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RESEARCH ARTICLE

Investigating the role of urban development in the conventional environmental Kuznets curve: evidence from the globe

Setareh Katircioglu[1] · Salih Katircioglu[2] · Ceyhun C. Kilinc[3]

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Abstract
We investigated the role of urbanization in the conventional environmental Kuznets curve (EKC) of the globe. The overall population and rural population were also considered for control purposes. Based on our findings, we suggest that the conventional EKC of the globe is not an inverted U-shape but becomes downward sloping when urban development is added and inverted U-shapes when the overall population and rural population volumes are added.

Keywords Environmental Kuznets curve · Energy · Carbon emissions · Urban development

JEL classification C22 · C51 · O13 · O18

Introduction

Rapid urbanization is considered a driving force behind global climate change which is likely to lead to a surge in carbon dioxide (CO_2) emissions (Xu and Lin 2015) and to raise environmental pressures like energy consumption (Zhang and Lin 2012). The main concern with this respect is whether urbanization exerts an upward or downward pressure on the volume of climate level (Katircioglu and Katircioglu 2017). UN-HABITAT (2008) reported that the developing world would constitute 95% of the world's urban population growth in the next four decades. This reality is likely to affect the overall trend of environmental quality in the globe then. Rafiq et al. (2016), Fang (2014), and Pacione (2009), on the other hand, documented that urban areas are responsible for the 70% of energy-related greenhouse gas emissions. Environmental costs have increased to address concerns about the quality of rapidly growing urban environments (Rafiq et al. 2016; Anderson et al. 1996) as also mentioned in the study of Katircioglu and Katircioglu (2017).

Several studies confirmed the effects of energy consumption on climate change, even in the context of the environmental Kuznets curve (EKC) theory (Cetin and Ecevit 2017; Ozcan and Ari 2017; Katircioglu 2017; Katircioglu and Katircioglu 2017; Katircioglu et al. 2017; Istaiteyeh 2016; Anatasia 2015; Kalayci and Koksal 2015; Kapusuzoglu 2014; Katircioglu 2014a, b; Katircioglu et al. 2014; Heidari et al. 2013). Katircioglu and Katircioglu (2017) mention and find that as urbanization and population continue to grow, alternative energy sources are priorities for countries to prevent environmental degradation. Literature studies report that urbanization may lead to higher amounts of commercial energy consumption (Jones 1989, 1991; Parikh and Shukla 1995; York 2007; Zhang and Lin 2012; Ma 2015; Katircioglu and Katircioglu 2017). In the literature, the effect of urban development on emission levels is positive in some studies (Katircioglu and Katircioglu 2017) and negative in some others. Katircioglu and Katircioglu (2017) and Sadorsky

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✉ Setareh Katircioglu
setareh.katircioglu@kyrenia.edu.tr

Salih Katircioglu
salih.katircioglu@emu.edu.tr

Ceyhun C. Kilinc
ceyhunkilinc@hotmail.com

[1] Faculty of Economics and Administrative Sciences, University of Kyrenia, Karakum, Northern Cyprus, Via Mersin 10, Kyrenia, Turkey

[2] Department of Banking and Finance, Faculty of Business and Economics, Eastern Mediterranean University, P.O. Box 99628, Northern Cyprus, Via Mersin 10, Famagusta, Turkey

[3] Faculty of Tourism, Selcuk University, Alaeddin Keykubat Yerleşkesi, Akademi Mah., Yeni İstanbul Cad. No: 369, Selçuklu, PO Box: 42130, Konya, Turkey

(2014) mention urbanization may have both positive and negative impacts on the natural environment. Against this backdrop in the regional- or country-based studies, the present article investigates the role of urban development on the conventional EKC in the globe. These study's findings will provide clear cut insights, not only for other researchers, but especially for policy makers. It is expected that the results of this study will also shed light for policy makers in every country due to the fact that startling news about climate changes around the globe are increasingly shared by the related authorities. Thus, since this study adapts a global aggregate data for urbanization and climate change proxy, results are expected to be important with this respect.

The rest of this study is structured as follows: "Methodology and data" introduces the data and methodology, "Results and discussion" presents the empirical results and discussion, and "Conclusion" concludes the study.

Methodology and data

Modeling

Climate has been proxied by CO_2 emissions (kt) in relevant energy studies (Katircioglu and Katircioglu 2017; Kapusuzoglu 2014). In the original EKC framework, gross domestic product (GDP) and squared GDP are the main determinants of CO_2 emissions. Squared GDP has been considered and suggested in the literature because countries or regions may have inverted U-shaped EKCs (Katircioglu and Katircioglu 2017). Energy consumption is exogenously added to this setting and is another important determinant of CO_2 emissions (Kapusuzoglu 2014). Katircioglu and Katircioglu (2017) argue that energy consumption contributes to the effects of GDP on CO_2 emissions. In parallel to this theoretical description, the following is a revised EKC model proposed in this study:

$$\mathrm{CO}_{2t} = f\left(GDP_t^{\beta_1} GDP_t^{2\beta_2} E_t^{\beta_3} X_t^{\beta_4}\right) \quad (1)$$

where E is energy consumption (equivalent of oil kt) and X stands for control variables, which will be urban development, population, and rural population in this study. The parameters of β_1, β_2, β_3, and β_4 are the regression coefficients.

The revised EKC model in Eq. (1) will be estimated via double logarithmic regression form to capture the growth impacts over a long-term economic period (Katircioglu 2017, 2010, 2009):

$$\ln CO_{2t} = \beta_0 + \beta_1 \ln GDP_t + \beta_2 \ln GDP_t^2 + \beta_3 \ln E_t + \beta_4 \ln X_t + \varepsilon_t \quad (2)$$

where, for period t, "ln" stands for the natural logarithm of series in Eq. (2), while ε is the error disturbance.

The dependent variable in Eq. (2) may not immediately adjust to its long-term equilibrium path following any changes in its determinants as also documented in the literature (Sodeyfi and Katircioglu 2016). Thus, the speed of adjustment between the short-run and long-run levels for the dependent variable was captured by estimating the following error correction model in this study:

$$\Delta \ln CO_{2t} = \beta_0 + \sum_{i=1}^{n} \beta_1 \Delta \ln CO_{2t-j} + \sum_{i=0}^{n} \beta_2 \Delta \ln GDP_{t-j} + \sum_{i=0}^{n} \beta_3 \Delta \ln GDP_{t-j}^2 + \sum_{i=0}^{n} \beta_4 \Delta \ln E_{t-j} + \sum_{i=0}^{n} \beta_5 \Delta \ln X_{t-j} + \beta_6 \varepsilon_{t-1} + u_t \quad (3)$$

where Δ represents the changes in CO_2, E, GDP, GDP^2, and X, and $\varepsilon_{t\text{-}1}$ is the one period lagged error correction term (ECT), which is estimated from the residuals of Eq. (2) (Sodeyfi and Katircioglu 2016). The ECT in Eq. (3) shows how fast the disequilibrium between the short-term and long-term values of the dependent variable (CO_2) is eliminated each period. The expected sign of ECT is negative (Katircioglu 2010).

Data

Annual figures from 1960 to 2013 comprised the data for this research, and the variables of the study are CO_2 emissions (kt), energy use (E) (kt of oil equivalent), constant GDP (2010 = 100), constant GDP^2 (2010 = 100), and the total number of people living in urban areas in around the globe (U) as reported by the World Bank (2017). In this study, overall population (P) and rural population (R) have also been selected and analyzed via Eq. (2) for comparison purposes. Therefore, the Eq. (2) of this study will be estimated for three different model options: (1) EKC with urbanization, (2) EKC with population, and (3) EKC with rural population. The variable, X, in Eq. (2) will be replaced by U, P, and R in the current study.

Methods

This study estimates an urbanization-induced EKC model in the globe. The quasi-generalized least squares

(GLS)-based unit root tests, developed by Carrion-i-Silvestre et al. (2009), took multiple structural breaks until five into consideration were carried out initially for time series of the study. This was due to the fact that series exhibit breaks over the years. In the second step, the Johansen cointegration tests by Johansen (1988) and Johansen and Juselius (1990) were carried out to confirm the existence of a cointegrating vector in Eq. (2). In the next step, level coefficients were estimated in Eq. (2). Then after, conventional EKC and revised EKCs with urbanization, overall population, and rural population were plotted via level coefficients in Eq. (2). Finally, short-run models with error correction terms were estimated using the vector error correction (VEC) framework.

Results and discussion

Table 1 presents the GLS-based unit root test results from Carrion-i-Silvestre et al. (2009) for the series under consideration. Results suggest five successful and significant structural break points in the series. By taking these break years into account, unit root test results of this study show that all series under consideration are non-stationary at their levels, but become stationary at their first difference since the null hypothesis of a unit root can be rejected. Therefore, the GLS-based unit root tests in this study suggest that $\ln CO_2$, lny, lnE, lnU, lnP, and lnR are integrated of order one, I (1). It is suggested that Eq. (1) may be a sufficient cointegration model.

The results of the Johansen cointegration tests, shown in Table 2, suggest the null hypothesis of H_0: $r = 0$ (no cointegrating

Table 1 The quasi-GLS-based unit root tests under multiple structural breaks

	Levels					Break years
	P_T	MP_T	MZ_α	MSB	MZ_t	
$\ln CO_2$	21.536 [8.797]	18.876	−21.672	0.150	−3.268	1973; 1980; 1991; 2002; 2008
		[8.797]	[−45.341]	[0.104]	[−4.763]	
lny	20.461	19.679	−21.370	0.152	−3.261	1973; 1980; 1990; 1997; 2008
	[8.987]	[8.987]	[−45.950]	[0.103]	[−4.794]	
$\ln y^2$	19.549	19.262	−21.854	0.150	−3.296	1973; 1981; 1990; 1995; 2008
	[9.013]	[9.013]	[−45.879]	[0.104]	[−4.783]	
lnE	22.261	20.771	−21.239	0.152	−3.233	1968; 1973; 1979; 1989; 2002
	[9.229]	[9.229]	[−46.818]	[0.103]	[−4.821]	
lnU	25.987	23.510	−17.603	0.168	−2.965	1964; 1975; 1980; 1990; 2008
	[8.918]	[8.918]	[−45.626]	[0.104]	[−4.765]	
lnP	24.514	21.461	−19.950	0.157	−3.142	1964; 1972; 1989; 1991; 2001
	[9.071]	[9.071]	[−46.513]	[0.103]	[−4.808]	
lnR	27.226 [9.140]	24.632	−17.892	0.163	−2.934	1964; 1971; 1977; 1990; 1999
		[9.140]	[−47.307]	[0.102]	[−4.847]	
	First differences					
$\Delta \ln CO_2$	4.703*	4.363*	−21.100*	0.153*	−3.240*	–
	[5.543]	[5.543]	[−17.325]	[0.168]	[−2.896]	
Δlny	3.680*	3.821*	−23.913*	0.144*	−3.456*	–
	[5.543]	[5.543]	[−17.325]	[0.168]	[−2.896]	
$\Delta \ln y^2$	3.646*	3.786*	−24.112*	0.143*	−3.470*	–
	[5.543]	[5.543]	[−17.325]	[0.168]	[−2.896]	
ΔlnE	3.394*	3.523*	−25.948*	0.138*	−3.599*	–
	[5.543]	[5.543]	[−17.325]	[0.168]	[−2.896]	
ΔlnU	4.131*	4.407*	−22.305*	0.151*	−3.480*	–
	[5.543]	[5.543]	[−17.325]	[0.168]	[−2.896]	
ΔlnP	3.726*	3.815*	−24.281*	0.142*	−3.471*	–
	[5.543]	[5.543]	[−17.325]	[0.168]	[−2.896]	
ΔlnR	4.306*	4.021*	−23.545*	0.149*	−3.410*	–
	[5.543]	[5.543]	[−17.325]	[0.168]	[−2.896]	
						–

Break years are obtained using the quasi GLS-based unit root tests of Carrion-i-Silvestre et al. (2009). Asterisk denotes the rejection of the null hypothesis of a unit root at the 0.05 significance level. Numbers in brackets are critical values from the bootstrap approach by Carrion-i-Silvestre et al. (2009). Notes are adapted from Katircioglu and Katircioglu (2017)

Table 2 Johansen cointegration test

Null hypothesis	Trace statistics
Model-1: $\ln CO_2 = f(\ln GDP, \ln GDP^2, \ln E, \ln U)$	
H0: $r = 0$	81.352*
H0: $r \leq 1$	38.335
H0: $r \leq 2$	19.501
H0: $r \leq 3$	5.375
H0: $r \leq 4$	0.303
Model 2: $\ln CO_2 = f(\ln GDP, \ln GDP^2, \ln E, \ln P)$	
H0: $r = 0$	108.548*
H0: $r \leq 1$	45.371
H0: $r \leq 2$	23.489
H0: $r \leq 3$	9.681
H0: $r \leq 4$	0.730
Model 3: $\ln CO_2 = f(\ln GDP, \ln GDP^2, \ln E, \ln R)$	
H0: r = 0	110.646*
H0: r ≤ 1	40.885
H0: $r \leq 2$	22.378
H0: $r \leq 3$	6.941
H0: $r \leq 4$	0.412

Asterisk denotes statistical significance at 0.01 level

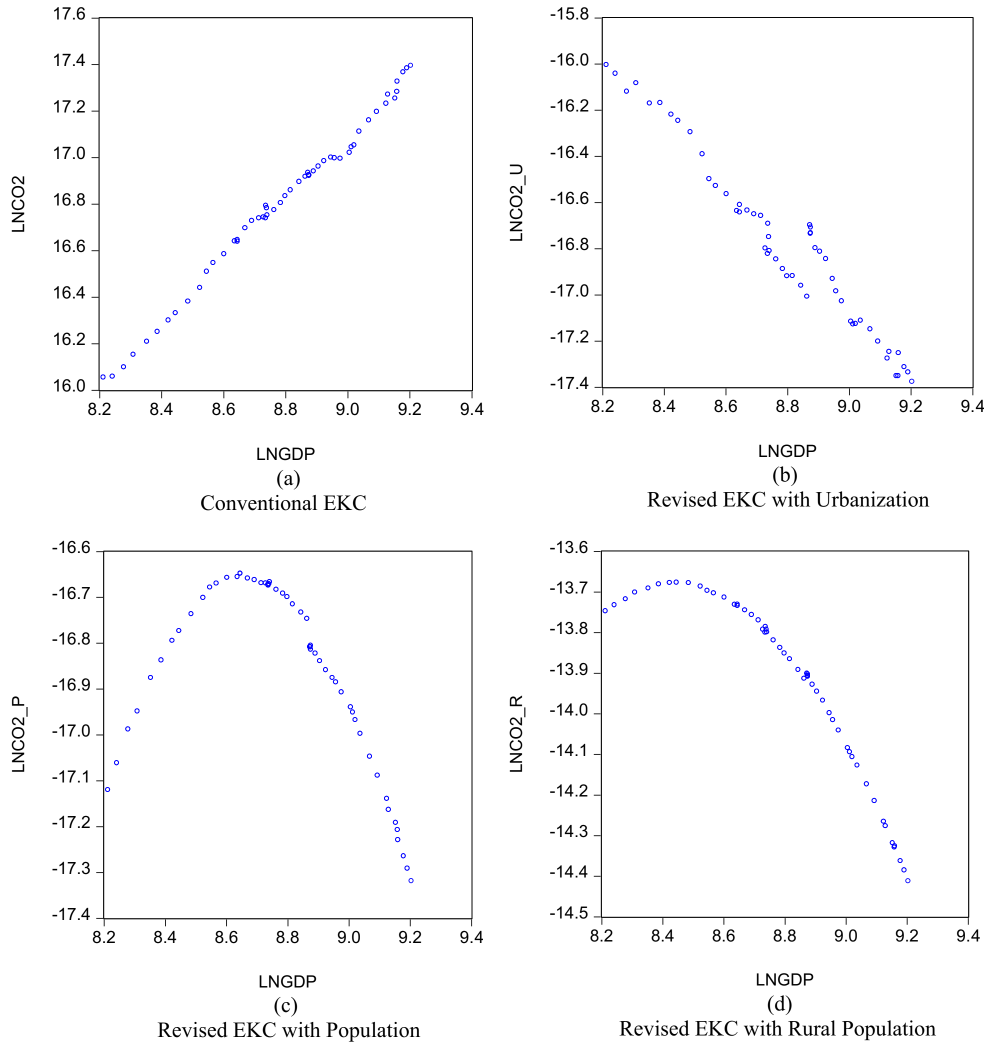
vector) can be rejected in all of the model options; thus, the results in Table 2 suggest that Eq. (1) is a cointegration model and estimating parameters in Eq. (2) will be robust for a longer period of EKCs with urbanization, overall population, and rural population.

Long-term coefficients for the three model options, as described in Eq. (2), were estimated through the VEC approach and presented in Table 3. The coefficient of GDP was always positive, GDP^2 was always negative, and both were statistically significant across all of the models. This finding aligns with the inverted U-shaped EKC hypothesis. Energy consumption, on the other hand, exerted positively significant and highly elastic effect on carbon emissions ($\beta = 2.734$, $p < 0.01$) in the first revised EKC model with urbanization. However, this coefficient is negative and inelastic effect in the cases of model with overall population and rural population. Most importantly, coefficient of urbanization was inelastic, positive, and statistically significant ($\beta = 0.843$, $p < 0.01$) in the first revised EKC model, which suggests that a 1% change in urbanization would lead to a 0.843% change in carbon emissions in the same direction. This level of (low) coefficient compared to income and energy consumption should not be surprising due to the fact that movements in carbon dioxide emissions are mainly driven by the kind of energy consumption via or depending on income level in the countries (Gokmenoglu and Kaakeh 2018; Ozatac et al. 2017; Ozcan and Ari 2017; Gokmenoglu and Taspinar 2015; Borhan and Ahmed 2012; Jumadilova 2012). This finding suggests increasing urbanization alone exerts damaging effects on climate. This finding is parallel to the finding of Katircioglu and Katircioglu (2017). Energy conservation efforts during urban development around the globe were not so much successful. On the other hand, coefficient of the overall population in the second model of Table 2 is negative as expected, inelastic, and statistically significant ($\beta = -0.439$, $p < 0.01$). This finding suggests that climate is not damaged with an increased global population. Finally, Table 2 shows the coefficient of the rural population variable was positive but not statistically significant. The coefficients of intercept were always negative, which are reasonable since in the absence of any changes in

Table 3 Level coefficients

Dependent	Variable Urbanization	$\ln CO_2$ EKC with Population	Rural population
Regressors			
Intercept	− 89.536	− 164.378	− 106.687
lny	11.899	36.448	21.591
	(2.223)**	(10.724)*	(3.079)*
$\ln y^2$	− 0.904	− 2.071	− 1.285
	(3.140)*	(− 11.270)*	(− 3.263)*
lnE	2.734	− 0.398	− 0.200
	(5.896)*	(− 1.987)**	(− 0.926)
lnU	0.843	–	–
	(3.022)*		
lnP	–	− 0.439	–
		(− 2.065)**	
lnR	–	–	0.041
			(0.142)

Fig. 1 Conventional and revised EKCs. **a** Conventional EKC, **b** revised EKC with urbanization, **c** revised EKC with population, and **d** revised EKC with rural population



the determinants in the three model options, carbon emissions were likely to decline significantly. And the coefficients of intercept with the overall population and rural population respectively become higher, showing how these two aggregates are important for the level of movements in carbon emissions.

>Before proceeding with the ECM regressions, the EKC figures, with and without urbanization, overall population, and rural population volumes, are presented in Fig. 1. Based on the estimations from Table 2, Fig. 1 plots the conventional EKC for the globe without urban population, overall population, and rural population, and the revised EKCs of the three different EKC model options: (1) revised EKC with urban population, (2) revised EKC with the overall population, and (3) revised EKC with rural population. Figure 1a shows that the conventional EKC of globe did not have an inverted U-shape. However, as Fig. 1b shows, in the existence of urbanization, the revised EKC is always downward sloping. Furthermore, as Fig. 1c, d shows, the revised EKCs in the existences of overall population and rural population had inverted U-shapes. Figure 1 clearly shows that the EKC of globe does not have an inverted U-shape; but, when the overall and rural population volumes are added to Eq. (2), then the revised EKCs become inverted U-shapes while the revised EKC is downward sloping with urban population.

The ECM regressions associated with the cointegration model in Eq. (2) were estimated as a next step. The ECM regression results are presented in Table 4. The ECT terms for Eq. (3), where $\ln CO_2$ is the dependent variable, were always negative and statistically significant across the three model options in Table 4. It is important to note that the ECT terms are considerably low in the revised EKCs of Table 4. The highest ECT term has been obtained from the revised EKC model with rural population ($\beta = -0.5222$, $p < 0.01$). The ECT in the revised EKC with urban population implies that $\ln CO_2$ (carbon dioxide emission) converged to its long-term equilibrium path by 25.59% speed of adjustment ($\beta = -0.2559$, $p < 0.05$) through the channels of energy consumption, real income, and urbanization growth.

Table 4 Error correction models

Dependent variable: $lnCO_2$						
	EKC with urbanization		EKC with population		EKC with rural population	
Regressor	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat
Intercept	0.2626	1.310	− 0.0877	− 0.871	− 0.0424	− 0.909
$\hat{u}_{t-1}$	− 0.2559	− 1.966**	− 0.2482	− 1.893***	− 0.5222	− 2.207**
$\Delta lnCO_{2t-1}$	0.1125	0.583	− 0.0829	− 0.321	0.1604	0.596
$\Delta lnCO_{2t-2}$	0.6353	3.158*	0.6144	2.165**	0.7235	2.436**
$\Delta lnCO_{2t-3}$	0.1150	0.479	0.0732	0.238	0.3294	0.967
$\Delta lnCO_{2t-4}$	0.2321	1.013	− 0.0771	− 0.301	− 0.0843	− 0.292
$\Delta lnCO_{2t-5}$	− 0.0539	− 0.192	− 0.5011	− 1.651	− 0.2927	− 0.932
$\Delta lnCO_{2t-6}$	− 0.2034	− 0.803	− 0.2659	− 0.753	− 0.2445	− 0.806
Δlny_{t-1}	11.5211	0.778	2.5034	0.236	5.7059	0.435
Δlny_{t-2}	− 19.6150	− 0.428	− 16.8575	− 1.661	− 21.8049	− 1.727***
Δlny_{t-3}	23.3613	2.549**	− 13.0501	− 1.112	− 11.2658	− 0.880
Δlny_{t-4}	− 19.7245	− 1.793***	− 20.7349	− 1.850***	− 29.9828	− 2.197**
Δlny_{t-5}	34.3026	2.098**	3.8789	0.196	− 1.0359	− 0.049
Δlny_{t-6}	13.4650	0.834	− 14.9679	− 0.804	−15.6392	− 0.726
Δlny^2_{t-1}	− 0.6984	− 0.824	− 0.1148	− 0.191	− 0.3266	− 0.445
Δlny^2_{t-2}	0.9752	1.250	0.8982	1.593	1.1502	1.641
Δlny^2_{t-3}	− 1.3373	− 2.517**	0.7413	1.120	0.6212	0.873
Δlny^2_{t-4}	1.0911	1.725	1.2093	1.918**	1.7022	2.231**
Δlny^2_{t-5}	− 1.9985	− 2.154**	− 0.2183	− 0.193	0.0361	0.029
Δlny^2_{t-6}	− 0.7332	− 0.7737	0.9174	0.858	0.9266	0.753
ΔlnE_{t-1}	0.6308	1.889***	0.0692	0.416	0.0320	0.187
ΔlnE_{t-2}	0.2948	0.910	− 0.1123	− 0.672	− 0.0717	− 0.391
ΔlnE_{t-3}	0.2004	0.778	− 0.0788	− 0.457	− 0.1847	− 1.052
ΔlnE_{t-4}	0.1866	0.655	− 0.1153	− 0.640	− 0.0915	− 0.539
ΔlnE_{t-5}	0.1360	0.672	− 0.1690	− 0.957	− 0.0314	− 0.182
ΔlnE_{t-6}	0.1455	0.893	− 0.0392	− 0.221	− 0.0125	− 0.068
ΔlnU_{t-1}	− 2.8208	0.438	–	–	–	–
ΔlnU_{t-2}	− 0.2226	0.029	–	–	–	–
ΔlnU_{t-3}	− 14.5199	− 2.969*	–	–	–	–
ΔlnU_{t-4}	10.5581	1.812***	–	–	–	–
ΔlnU_{t-5}	− 10.6309	− 2.124**	–	–	–	–
ΔlnU_{t-6}	9.0411	1.855***	–	–	–	–
ΔlnP_{t-1}	–	–	0.4905	0.030	–	–
ΔlnP_{t-2}	–	–	21.1951	0.912	–	–
ΔlnP_{t-3}	–	–	− 40.8692	− 2.111**	–	–
ΔlnP_{t-4}	–	–	16.2667	1.143	–	–
ΔlnP_{t-5}	–	–	3.1466	0.210	–	–
ΔlnP_{t-6}	–	–	6.2471	0.666	–	–
ΔlnR_{t-1}	–	–	–	–	10.1462	1.078
ΔlnR_{t-2}	–	–	–	–	− 14.2050	− 1.037
ΔlnR_{t-3}	–	–	–	–	9.6389	0.838
ΔlnR_{t-4}	–	–	–	–	− 3.6715	0.398
ΔlnR_{t-5}	–	–	–	–	12.8811	1.273
ΔlnR_{t-6}	–	–	–	–	− 5.2749	− 0.779
Adj. R^2 = 0.607			Adj. R^2 = 0.788,		Adj. R^2 = 0.756	
S.E. of Regr. = 0.014			S.E. of Regr. = 0.018		S.E. of Regr. = 0.019	
AIC = − 5.437			AIC = − 4.938		AIC = − 4.795	
SBC = − 4.178			SBC = − 3.679		SBC = − 3.536	
F-stat. = 3.292			F-stat. = 1.808		F-stat. = 1.502	

Single, double, and triple asterisks denote statistical significance respectively at the 0.01, 0.05, and 0.10 levels

Conclusion

This paper empirically tested the urbanization-induced EKC hypothesis and thus searched the long-term equilibrium relationship causality between urban development and CO_2 emissions from energy consumption and real income growth in the globe. In addition to urban development, the overall population and rural population volumes of the globe have been also included in the empirical analyses for comparison purposes. The results showed that the conventional EKC of the globe did not have inverted U-shape, but it becomes downward sloping with urbanization and inverted U-shaped with the overall population and rural population. The results of this study suggest that urbanization and population growths in the globe were successfully managed as far as "Green Energies and Green Environment" are concerned. For comparison purposes, similar research can replicate our methods for the regional analysis around the globe. Furthermore, alternative methodological approaches can also be adapted again for comparison purposes to provide the level of robustness of our current results. Thus, we propose that using aggregate data in this study would not be the end in this research field.

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