy consumption.
Zhang & Yang[29]	1978–2009	China.	Toda and Yamamoto Granger causality	GDP, total energy consumption, coal, gas and oil consumption, capital and employment.	Na	Na	Unidirectional from total energy and coal, oil and gas consumption to GDP.
Mohammadi & Parvaresh[30]	1980–2007	14 oil exporting countries.	Fixed effect, group mean and pooled model, mean-group estimation of the error correction model.	GDP, total energy consumption, urbanization, exports and CO_2 emission.	Na	Yes+	Bi-directional between total energy consumption and GDP.

Wolde-Rufael[31]	1975–2010	Transition countries.	Bootstrap panel causality approach.	GDP and total electricity consumption.	Na	Na	Unidirectional from total electricity consumption to GDP in Belarus and Bulgaria. Unidirectional from GDP to total electricity consumption in Czech Republic, Latvia, Lithuania and the Russian Federation. Bi-directional between total electricity consumption and GDP in Ukraine. No causality in Albania, Macedonia, Moldova, Poland, Romania, Serbia, Slovak Republic and Slovenia.
Tiwari[32]	1973–2011	USA	Hatemi-J asymmetric Granger-causality	GDP, total energy consumption, total electricity consumption, coal consumption, natural gas consumption and renewable energy consumption.	Na	Na	Bi-directional causality between natural gas, total energy consumption and renewable energy consumption and GDP. Unidirectional from GDP to coal consumption. Unidirectional from total electricity consumption to GDP.
Al-mulali & Ozturk[33]	1980–2012	Gulf Cooperation Council (GCC) countries.	ARDL and Toda and Yamamoto causality.	GDP, total electricity consumption, capital, labor, imports and exports of goods and services.	Yes	Yes+	Bi-directional between total electricity consumption and GDP in Bahrain and the United Arab Emirates. Unidirectional from total electricity consumption to GDP in Oman and Qatar. No causality between total electricity consumption and GDP in Kuwait and Saudi Arabia.
Lin & Wesseh, P. K[55]	1971–2010	South Africa	ARDL and bootstrap Granger causality.	GDP, total energy consumption and employment.	Yes	Yes+	Bi-directional causality between total energy consumption and GDP.
Iyke[60]	1971–2011	Nigeria.	Johansen and threshold cointegration and VECM Granger causality.	GDP, total electricity consumption and inflation.	Yes	Na	Unidirectional from total electricity consumption to GDP.
Kyophilavong *et al.*[34]	1980–2012	Thailand.	ARDL, Bayer and Hanck cointegration and VECM Granger causality.	GDP, total energy consumption, capital and labor.	Yes	Yes+	Bi-directional between total energy consumption and GDP.

Table 1. (Continues)

Studies on renewable energy and economic growth							
Yoo & Ku[46]	1985–2005	20 nuclear consuming countries.	Johansen cointegration, VECM Granger causality and Hsiao's Granger causality.	GDP and nuclear energy consumption.	Yes for Pakistan and South Korea only	Na	Bi-directional causality between nuclear energy consumption and GDP in Switzerland. Unidirectional from GDP to nuclear energy consumption in France and Pakistan. Unidirectional from nuclear energy consumption and GDP in South Korea.
Wolde-Rufael & Menyah[47]	1971–2005	9 developed countries.	Toda and Yamamoto Granger causality.	GDP, nuclear energy consumption, capital and labor.	Na	Na	Unidirectional from nuclear energy consumption to GDP in Japan, Netherlands and Switzerland. Unidirectional from GDP to nuclear energy consumption in Canada and Sweden. Bi-directional between nuclear energy consumption and GDP in France, Spain, the United Kingdom and the United States.
Apergis & Payne[48]	1992–2007	Eurasian countries.	Pedroni cointegration, FMOLS and VECM Granger causality.	GDP, renewable energy consumption, capital and labor.	Yes	Yes+	Bi-directional between renewable energy consumption and GDP.
Nazlioglu *et al.*[49]	1980–2007	OECD countries.	Ko´nya Granger causality and Toda and Yamamoto Granger causality.	GDP and nuclear energy consumption.	Na	Na	Bi-directional causality between nuclear energy consumption and GDP in UK and USA. Unidirectional from nuclear energy consumption to GDP in UK, Spain, Germany and Finland. Unidirectional from GDP to nuclear energy consumption in Canada, Hungary, Japan, Korea, and Sweden. No causality between nuclear energy consumption and GDP for the rest of the OECD countries.
Apergis & Payne[29]	1990–2007	80 developed and developing countries.	Pedroni cointegration, FMOLS and VECM Granger causality.	GDP, renewable and non-renewable energy consumption, capital and labor.	Yes	Yes+ for both renewable and non-renewable energy consumption.	Bi-directional between renewable and non-renewable energy consumption and GDP.

Shahbaz *et al*.[50]	1972–2011	Pakistan	ARDL and VECM Granger causality.	GDP, renewable and non-renewable energy consumption, capital and labor.	Yes	Yes+	Bi-directional between renewable and non-renewable energy consumption and GDP.
Aslan & Çam[51]	1985–2009	Israel.	Bootstrap-corrected causality and Toda and Yamamoto Granger causality.	GDP, nuclear energy consumption, capital and labor.	Na	Na	Unidirectional from nuclear energy consumption to GDP.
Ocal & Aslan[52]	1990–2010	Turkey.	ARDL and Toda and Yamamoto causality.	GDP and renewable energy consumption.	Yes	Yes-	Unidirectional from GDP to renewable energy consumption.
Al-mulali[53]	1990–2010	30 major nuclear consuming countries.	Pedroni cointegration, FMOLS and VECM Granger causality.	GDP, nuclear energy consumption, fossil fuels energy consumption, investment and capital.	Yes	Yes+	Bi-directional between nuclear energy consumption and GDP.
Chang *et al*.[54]	1971–2011	G6 countries.	Emirmahmutoglu and Kose bootstrap causality.	GDP and nuclear energy consumption.	Na	Na	Unidirectional from GDP to nuclear energy consumption for all countries. Bi-directional between nuclear energy consumption and GDP in United Kingdom. Unidirectional from nuclear energy consumption to GDP in Germany. No causality for the rest of the G6 countries.
Lin & Moubarak[55]	1977–2011	China.	ARDL and VECM Granger causality.	GDP, renewable energy consumption, labor and CO_2 emission.	Yes	Na	Bi-directional causality between renewable energy consumption and GDP.
Shahbaz *et al*.[50]	1972–2011	Pakistan.	ARDL and VECM Granger causality.	GDP, renewable energy consumption, capital and labor.	Yes	Yes+	Bi-directional between renewable energy consumption and GDP.
Studies on fossil fuel energy consumption and economic growth							
Zhang & Yang[29]	1978–2009	China.	Toda and Yamamoto Granger causality	GDP, total energy consumption, coal, gas and oil consumption, capital and employment.	Na	Na	Unidirectional from total energy and coal, oil and gas consumption to GDP.

Table 1. (Continues)

Das *et al.*[41]	1980–2010	Bangladesh.	Johansen cointegration and pairwise Granger causality.	GDP and natural gas consumption.	Yes	Na	Unidirectional from GDP to natural gas consumption.
Satti *et al.*[42]	1974–2010	Pakistan	ARDL and VECM Granger causality.	GDP, coal consumption, unemployment, urbanization, service sector value and fiscal deficit.	Yes	Na	Bi-directional between coal consumption and GDP.
Manso & Behmiri[43]	1980–2012	Latin American countries.	Pedroni cointegration, FMOLS and VECM Grager causality.	GDP, oil consumption and oil prices.	Yes	Yes+	Unidirectional from oil consumption to GDP in Central America. No causality between oil consumption and GDP in Caribbean and South America.
Solarin & Shahbaz[44]	1971–2012	Malaysia.	ARDL and VECM Granger causality.	GDP, Natural gas consumption, foreign direct investment, capital formation and trade openness.	Yes	Yes+	Bi-directional between natural gas consumption and GDP.
Ozturk & Al-Mulali[45]	1980–2012	GCC countries.	Pedroni cointegration, FMOLS, DOLS and VECM Granger causality.	GDP, natural gas consumption, trade, capital and labor.	Yes	Yes+	Bi-directional between natural gas consumption and GDP.

increase in economic growth requires energy to engine it, as the more developed the country becomes, the more the economic growth level will start to fall as well as the consumption of energy (as the country becomes more productive and more energy efficient) and its importance to engine economic growth. Thus, growth and the feedback hypothesis are more present in emerging countries while the conservation hypothesis is more present in developed countries.

Moreover, from the literature it is clear that there is a lack of empirical studies that have examined the biofuel energy consumption-GDP growth nexus relationship in Brazil. Brazil is the largest biofuel energy producer and consumer in the world after the United States in 2014.[67] Therefore, the researchers of this study found it essential to examine the biofuel consumption- GDP growth relationship in Brazil.

From the foregoing papers, it is also observed that in addition to the conventional causality tests, the bound testing of Pesaran *et al.* (2001)[73] has been used in the studies with limited data span. The use of a bound testing approach to estimate the long-run and short-run parameters is not surprising because the approach is not affected by a small sample size problem (unlike most of the other existing cointegration methods) in addition to the fact that it provides long- and short-run parameters of the model. Being a paper with a limited sample size (which has 33 observations), we utilize the bound testing of Pesaran *et al.*[73] to investigate the relationship between the series.

Model construction, data, and estimation strategy

Model construction

In order to examine the relationship between energy use and output growth, we used the augmented neoclassical framework available in the works of Yuan *et al.*[68] and Solarin and Ozturk.[69] The approach suggests that national output is a function of energy consumption, capital stock, and labor force. In other words, there is a direct influence of energy consumption, capital stock, and labor force on economic performance. The aggregate production function is stated as follows:

$$GDP_t = f(CAP_t, LAB_t, ENE_t) \quad (1)$$

where GDP is the real GDP; CAP is the capital stock represented by the real gross fixed capital formation,; LAB is labor force, which is represented by the total population in the country; and ENE is ethanol consumption (fuel ethanol consumption in barrels per day, which has been selected as the only proxy for ethanol indicator because of data limitation). In order to generate the per capita variants of the variables, we divided GDP, ENE, and CAP by the total population. We also transformed the variables into their logarithmic form and the resulting baseline empirical equation is as follows:

$$\ln Y_t = \alpha_1 + \alpha_2 \ln K_t + \alpha_3 \ln E_t + \alpha_4 T + \alpha_5 D_1 + \alpha_6 D_2 + \mu_t \quad (2)$$

where Y is the real GDP per capita, K is the real gross fixed capital formation per capita, and E is the ethanol consumption per capita. We also provided for two structural breaks in the model. T is the time trend and the two D_t represent the dummy variables, which capture two structural breaks. The structural breaks were selected based on the structural breaks in the unit root analysis of real GDP at level. Beyond energy consumption and capital stock, there are other variables that influence the aggregate output of an economy. Hence, we introduced few variables and, so the following equation is also investigated:

$$\ln Y_t = \alpha_1 + \alpha_2 \ln K_t + \alpha_3 \ln E_t + \alpha_4 \ln Z_t + \alpha_5 T + \alpha_6 D_1 + \alpha_7 D_2 + \mu_t \quad (3)$$

where *Z* depicts the vector of control variables, which include U or urban population ratio; TG represents aggregate globalization index; and EG depicts economic globalization index. These additional variables are sequentially introduced into the model because of the small sample size of our dataset. The role of the other variables (besides ethanol consumption, which has been explained) has been well-discussed in the literature. For instance, capital stock is a significant factor in production function as capital stock improves the potential national output. Economic development is not feasible in the absence of industrial machinery, bridges, good roads, effective railways systems, and ports which are all physical capital. Although the relationship between capital and energy is debatable, Ebohon[70] argues that energy complements the role of capital in developing countries. Moreover, the inclusion of more variables such as capital incorporates more information that affects aggregate output than in the bivariate case, in which energy alone is considered as the sole factor. In the past, the previous literature included capital formation in energy-growth equation.[69,71]

Urbanization is a major characteristic of economic development, especially in developing countries, where the pace of urbanization is most significant. In developing countries, urbanization triggers several structural shifts throughout the economy and has important implications on energy consumption. The increase in economic activities, resulting from urbanization, causes the demand for energy (including electricity) consumption to rise.[72] Halicioglu[35] argues that it is not only energy consumption, but also urbanization that matters in the process of economic development. Few studies have included urbanization as one of the potential determinants of economic growth in an energy consumption-economic growth equation.[30,42,72]

Globalization increases the total factor productivity by enhancing trading activities of a nation. The transfer of sophisticated technology and foreign direct investment from advanced countries can boost the economic activity of developing economies. International trade in merchandise can enhance the standard of living of the citizenry. Trade is, in some ways, a type of technology. A nation that eliminates restrictions on international trade will usually enjoy technological change. Globalization promotes the division of labor and enhances the comparative advantages of various nations. Globalization generates investment opportunities through foreign capital inflows. It is reported that globalization influences energy demand and environmental quality by transferring the pollution-inclined technology to nations where environmental regulations are feeble, especially in the underdeveloped economies.

Data collection

The data for real GDP (constant 2005 US$), real gross fixed capital formation (constant 2005 US$), urban population ratio, and total population of the country have been attained from the World Bank's *World Development Indicators*. The data for ethanol consumption (fuel ethanol consumption in barrels per day) was collected from *Energy Information Administration* database. Data for both the aggregate globalization index and economic globalization were generated from Dreher.[24] We used these globalization indicators to represent globalization instead of the trade openness, which is known to be somewhat distorted as it does not capture the size of barriers (tariff or non-tariff) to foreign trade. The globalization index is based on three different components: economic, political, and social globalization. The economic globalization index is based on two sub-indexes: (i) actual economic flows (trade, portfolio investment, and foreign direct investment) and (ii) restrictions to trade and capital (which include capita and trade restrictions that consist of hidden import barriers, mean tariff rates, taxes on international trade as a share of current revenue, and an index of capital controls).[†]

Unit root tests

Time series literature provides several unit root tests including the Kwiatkowski *et al.*[74] or KPSS test, which assumes a null of stationarity. There are several concerns with this test including the fact that it does not provide for structural breaks. In response, many unit root tests have been devised to allow structural breaks.[75] Most of these unit root tests include exogenous and endogenous break unit root tests. Exogenous break unit root tests have been criticized because of their arbitrary approach of choosing the break date. Besides, the endogenous break unit root tests usually find and include the number of breaks that are pre-specified in the model tests. This feature may weaken the reliability of the tests because one or more unnecessary breaks are likely to be included in the unit root test.[75] In other words, endogenous break unit root tests are less powerful than exogenous unit root tests when the break date is known previously. Therefore, it is necessary to adopt a method that combines the merits of both exogenous and endogenous unit root tests.

The Lee *et al.*[75] test considers a two-step procedure to identify breaks and test for a unit root. The first step examines the presence of structural breaks in the series, while the second step involves testing for a unit root. To identify and test the significance of breaks, the test adopts a maximum F (*maxF*) test. Since the location and/or existence of breaks are known following the first step, the exogenous test is adopted in the second step. This is important, because the exogenous tests have greater power than the endogenous tests. The Lee *et al.*[75] test starts with the following data generating process (DGP), which is premised on component representation:

$$y_t = \delta' \Delta Z_t + e_t,\ e_t = \beta e_t + \varepsilon_t \qquad (4)$$

where Z_t is the vector containing the exogenous series and $\beta = 1$ is the null of the unit root hypothesis. Because of its capacity to shift in both level and trend, the generalized form of the model can be expressed as $Z_t = [1, t, D_{1t}, DT_t^*]'$. In order to provide for several breaks, more dummy variables can be incorporated into the regression as follows:

$$Z_t = [1, t, D_{1t}^*, \ldots, D_{Rt}^*, DT_{1t}^*, \ldots, DT_{Rt}^*]' \qquad (5)$$

[†]See in details http://globalization.kof.ethz.ch/

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where $D^*_{1t} = 1$ for $t \geq T_B + 1$, $i = 1,\ldots, R$, and 0, otherwise, and $D^*_{1t} = t - T_{Bi}$ for $t \geq T_B + 1$ and 0 otherwise. T_{Bi} represents the location of the breaks. The null restriction of $\beta = 1$ is levied based on the LM (score) procedure and the regression in differences is used in the first stage as follows:

$$\Delta y_t = \delta' \Delta Z_t + u_t \tag{6}$$

where $\delta = [\delta_1, \delta_2, \delta'_{3i}, \delta'_{4i}]'$, $i = 1,\ldots, R$. Subsequently, the statistics of the unit root test can be obtained from the following regression:

$$\Delta y_t = \delta' \Delta Z_t + \varphi \tilde{S}_{t-1} + e_t \tag{7}$$

where $\tilde{S}$ shows the detrended series as follows:

$$\tilde{S}_t = y_t - \tilde{\psi} - Z_t \tilde{\delta}, \tag{8}$$

where the coefficientis $\tilde{\delta}$ derived from Eqn (5) by employing the first-differenced data and $\tilde{S}_t = y_t - Z_1\tilde{\delta}$. This process removes the dependency of the nuisance parameters from the crash model. However, the dependency on nuisance parameters is not removed in the model with trend breaks. As shown by Lee *et al.*,[75] the asymptotic distribution of the test statistic for the trend break model relies on the nuisance parameters, λ^*_i showing the fraction of subsamples in each regime such that $\lambda^*_i = T_{B1}/T$, $\lambda^*_i = (T_{Bi} - T_{Bi-1})/T$, $i = 2,\ldots, R$ and $\lambda^*_{R+1} = (T - T_{BR})/T$. According to Lee *et al.* (2012),[75] the dependency of the test statistic on the nuisance parameter can be removed by performing the following transformation:

$$\tilde{S}^*_t = \begin{cases} \dfrac{T}{T_{B1}} \tilde{S}_t & \text{for } t \leq T_{B1}, \\ \dfrac{T}{T_{B2} - T_{B1}} \tilde{S}_t & \text{for } T_{B1} \prec t \leq T_{B2}, \\ \vdots & \\ \dfrac{T}{T_{B1} - T_{BR}} \tilde{S}_t & \text{for } \leq T_{BR} \prec t \leq T, \end{cases} \tag{9}$$

Thereafter, $\tilde{S}_{t-1}$ in Eqn (7) is substituted withsuch $\tilde{S}^*_{t-1}$ that:

$$\Delta y_t = \delta' \Delta Z_t + \phi \tilde{S}^*_{t-1} + \sum_{j=1}^{k} d_j \Delta \tilde{S}_{t-j} + e_t, \tag{10}$$

where the t-staticstics for $\phi = 0$ is denoted by $\tilde{\tau}^*_{LM}$. Due to this transformation, the unit root statistic, $\tilde{\tau}^*_{LM}$ does no longer rely on the nuisance parameter λ_i in the model with a trend break. As the distribution is given as the sum of R+1 independent stochastic terms, the asymptotic distribution of $\tilde{\tau}^*_{LM}$ is a function of the number of trend shifts. Under the scenario of one shift in the trend (R=1), the distribution of $\tilde{\tau}^*_{LM}$ is identical to the untransformed case ($\tilde{\tau}_{LM}$) using the $\lambda = 1/2$ regardless of the first location of shift(s). Equally, in the case of dual shifts in the trend, (R=2), the distributions of $\tilde{\tau}^*_{LM}$ is identical to the untransformed case ($\tilde{\tau}_{LM}$) using the $\lambda_1 = 1/3$ and $\lambda_1 = 2/3$. Similar procedure is obtainable for the case of multiple shifts in the trend such that the distributions of the transformed test $\tilde{\tau}^*_{LM}$ and untransformed test $\tilde{\tau}_{LM}$ are identical for $\lambda_i = i/(R + 1)$, $i = 1\ldots, R$. Therefore there is no need for simulation of new critical at all possible break point combinations. All that is required are the critical values that coincide with the number of breaks. The augmented terms of $\Delta\tilde{S}_{t-j}$ are incorporated into the estimations to make sure that no serial correlations exist in the errors.

ARDL cointegration approach

After investigating the unit root properties of the variables, we employed the bound testing procedure that was introduced by Pesaran *et al.*[73] to investigate cointegration for long-run relationship between real GDP, capital formation, and biofuel consumption in the Brazilian economy. The Autoregressive Distributed Lag (ARDL) approach was chosen because it ensures consistent and efficient test statistics for short-spanned data. The unrestricted error correction model variant of the baseline regression in Eqn (2) is stated as follows:

$$\begin{aligned} \Delta \ln Y_t = {} & \alpha_1 + \sum_{i=1}^{k} \alpha_2 \Delta \ln Y_{t-i} + \sum_{i=1}^{k} \alpha_3 \Delta \ln K_{t-i} \\ & + \sum_{i=1}^{k} \alpha_4 \Delta \ln E_{t-i} + \alpha_5 Y_{t-1} + \alpha_6 K_{t-1} \\ & + \alpha_7 E_{t-1} + \alpha_8 T + \alpha_9 D_1 + \alpha_{10} D_2 + \upsilon_t \end{aligned} \tag{11}$$

The null hypothesis of no-cointegration $\alpha_5 = \alpha_6 = \alpha_7 = 0$ is tested against the alternative hypothesis of $\alpha_5 \neq \alpha_6 \neq \alpha_7 \neq 0$[‡]. After testing the long-run correlation in the series and finding the long-run coefficients, we investigated the short-run coefficients. Thus, the following short-run model of Eqn (2) was used:

$$\begin{aligned} \Delta \ln Y_t = {} & \alpha_1 + \sum_{i=1}^{k} \alpha_2 \Delta \ln Y_{t-i} + \sum_{i=0}^{k} \alpha_3 \Delta \ln K_{t-i} \\ & + \sum_{i=0}^{k} \alpha_4 \Delta \ln E_{t-i} + \alpha_5 \Delta T + \alpha_6 \Delta D_1 \\ & + \alpha_7 \Delta D_2 + \alpha_8 ECT_{t-1} + \upsilon_t \end{aligned} \tag{12}$$

[‡]We also test for cointegration with the capital formation and ethanol consumption expressed as dependent variables. However, we do not express the equations here in order to conserve space.

α_8 is the coefficient depicting the speed of adjustment and it is the residuals generated from the regression in Eqn (2). For the ECT to be useable, it must have a negative and significant negative coefficient. The same procedure is also applied to the three equations involved in Eqn (3), in which the additional variables are introduced into the model.

VECM Granger causality test

The presence of cointegration between the variables compelled us to examine the causal association. It is indicated by Granger[76] that the VECM is suitable to examine causality between the variables in the presence of cointegration, if all the variables have unique order of integration. The VECM Granger causality provides the causal association between the variables not only in the long run but also in the short run. The functional form of the baseline model is stated as follows:

$$\Delta \ln Y_t = \alpha_{11} + \sum_{i=1}^{k} \alpha_{12} \Delta \ln Y_{t-i} + \sum_{i=1}^{k} \alpha_{13} \Delta \ln K_{t-i} + \sum_{i=1}^{k} \alpha_{14} \Delta \ln E_{t-i} + \alpha_{15} T + \alpha_{16} \Delta D_1 + \alpha_{17} \Delta D_2 + \alpha_{18} ECT_{t-1} + \upsilon_t \quad (13)$$

$$\Delta \ln K_t = \alpha_{21} + \sum_{i=1}^{k} \alpha_{22} \Delta \ln Y_{t-i} + \sum_{i=1}^{k} \alpha_{23} \Delta \ln K_{t-i} + \sum_{i=1}^{k} \alpha_{24} \Delta \ln E_{t-i} + \alpha_{25} T + \alpha_{26} \Delta D_1 + \alpha_{27} \Delta D_2 + \alpha_{28} ECT_{t-1} + \upsilon_t \quad (14)$$

$$\Delta \ln B_t = \alpha_{31} + \sum_{i=1}^{k} \alpha_{32} \Delta \ln Y_{t-i} + \sum_{i=1}^{k} \alpha_{33} \Delta \ln K_{t-i} + \sum_{i=1}^{k} \alpha_{34} \Delta \ln E_{t-i} + \alpha_{35} T + \alpha_{36} \Delta D_1 + \alpha_{37} \Delta D_2 + \alpha_{38} ECT_{t-1} + \upsilon_t \quad (15)$$

The *F*-test of joint significance of these lagged terms was utilized to examine the short-run Granger causality. For instance, causality runs from ethanol consumption to real GDP emission in the short term if the joint null hypothesis is rejected as $\alpha_{14} \neq 0\forall$. The parameter associated with ECT signifies the speed of adjustment to the long-run equilibrium. The *t*-test for the coefficient of ECT provided the estimates of the long-run Granger causality. A significant ECT coefficient suggests that previous equilibrium errors play important roles in determining present values. If the coefficient α_{18} is negative and significant in Eqn (13), then capital formation and ethanol consumption Granger cause real GDP in the long term. The same analysis can be applied to the remaining equations.

Results and discussion

A descriptive presentation of the variables is presented in Table 2, which shows several statistics of all the variables in this study. With an average GDP per capita of US$4389.629 (or USD$8.387 in natural logarithm), Brazil has one of the largest GDP per capita among the emerging countries. With an average real gross capital formation per capita of US$849.7991 (or USD$6.745 in natural logarithm), Brazil has one of the largest real gross capital formation per capita among the developing countries. The Jarque-Bera statistics suggest that all the variables follow the normal distribution. Hence, the use of natural logarithm removed any possibility of non-normality in the variables. The pair-wise correlation estimates for the series in this study are also reported in Table 2. We used the Spearman's rank correlation coefficient, which could tell whether the correlation is positive or negative. The statistics show that there is positive and significant correlation between most of the variables. For example, GDP per capita has positive and significant correlation with the other series.

In order to conduct the cointegration test, we needed information on the integration properties of the series. For this purpose, we estimated unit roots of real GDP per capita, capital formation, ethanol consumption, urbanization, aggregate globalization index, and economic globalization index by using the Kwiatkowski *et al.*[74] tests. The results of the tests are presented in Table 3. The empirical outputs suggest that the null of stationarity can be rejected at 1% for all the series in the level forms. However, the null of stationarity cannot be rejected, when the variables are entered in their first difference.

Due to the concerns over the presence of structural breaks in the series, we applied the Lee *et al.*[75] test to examine the unit root properties of the series. We found that the variables are not stationary at level. However, when the variables are entered in the first difference, they are stationary at 5% significance level or better. From the foregoing results, we can say that the series has a unique level of integration, i.e., I(1). The structural breaks show that 29% (or 7 breaks) of the total 24 breaks are located in the early 1980s. This period coincide with the occurrence of the Latin American debt crisis. Brazil, alongside most with its Latin American neighbors, borrowed heavily from

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Table 2. Descriptive statistics and correlation analysis.

Variables	ln Y_t	ln K_t	ln E_t	ln U_t	ln TG_t	ln EG_t
Mean	8.387	6.745	–0.850	4.343	3.948	3.874
Median	8.363	6.714	–0.813	4.361	4.001	3.864
Maximum	8.664	7.142	–0.315	4.441	4.094	4.051
Minimum	8.188	6.508	–1.656	4.182	3.736	3.720
Std. Dev.	0.124	0.167	0.314	0.081	0.131	0.099
Jarque-Bera	3.326 (0.190)	4.257 (0.119)	2.426 (0.297)	2.928 (0.231)	4.018 (0.134)	1.873 (0.392)
ln Y_t	1.000					
ln K_t	0.654*** (0.000)	1.000				
ln E_t	0.387** (0.010)	0.249 (0.162)	1.000			
ln U_t	0.938*** (0.000)	0.468*** (0.000)	0.304* (0.085)	1.000		
ln TG_t	0.862***(0.000)	0.396** (0.023)	0.172 (0.339)	0.947*** (0.000)	1.000	
ln EG_t	0.752*** (0.000)	0.252 (0.157)	–0.032 (0.859)	0.837*** (0.000)	0.913*** (0.000)	1.000

All the variables are expressed in logarithmic form. The probability values are reported in the parenthesis.

international creditors in the 1960s and 1970s. Therefore, the funds that were meant to solve unemployment, poverty, and other social issues were used to pay the debt. Consequently, economic growth stagnated, real wage declined, unemployment rose to high levels, and inflation accelerated.[76] Another 29% (or 7 breaks) of the total 24 breaks are located in the early 2000s. Brazil underwent severe stress tests in this period due to worries related to the increasing global spreads, especially on the corporate bonds in the USA. The economy registered unexpected decrease of capital flows, rising public debt profile, and the currency lost half of its value.[77]

Having determined that the variables are integrated of order (1), we proceeded to the cointegration test, which is augmented with two dummies representing the structural breaks in the years 1983 and 2002. From Table 4, it is observed that there is a long-run link in Model 1, which includes real GDP, capital formation, and ethanol consumption. The F-statistics (7.541) is above the upper bounds critical values (6.570) at 5% significance level. By introducing urbanization into the regression in Model 2, we observed that the F-statistics (6.293) are above the upper bounds critical values (5.795) at 5% significance level. The F-statistics (9.876 and 16.782) are above the upper bounds critical values (7.730) at 5% significance level when aggregate globalization index and economic globalization index are introduced in Model 3 and Model 4, respectively. The foregoing results illustrate that there is at least one cointegrating vector in each of the four models examined, when real GDP is entered as the dependent variable.

After finding cointegration among the variables, we can report the long-run and short-run results in Table 5. In Model 1 of Table 5, we examined the long-run and short-run impact of ethanol consumption and capital formation on economic performance. The results show that both capital formation and ethanol consumption are positively linked to economic performance. Keeping other factors constant, we noted that a 100% increase in ethanol consumption leads to economic growth by 2.2% in the country. Moreover, 100% rise in capital formation will improve economic performance by 13.9% in Brazil. The positive impact of the ethanol consumption is consistent with the studies of Solarin and Shahbaz[72] for Angola, Al-mulali[53] for 30 major nuclear consuming countries, Mohammadi and Parvaresh[30] for 14 oil exporting countries, Solarin and Shahbaz[44] for Malaysia, and Solarin and Ozturk[69] for seven Latin American countries. However, these results are contrary to the results of Ocal and Aslan[52] for Turkey. The difference between the results of our paper and that of Ocal and Aslan[52] can be attributed to the fact that the two studies have used different samples, sources of energy and time periods.

We observed that the structural breaks in 1983 and 2002 have negative long-run impact on economic growth.

Proceeding to the short-run results, it is observed that ethanol consumption does not significantly affect economic growth. There is positive and significant impact of capital formation on economic growth in the short run at 1% significance level. The estimate of ECMt–1 is negative and significant, which suggest that the yearly speed of adjustment towards long-run is 84.1% at 1% significance level.

By introducing urbanization in Model 2, we observed that ethanol consumption, capital formation, and

Table 3. Unit root test.

Variable	KPSS test	LM test						
	T-statistics	T-statistics	TB1	TB2	DU1	DT1	DU2	DT2
ln Y_t	0.283***	–2.415 [0]	1983	2002	0.010 (0.402)	0.068*** (4.434)	–0.035 (–1.383)	0.014*** (3.575)
Δln Y_t	0.050[1]	–7.689*** [0]	1984	1991	0.062** (2.459)	0.021 (1.351)	–0.056*** (–2.297)	0.073*** (5.410)
ln K_t	0.366***[0]	–3.419[0]	1984	2002	0.023 (0.347)	0.180*** (4.634)	–0.118* (–1.782)	0.023 (0.870)
Δln K_t	0.070[0]	–5.997[0]	1985	1989	0.296*** (3.443)	–0.050 (–0.932)	–0.196** (–2.571)	0.272*** (4.841)
ln E_t	0.280[0]	–3.703[1]	1984	2005	0.040 (0.391)	–0.295*** (–4.761)	–0.182 (–1.613)	0.267*** (4.319)
Δln E_t	0.022[0]	–4.897*** [0]	1983	2007	0.363** (2.567)	–0.437*** (–4.215)	0.114 (0.805)	0.140* (1.822)
ln U_t	0.800***[0]	–2.070[0]	1987	1999	0.001 (1.635)	–0.003*** (–9.964)	0.005*** (7.747)	–0.006*** (–23.524)
Δln U_t	0.114[1]	–20.788*** [0]	1982	2000	0.001 (1.249)	–0.014*** (–28.798)	–0.004*** (–7.793)	0.001*** (3.131)
ln TG_t	0.222***[1]	–3.389 [0]	1987	1998	–0.077*** (–4.187)	0.041*** (4.665)	0.007 (0.386)	–0.039*** (–4.705)
Δln TG_t	0.015[0]	–9.921*** [0]	1987	1992	–0.069*** (–3.957)	0.050*** (5.010)	0.008 (0.492)	–0.078*** (–7.622)
ln EG_t	0.235***[0]	–2.404*** [0]	1999	2002	–0.128*** (–3.357)	0.098*** (4.149)	–0.053 (–1.627)	–0.105*** (–4.326)
Δln EG_t	0.008[0]	–4.570*** [0]	2000	2003	0.280*** (7.303)	–0.122*** (–5.158)	0.075** (2.259)	0.093*** (3.766)

***, ** and * denote significance at the 1%, 5% and 10% levels, respectively. TB stands for the estimated break points. The critical values for the KPSS test are 0.216, 0.146 and 0.119 at the 1%, 5% and 10% levels, respectively. The critical values for the LM test are -4.689, -4.183 and -3.921 at the 1%, 5% and 10% levels, respectively. TB1 and TB2 stand for the structural break dates. DU1 and DU2 stand for the dummy variables for breaks in intercept, while DT1 and DT2 stand for the dummy variables for trend breaks. Critical values for the other coefficients are based on the standard t-distribution 1.65, 1.96, 2.58 With maximum lag set at 4, the optimal lags are selected based on Akaike Information Criterion. The optimal lag length are reported in the brackets, while the t-statistics are reported in parenthesis.

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urbanization have a positive influence on economic growth in the country. Urbanization has a positive influence on economic growth in both the short run and the long run. We observed that the structural breaks in 1983 and 2002 have a negative long-run impact on economic growth, which is not surprising considering the facts that these periods were associated with economic crises. In the short run, ethanol consumption has an insignificant positive impact on economic growth, while it has a significant positive impact on both capital formation and urbanization. The estimates of ECM_{t-1} are negative and significant, which suggest that the yearly speed of adjustment toward the long run is 25.1% at 1% significance level.

By introducing the total globalization index in Model 3, we observed that ethanol consumption, capital formation, and urbanization have a positive influence on economic growth in the country. The overall globalization index comprises economic, political, and social dimensions of globalization. However, in this study, we focused on the economic dimension of globalization. Therefore, we replaced the overall globalization with economic globalization in Model 4. Economic globalization has a positive impact on economic growth at 1% significance level. The other results are similar to the previous output. The diagnostics tests indicate that all the models are free from serial correlation and heteroscedasticity. Functional form tests proposed by Ramsey[78] and normality tests provide evidence for well specified model and normally distributed error, respectively. With these results, logarithmic transformation has erased normality problems in the estimation. CUSUM and CUSUMSQ tests largely support stability of the coefficients of regression equations.

Table 6 deals with long-run and short-run causal relationship between the variables. We included two dummies, which are based on the shift found in the unit root test (the dependent variable of the concerned equation), to capture the structural breaks in each equation. For instance, in all the equations involving real GDP as the dependent variable, the incorporated dummies capture the breaks that exist in 1983 and 2002. Moreover, in all the equations involving ethanol as the dependent variable, the included dummies capture the breaks that exist in 1984 and 2005.

In Panel A of the Table, we dealt with the causal relationship involving real GDP, capital formation, and ethanol consumption. There is a long-run evidence of unidirectional causality from capital formation to economic performance without feedback in the long run. There is long-run causality from ethanol consumption to economic performance with feedback from economic growth. Long-run unidirectional causality exists from capital formation to ethanol consumption and economic performance. There is no short-run causality between ethanol consumption and economic growth. Short-run unidirectional causality exists from capital formation and real GDP to ethanol consumption.

In Model 2, we introduced urbanization into the causal relationship and observed that causal relationship between the baseline variables remained unchanged. There is a long-run feedback relationship between urbanization and economic growth as well as between urbanization and capital formation. However, long-run unidirectional causality exists from capital formation to urbanization. Similar bidirectional relationship exists between urbanization and ethanol consumption. There is no causality between urbanization and the remaining variables in the short run.

In Model 3 of the causal analysis, we introduced the aggregate globalization index into the causal analysis. In addition to finding similar results with the foregoing analysis, we noted that on one hand a bidirectional causality exists between total globalization index as well as economic growth, and on the other hand, there is a bidirectional causality between total globalization index and ethanol consumption. A unidirectional causality is present from capital formation to total globalization index in both the short run and in the long run.

In Model 4 of the analysis, the economic globalization is introduced into the analysis. Bidirectional causality is present between economic globalization index and economic growth in the long run. There is a long-run bidirectional causality between economic globalization index and ethanol consumption. A unidirectional causality is present from capital formation to economic globalization index in the long run but there is no relationship in the short run.

The bidirectional causality between ethanol consumption and economic growth is consistent with the works of Apergis and Payne[39] for 80 developed and developing countries, Shahbaz *et al.*[40] for Pakistan, Mohammadi and Parvaresh[30] for 14 oil exporting countries, and Kyophilavong *et al.*[34] for Thailand. There are several justifications for the positive causality flowing from ethanol consumption to economic growth. The results fulfil the role of energy as one of the main determinants of output. The country continues to generate increasing level of biofuel ethanol energy for economic activities. According to Energy Information Administration[3], biofuel ethanol energy consumption increased by more than 200% in

Table 4. Bound testing approach to cointegration.

Model		F-stat	Lag	χ^2_{serial}	χ^2_{ARCH}	χ^2_{Normal}	χ^2_{Ramsey}
Model 1	$\ln Y_t = f(\ln K_t, \ln E_t)$	7.541**	(1,0,0)	0.854[1]	0.169[1]	0.625[2]	0.469[1]
Model 2	$\ln Y_t = f(\ln K_t, \ln E_t, \ln U_t)$	6.293**	(1,1,0,0)	0.163[1]	0.743[1]	0.976[2]	0.248[1]
Model 3	$\ln Y_t = f(\ln K_t, \ln E_t, \ln TG_t)$	9.876***	(1,1,1,1)	0.332[1]	0.109[1]	0.760[2]	0.223[1]
Model 4	$\ln Y_t = f(\ln K_t, \ln E_t, \ln EG_t)$	16.782***	(1,0,1,1)	0.880[1]	0.728[1]	0.657[2]	0.154[1]

For the three-variable model, the critical values (for lower and upper bounds) are (7.643 9.063) (5.457 6.570) (4.517 5.480), at 1%, 5% and 10%, respectively. For the four-variable models, the critical values (for lower and upper bounds) are (6.380 7.730) (4.568 5.795) (3.800 4.888), at 1%, 5% and 10%, respectively. The breaks included in the model are dummies for 1983 and 2002.

Table 5. Long-run and short-run coefficients.

Panel A: Long-run elasticities				
Independent Variable	Model 1	Model 2	Model 3	Model 4
$\ln K_t$	0.271*** (5.438)	0.139*** (2.991)	0.236*** (5.720)	0.251** (2.172)
$\ln E_t$	0.022** (2.013)	0.054*** (2.702)	0.013*** (2.599)	0.038*** (2.608)
$\ln U_t$	–	4.678*** (5.041)	–	–
$\ln TG_t$	–		0.402*** (3.285)	–
$\ln EG_t$	–		–	0.446*** (3.074)
Constant	6.380*** (15.955)	26.697 (1.241)	8.129***	4.696** (2.280)
Trend	0.030 (0.850)	0.144 (1.090)	0.017 (2.594)	0.093 (1.034)
Dummy 1983	–0.023*** (–2.645)	–0.091*** (–2.900)	–0.003** (–2.102)	–0.091*** (–2.978)
Dummy 2002	–0.007*** (–2.683)	–0.023*** (–2.609)	0.003 (1.053)	–0.009 (0.006)
Panel B: Short-run elasticities				
Independent Variable	Model 1	Model 2	Model 3	Model 4
$\Delta\ln K_t$	0.228*** (4.621)	0.305*** (8.374)	0.328*** (8.712)	0.293*** (8.571)
$\Delta\ln E_t$	0.018 (1.025)	0.013 (0.796)	0.016 (0.772)	0.010 (0.671)
$\Delta\ln U_t$	–	6.699** (1.961)	–	–
$\Delta\ln TG_t$	–	–	–0.411** (2.152)	–
$\Delta\ln EG_t$	–	–		–0.021 (–0.290)
Δ Constant	5.366*** (5.501)	–	5.944*** (2.762)	1.194 (1.087)
Δ Trend	0.025 (0.883)	0.036 (1.703)	0.012 (0.646)	0.024 (1.322)
Δ Dummy 1983	–0.019 (–0.664)	–0.023 (–1.158)	–0.002 (–0.103)	–0.023 (–1.266)
Δ Dummy 2002	–0.006** (2.367)	–0.006 (–0.768)	0.002 (1.144)	–0.002 (–1.243)
ECM (-1)	–0.841*** (–6.413)	–0.251* (–1.786)	0.731*** (–2.918)	–0.254* (–1.839)
Adjusted R^2	0.681	0.854	0.872	0.875
Diagnostic test				
Test	Model 1	Model 2	Model 3	Model 4
χ^2_{SERIAL}	0.682[1]	0.390[1]	0.404[2]	0.316[1]
χ^2_{ARCH}	0.455[1]	0.366[1]	0.632[1]	0.464[1]
χ^2_{NORMAL}	0.812[1]	0.642[1]	0.312[2]	0.364[1]
χ^2_{RESET}	0.879[1]	0.121[1]	0.105[1]	0.151[1]
CUSUM	Stable	Stable	Stable	Stable
CUSUMSQ	Stable	Stable	Stable	Stable

The optimal lag length is determined by Akaike Information Criterion. The probability values are reported and the parenthesis contains the standard errors while the bracket contains the order of diagnostic tests.

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Table 6. Granger causality test.

Panel A: Model 1

Dependent Variable	Direction of Causality			
	Short Run			Long Run
	Δ ln Y_{t-i}	Δ ln K_{t-i}	Δ ln E_{t-i}	*ECT*
Δ ln Y_t	–	2.421 (0.120)	0.362 (0.548)	–0.444** [1.999]
Δ ln K_t	1.618 (0.203)	–	0.027 (0.871)	–0.286 [–1.149]
ln Δ E_t	9.192*** (0.002)	5.896** (0.015)	–	–0.760*** [–5.634]

Panel B: Model 2

Dependent Variable	Direction of Causality				
	Short Run				Long Run
	Δ ln Y_{t-i}	Δ ln K_{t-i}	Δ ln E_{t-i}	Δ ln U_{t-i}	ECT_{t-1}
Δ ln Y_t	–	0.342 (0.558)	1.365 (0.243)	0.289 (0.591)	–0.444** [–2.176]
Δ ln K_t	2.182 (0.140)	–	0.001 (0.991)	0.001 (0.999)	–0.223 [–1.125]
Δ ln E_t	9.679*** (0.002)	6.799*** (0.009)	–	0.218 (0.640)	–0.560*** [–5.129]
Δ ln U_t	2.536 (0.111)	1.154 (0.283)	1.303 (0.254)	–	–0.248*** [–8.913]

Panel C: Model 3

Dependent Variable	Direction of Causality				
	Short Run				Long Run
	Δ ln Y_{t-i}	Δ ln K_{t-i}	Δ ln E_{t-i}	Δ ln TG_{t-i}	ECT_{t-1}
Δ ln Y_t	–	1.863 (0.172)	0.001 (0.985)	0.211 (0.646)	–0.723** [–2.185]
Δ ln K_t	0.076 (0.783)	–	1.106 (0.293)	0.111 (0.739)	–0.059 [–1.444]
Δ ln E_t	27.099*** (0.000)	15.820*** (0.000)	–	6.922*** (0.009)	–0.695*** [–6.756]
Δ ln TG_t	0.002 (0.969)	4.652** (0.032)	0.325 (0.569)	–	–0.166*** [–6.154]

Panel D: Model 4

Dependent Variable	Direction of Causality				
	Short Run				Long Run
	Δ ln Y_{t-i}	Δ ln K_{t-i}	Δ ln E_{t-i}	Δ ln EG_{t-i}	ECT_{t-1}
Δ ln Y_t	–	2.129 (0.145)	1.348 (0.246)	0.014 (0.906)	–0.587** [–1.961]
Δ ln K_t	2.453 (0.117)	–	0.005 (0.942)	0.405 (0.525)	–0.179 [–0.697]
Δ ln E_t	11.782*** (0.001)	7.110*** (0.008)	–	2.998* (0.083)	–0.806*** [–6.081]
Δ ln EG_t	0.687 (0.407)	0.171 (0.679)	0.008 (0.928)	–	–0.331*** [–5.976]

***, ** and * denote significance at the 1%, 5% and 10% levels, respectively. The parentheses contain the probability values, while the brackets contains the t-statistics.

1980–2012. In the same period, the real GDP increase by more than 30%. Fuel-ethanol facilitates a tangible and defensible transition towards sustainable energy development, which is increasingly considered valuable by energy intensive businesses. Lastly, it provides a critical back up to grid electricity, which is significantly compromised by climate-induced drought conditions. Apart from creating energy in Brazil, another important economic contribution of ethanol is in terms of tax revenues generated from the different entities within the industries.

Fuel-ethanol in Brazil provides the chance assisting to reduce environmental degradation as well as generating new channels of income. This activity is a significant part of the financial income for peasant families. Due to the substitution of gasoline program (which entails the expansion of domestic available energy resources including ethanol), that started in the late 1970s, the country has been able to save several billions of dollars from imports expenditures, foreign exchange, and interest on foreign debt.[79]

The positive causality from capital to economic growth is not surprising because infrastructural facilities have been one of the main drivers of economic development in the country. The long-run positive causality from globalization to economic growth can be explained on the basis of the contribution of globalization to the economy of Brazil. In the 1980s, foreign companies created subsidiaries and enhanced bilateral arrangements with Brazil. Globalization, through more foreign investment, also reduced corruption in Brazil. The country has also included several concepts of globalization to improve its economic performance. For instance, Brazil turned to exports in the 1980s in order to boost its economy. Brazil shifted from the model of self-sufficiency and import substitution, which has caused slow or no growth by the 1980s. In the process, Brazil became a member of the Mercosur and World Trade Organization, which allows free trade across all the member countries and several trade barriers are eliminated. This has increased the size of markets for goods and services produced in Brazil and also helped the country to grow its economy.

The long-run positive causality from urbanization to economic growth is not surprising given the fact that the urban centres in Brazil are important to the prosperity of the country. Brazil is a heavily urbanized nation with more than 80% of its populace resides in the urban centres and 90% of GDP is created in cities.[80] This result may not be peculiar to Brazil, as global cities and towns are the centres of affluence since more than 80% of global economic activities are produced by urban citizens, who constitute just over 50% of the global population.[81]

Conclusion and policy implications

The main aim of this research is to examine the impact of biofuel energy consumption on the Brazilian economic growth during the period 1980–2012. To achieve this object, an augmented neoclassical model was constructed. Moreover, the Autoregressive Distributed Lag (ARDL) approach and the vector error correction model (VECM) Granger causality were implemented. Several structural breaks were found in the early 1980s and early 2000s due to the Latin American debt crisis and the worries related to the increasing global spreads. The results revealed that economic growth, biofuel energy consumption, capital, urbanization, and economic globalization are co-integrated. Moreover, biofuel energy consumption, capital, urbanization, total population, and globalization increase Brazil's economic growth. However, the two structural breaks found to have a negative significant impact on Brazil's economic growth. Moreover, with the exclusion of capital, the VECM Granger causality results revealed a feedback causal relationship between all the variables while one way causality was found from capital to economic growth, biofuel energy consumption, urbanization, and globalization indicators.

From the outcome of this study, it is suggested that expansive energy policies should be pursued by the authorities as such actions will yield sustainable economic growth in Brazil. On the other hand, the implementation of polices to conserve the use of ethanol is expected to hinder the national production. Moreover, reductions in output will adversely affect the demand for ethanol use in return. Shocks to one of these variables are expected to pass to the other and the chain will persist via the feedback effect. Expansion of ethanol use is further expected to decrease the country's dependence on oil imports. Brazil's consumption of petroleum and other liquid fuels continues to surpass its production, which is leading to more imports of petroleum and other liquid fuels into the country[2]. Being a renewable energy, the expansion of biofuel usage will likely resolve some of the problems associated with environmental degradation there should be an expansion of ethanol usage in the country. Fossil fuels (oil, coal and natural gas), which are known to generate most emissions currently dominate the energy mix as they contribute about 60% of the primary energy consumption in the country. Gifted with large abundance of ethanol resources, including sugar cane, expanding the usage of ethanol will not be a difficult task for the country. Brazil is the second-largest producer of ethanol in the world after the USA. Ethanol production is 492 844 barrels per day, after achieving a 4% growth in 2014.[2]

However, increasing the availability of ethanol is not the only requirement for a sustainable economic development. The policies designed to encourage international trade, increase capital formation, and produce urban centers are needed to complement ethanol availability. These policies may not only directly influence economic growth, but also instigate economic growth through developing the energy sector. For example, improved capital formation generates new investments, which are essential in expanding the current ethanol distribution network in the country.

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Dr Usama Al-mulali

Dr Usama Al-mulali is a lecturer at Multimedia University. His research interests include applied economics, energy economics and tourism economics.

Dr Sakiru Adebola Solarin

Dr Sakiru Adebola Solarin is a Senior Lecturer in Economics at the Faculty of Business, Multimedia University Malaysia. Dr Solarin has been involved in many research areas, including Islamic Banking and Finance, Energy Economics, Tourism Economics, Defence Economics and Applied Econometrics. He holds a BSc in Economics from the University of Ilorin, Nigeria; an MSc in Economics from the University of Lagos, Nigeria; a Master of Islamic Finance and Banking from Insaniah University College, and a PhD in Economics from University Utara Malaysia.

Dr Ilhan Ozturk

Dr Ilhan Ozturk is currently working as Associate Professor at Cag University, Mersin, Turkey. His research interests include energy economics and international economics. He is the editor of IJEEP and IJEFI.