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RESEARCH ARTICLE

Environmental Kuznets curve revisit in Central Asia: the roles of urbanization and renewable energy

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Abstract

Based on the environmental Kuznets curve (EKC) hypothesis, the aim of this paper is to examine the relationships among per capita CO_2 emissions, per capita real GDP, per capita renewable energy consumption, and urbanization in a panel of five Central Asian countries (Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan) from 1992 to 2013. For robustness checking, three estimator techniques reveal no evidence of inverted U-shape EKC consistently. Moreover, renewable energy consumption plays negative impact on emissions, while urbanization plays positive, significantly. The findings of heterogeneous panel causality suggest that there are bidirectional causalities; each other expect no causality from emissions to renewable energy. Finally, some implications, such as developing a small renewable energy project and sustainable urbanization and strengthening in-regional and out-regional cooperation, are given in this region.

Keywords Central Asian countries · Urbanization · Carbon dioxide emissions · Renewable energy · Environmental Kuznets curve

Introduction

Urbanization is a global status along with human migration and economic trend both in developed and developing countries, and such changes have been with significant implications for development, energy use, human living, and environment (Brown 2012; Lin et al. 2016). The proportion of urban population grows very remarkably, from 30% in 1950 to over 50% today, predicted to get 60% in 2030 (Ponce De Leon Barido and Marshall 2014). Urban development has promoted concentrations of land, water, and air pollution (Bloom et al. 2008). According to Fu et al. (2017) and Ramaswami et al. (2016), global urbanization causes nearly 70% global greenhouse gas emissions, which relies on energy, fuel, construction, and chemical materials. Urbanization also becomes a major challenge and opportunity for Central Asian countries, which lead to a speedy growth of economy and demography. In 2013, the total population in this region is more than 65.6 million, with the urban rate of 43.8% on average. According to the United Nations Department of Economic and Social Affairs (UNDESA), by 2050, the total population in Central Asia will reach up to 82 million, nearly 55.2% urban rate.[1] Figure 1 presents the urban population and carbon dioxide emissions from five Central Asian countries (CAC-5). Urban population grows steadily, from 22.8 million (in 1992) to 446.3 million (in 2013), with a growth rate of 0.93% per year. After the fall of the Soviet Union in 1992, severe economic recessions happened to Central Asian countries (Perelet 2007). At the same time, the reduced carbon emissions touched the bottom of 275.1 million tons in 1997, and then rose up to 450 million tons total in 2013.

Nowadays, global climate change presents a grave threat to the environmental, ecological, and economic systems in Central Asian region. In the next several decades, the temperature in this region will rise of 1–3 °C, or even more. By the end of the century, the average temperature would go up 3–6 °C (Reyer et al. 2017). As the crossroads of Eurasia, Central Asia is a very important region for the world, especially in climate change. The climate stressors may lead to glacial melt, increases in temperature, and extreme weather events. From the 20th to early 21st century, the annual temperature increases obviously in this region, 0.3–1.2 °C in Tajikistan and

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[1] Center for Economic Research (CER), 2013. Urbanization in Central Asia: Challenges, Issues, and Prospects. http://www.unescap.org/sites/default/files/Urbanization%20in%20Central%20Asia_ENG_0.pdf

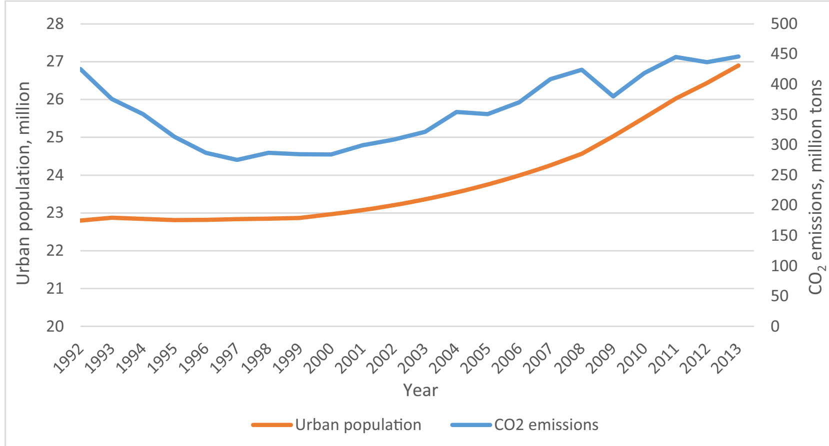

Fig. 1 Plots of urban population and CO_2 emissions in CAC-5

1.1–2.4 °C in Turkmenistan. Nearly one third of the glacial area has disappeared since 1930 in this region.[2] According to the IRENA, Central Asia possess large renewable energy potential, which remains largely untapped, which may provide opportunities for increasing renewable energy uptake in the region.[3] Considering sustainable development of Central Asian countries, each country has established the environmental framework and renewable energy development as a regional warming response policy. For example, Kazakh government adopted a law to foster the development of renewable energy project in 2009 and enacted a green economy law in 2015. Tajikistan government adopted renewable energy program in 2007 and passed the Law on the Use of Renewable Energy Resources (LURER) in 2010.[4]

The main aim of this study is to reveal the linkages among per capita CO_2 emissions, real GDP, renewable energy use, and urbanization in a panel of five Central Asian countries (CAC-5, including Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan) covering the period of 1992–2013. Several expected contributions are made to the related literatures. First, some papers mainly focused on the relationships between emissions, cooperation, and energy (Dorian et al. 1997; Karakaya and Özçağ 2005; Perelet 2007; Tookey 2007; Reyer et al. 2017) in this region, while there is little known about the relationships among renewable energy, urbanization, and CO_2 emissions in Central Asian countries. Therefore, this paper can enrich the related literatures and fill the research gap in this area. Second, former papers discussed about the hypothetical environmental Kuznets curve (EKC) using several countries as a whole (Oh and Yun 2014), while this paper focuses on this region separately, which may reveal important information to make targeted policy on Central Asian governments. Third, two types' panel unit roots (first and second generation) and two types' cointegration methodologies are used to argue their stationary of selected time series data and the co-integrating relationship among them, which can make use of mutual advantage and make up own shortage. Fourth, long-run coefficients of independent variables on the environment are estimated by three estimators' techniques for robustness checking in CAC-5, which may make the results more real and effective (Ahmad et al. 2017; Mirza and Kanwal 2017). Finally, for cross-sectional dependence, heterogeneous Granger causality is employed to examine the causality between emissions, renewable energy, economic growth, and urbanization (Bakirtas and Akpolat 2018; Saidi et al. 2018). With the findings, some suggestions and implications can be given to the local authorities.

Literature review on the linkages among energy, urbanization, and emissions

In the last few decades, there are many studies on energy and carbon dioxide emissions, as well as other variables, such as economic growth, population, capital stock, and foreign direct investment inflows (Saidi and Hammami 2015; Abdouli and Hammami 2017; Riti et al. 2017; Dogan and Inglesi-lotz 2017; Sarkodie 2018; Sarkodie and Adams 2018; Ulucak and Bilgili 2018; Ben Mbarek et al. 2018; Cetin et al. 2018; Destek et al. 2018; Emir and Bekun 2018; Hao et al. 2018; Bekun et al. 2019b; Lin and Zhu 2019; Sarkodie and Strezov 2019a,b; Bekun et al. 2019a; Dogan et al. 2019). The results of their relationships are mixed for different regions, countries, and development level. Along with the development of urban, lots of environmental economists focus on the linkages among energy, urbanization, and CO_2 emissions in recent years (Table 1).

[2] Climate Risk Profile in Central Asia, 2018. https://www.climatelinks.org/sites/default/files/asset/document/2018-April-30_USAID_CadmusCISF_Climate-Risk-Profile-Central-Asia.pdf

[3] International Renewable Energy Agency (IRENA), Central Asia Regional Initiative. https://www.irena.org/asiapacific/Central-Asia-regional-initiative

[4] New Technologies and Renewable Energy in Central Asia: Opportunities for Growth, 2016. http://www.eurasiancouncilforeignaffairs.eu/wp-content/uploads/2016/09/ECFA-Occasional-Paper-Sept-2016.pdf

Table 1 Recent literature on urbanization, energy, and CO_2 emissions

Authors	Time periods	Countries	method	Variables	Long-run linkage
A. Urbanization and emissions					
Farhani and Ozturk (2015)	1971–2012	Tunisia	ARDL VECM	URB;CO;GDP;FD; TR	URB → CO (+)
Xu and Zhang (2016)	2005–2014	China	FMOLS,	URB; CO	URB ↔ CO
Wang et al. (2016b)	1985–2014	BRICS	Granger causality	URB; CO	URB → CO
Saidi and Mbarek (2017)	1990–2013	19 emerging economies	GMM	URB;CO;GDP; FD; TR	URB → CO (−)
Zhang et al. (2017a, b)	1961–2011	141 countries	2SLS	URB;CO;TR;GDP; POP	URB → CO (+)
B. Urbanization, energy consumption, and emissions					
Poumanyvong and Kaneko (2010)	1975–2005	99 countries	OLS, FE, PW, First Difference	URB;CO;POP;GDP; IND; SER; EI	URB → CO (+) EN → CO (+)
Sharif Hossain (2011)	1971–2007	nine newly industrialized countries	VECM	URB;EN;CO;GDP;TR	No linkage
Al-Mulali et al. (2013)	1980–2009	21 MENA countries	DOLS, VECM	URB;EN;CO	URB ↔ CO EN ↔ CO
Xu and Lin(2015)	1990–2011	China	FE; NAR	URB; EN; CO; IND; GDP; EX; coal	URB → CO(+) Coal ↔ CO(+)
Kasman and Duman (2015)	1992–2010	15 new EU countries	FMOLS, VECM	URB; EN; CO; GDP; TR	URB → CO(+) EN ↔ CO
Al-Mulali and Ozturk (2015)	1996–2012	14 MENA countries	FMOLS, VECM	URB; EN; CO; TR; IND; PS	URB ↔ CO EN ↔ CO
Dogan and Turkekul (2016)	1960–2010	USA	ARDL VECM	URB; EN; CO; GDP; FD; TR	URB ↔ CO EN ↔ CO
Wang et al. (2016a)	1980–2009	ASEAN-8	FMOLS, VECM	URB; EN; CO;	URB → CO (+)
Effiong (2017)	1990–2010	49 African countries	Semi-parametric regression	POP;GDP;EI;URB	URB → CO (−)
Wang et al. (2018)	1980–2011	170 countries	VECM, IR, VD	URB; EN; CO; GDP	URB ↔ CO EN ↔ CO (total)
Bekhet and Othman (2017)	1971–2015	Malaysia	ARDL, VECM	URB; EN; CO; GDP; capital, labor	URB ↔ CO EN ↔ CO
Ouyang and Lin (2017)	1978–2011	China	VECM	URB; EN; CO; GDP; EI; CM	URB → CO EI → CO

MENA, Middle East and North Africa; *EU*, European Union; *ASEAN*, Association of Southeast Asian Nation; *ARDL*, autoregressive distributed lag; *VECM*, vector error correction model; *OLS*, ordinary least squares; *DOLS*, dynamic ordinary least squares; *FMOLS*, fully modified ordinary least squares; *GMM*, generalized method of moments; *FE*, fixed effect; *PW*, Prais Winsten; *2SLS*, two stage least squares; *IR*, impulse response; *VD*, variance decomposition; *NAR*, nonparametric additive regression; *FD*, financial developments; *TR*, trade; *POP*, population; *URB*, urbanization; *CO*, CO_2 emissions; *IND*, industry; *SER*, service; *EI*, energy intensity; *EX*, exports; *EN*, energy; *PS*, political stability; *CM*, cement manufacture

Some of these studies investigate the causal linkage between urbanization and emissions. For example, on the basis of panel data from Chinese provinces and regions, Liu et al. (2016) explore the relationships among urbanization, GDP, and CO_2 emissions from 1997 to 2010. Panel co-integration, estimation coefficients, and Granger causality among selected variables are tested. The empirical findings from parameter estimates indicate that the influence from urbanization to the environment in the western area is greater than that in other two areas. Moreover, feedback long-run causality between urbanization and emissions is found. Some suggestions are given as emissions reduction and urban expansion controlling in the long-run. By using applied autoregressive distributed lags (ARDL) methodology, Ali et al. (2017) explore how urbanization affects the environment in Singapore. The empirical result proves that the development of urbanization improves the quality of the environment by reducing carbon emissions.

Besides, some studies attempt to find out the causality among urbanization, energy, and CO_2 emissions. On account of Stochastic Impacts by Regression on Population, Affluence and Technology model, Sadorsky (2014) uses static and dynamic research methodologies to reveal the linkages between urbanization, energy intensity, and emissions in 16 emerging nations. The impacts of different estimation techniques are very similar. Among the estimated parameters, urbanization plays a positive role in emissions insignificantly, while energy intensity plays a positive role in emissions significantly. The similar model is also used by Shahbaz et al. (2016), which investigates such relationship in Malaysia by employing ARDL and VECM technologies. The empirical findings expose that the use of energy increases CO_2 emissions. Moreover, U-shaped EKC is found between urbanization and emissions. Namely, the development of urbanization reduces emissions initially, then after dropping into the bottom, it increases CO_2 emissions.

Methodology and data

Following the studies of Dogan and Turkekul (2016) and Dogan and Ozturk (2017), the relationships among per capita CO_2 emissions (CO), per capita real GDP (GDP), per capita renewable energy consumption (RE), and urbanization (URB) are explored in five Central Asian countries (CAC-5) based on hypothetical EKC. The log linear quadratic multivariate function is presented as follows:

$$\mathrm{LCO}_{it} = \varphi_i + \delta_i t + \gamma_{1i}\mathrm{LGDP}_{it} + \gamma_{2i}\mathrm{LGDP}^2_{it} + \gamma_{3i}\mathrm{LRE}_{it} + \gamma_{4i}\mathrm{LURB}_{it} + \varepsilon_{it} \quad (1)$$

where $i = 1, 2, 3, 4$, and 5 denotes the five Central Asian countries. t and ε are the covering period of 1992–2013 and error term, respectively. φ and δ are the trend and individual fixed country effects. γ is the long-run elasticity of CO_2 emissions with respect to independent variables. If γ_1 0 and γ_2 0, the hypothetical inverted U-shaped EKC is found; otherwise, it is not.

Methodology

Stationary test

Before checking stationary of the selected variables, cross-sectional dependence (CD) within the panel time series data is examined by Pesaran' s CD test (Pesaran 2004) to test integration properties of mentioned variables. The second step of the econometric methodology is to check the stationary of selected variables. Among several panel unit root technologies, Levin-Lin-Chu (LLC) (Levin et al. 2002) and Im-Pesaran-Shin (IPS) W-statistics (Im et al. 2003), based on the augmented Dickey-Fuller principle, are the most popular used by economists and econometricians. LLC presumes homogeneous autoregressive coefficients with common unit root for all panel members, while IPS allows for heterogeneity of the coefficient in individual unit roots, which can relax the restriction of the LLC test. The so-called LLC and IPS tests can be expressed as the following estimated model:

$$\Delta y_{it} = \delta y_{it-1} + \sum_{j=1}^{pi}\beta_{ij}\Delta y_{it-j} + \alpha_{mi}d_{mt} + \varepsilon_{it} \quad m = 1, 2, 3 \quad (2)$$

where Δ, j, α_{mi}, and d_{mt} are the first difference operator, the length of optimal lag, parameters, and the corresponding vector of coefficients for model $m = 1,2,3$, respectively.

The null hypothesis ($\boldsymbol{H_0}$) and the alternative hypothesis ($\boldsymbol{H_{1a}}$ and $\boldsymbol{H_{1b}}$) can be written based on the LLC and IPS tests

$$\begin{cases} H_0 : \beta_i = 0 \quad \text{for all } i; & \text{(Null Hypothesis)} \\ H_{1a} : \beta_i = \beta < 0 \quad \text{for all } i; & \text{(LLC)} \\ H_{1b} : \beta_i = 0 \quad \text{for some } i; \beta_i < 0 \quad \text{for at least one } i; & \text{(IPS)} \end{cases} \quad (3)$$

According to the LLC test, the autoregressive (AR) parameters are expressed to a fixed value (β). Namely, a common AR parameter guarantees homogeneity in the panel data analysis. In the IPS methodology, the AR parameters can vary across the panel members. Namely, the country-specific AR parameters guarantee the assumption of heterogeneity in the panel-data analysis.

Besides, the cross-sectional augmented Dickey-Fuller (CADF) (Pesaran 2007), second generational panel unit root test, is also considered, which can perform in each cross-sectional unit in panel and avoid misleading results.

Panel co-integration test

Panel co-integration suggested by Pedroni (1999, 2004) is a methodology, which is widely used to dissect the co-integrating linkage of the dependent and independent time series data with panel data in the long-run. Following the co-integration, equation is employed:

$$Y_{i,t} = \alpha_i + \rho_i t + \sum_{j=1}^{m}\beta_{ji}X_{ji,t} + \mu_{it} \quad (4)$$

Where $Y_{i,t}$ and $X_{ji,t}$ are integrated of order one. α_i and β_{ji} stand for the specific intercept term and slope coefficients.

In this panel co-integration test, there are seven panel co-integration tests based on residuals. The statistics are divided into two classes. Four of them consist of within-dimension group (panel ν, panel ρ, panel PP, and panel ADF) statistics; others consist of between dimension group (group ρ, group PP, and group ADF) statistics.

Null and alternative hypothesis are defined as the following:

H_0: no co-integrating linkage, $\forall\ i$. H_1: co-integrating linkage, $\forall\ i$.

Additionally, the Westerlund panel co-integration test (Westerlund 2007) is employed, considering cross-sectional dependence in the data series. The co-integration test would consider four statistics (G_τ, G_α, P_τ, and P_α). The null hypothesis of each test is no co-integration, while alternative one is co-integration.

Long-run estimations

To test the long-run coefficients, fully modified ordinary least squares (FMOLS) (Phillips and Hansen 1990) and dynamic ordinary least squares (DOLS) (Saikkonen 1991; Stock and Watson 1993) are used. The FMOLS and DOLS are basically unbiased with small samples, compared with traditional ordinary least square (OLS). Moreover, it can be free from the likely endogeneity issue and serial correlation.

Based on the work of Belke and Czudaj (2010), we can take into account the following vector process:

$$\hat{\beta}_{\text{FMOLS}} = \left[\sum_{t=1}^{T}\left(x_t - \overline{x}\right)'\right]^{-1}\left[\sum_{t=1}^{T}\left(x_t - \overline{x}\right)\hat{y}_t^{+} + T\hat{\Delta}_{\varepsilon\mu}^{+}\right] \quad (5)$$

where $\hat{\Delta}_{\varepsilon\mu}^{+}$ is the serial correlation term that gives covariance matrix of the residuals corrected for autocorrelation and $\hat{y}_{it}^{+}$ is the transformation of the dependent variable y_{it} for the purpose of achieving the endogeneity correction.

Based on Mark and Sul (2003), DOLS estimations can be expressed as the following framework:

$$\hat{\beta}_{\text{DOLS}} = \left[\sum_{t=1}^{T} z_t z'_t\right]^{-1}\left[\sum_{t=1}^{T} z_t \hat{y}_t^{+}\right] \quad (6)$$

where $z_{1t} = \left(x_t - \overline{x}, \ \Delta x_{t-q}, \ldots, \ \Delta x_{t+q}\right)$ is vector of repressors.

Dumitrescu-Hurlin Granger causality

The co-integrating examination only studies the existence of long-run causality linkage, but it does not show us the causal directions between the selected variables. Therefore, we would use the Dumitrescu-Hurlin panel Granger causality (Dumitrescu and Hurlin 2012) to examine the Granger causality between selected time series data. This test is based on the individual Wald statistic of the Granger non-causality test. Compared with the standard Granger causality, it assumes all coefficients to vary across cross-sections and considers heterogeneity in the dynamic model. The null hypothesis supports the existence of no homogenous Granger causality in the panel data. Such method calculates the test statistics with relatively strong in cases of small data using the Monte-Carlo simulation.

Data

The present paper uses panel data in the five Central Asian Countries (CAC-5), named Kazakhstan (KAZ), Kyrgyz Republic (KGZ), Tajikistan (TJK), Turkmenistan (TKM), and Uzbekistan (UZB) covering the period of 1992–2013. The data of per capita CO_2 emissions, real GDP, renewable energy consumption, and urbanization are all selected from World Development Indicator.[5] Per capita CO_2 emissions, measured by the metric ton, mainly stems from energy consumption and the manufacture of cement. Per capita real GDP and renewable energy use are measured by 2010 US$ and kilogram of oil equivalent, respectively. Renewable energy mainly includes hydropower, wind and solar power, bioenergy, and other renewable energies. Urbanization is described as the proportion of urban population in the total population.

Figure 2 displays the plots of per capita CO_2 emissions from 1992 to 2013. The emissions of Kazakhstan are the biggest value among these five countries. Kazakhstan's energy sector accounts for 82% of emissions, while more than 80% of produced electricity is coal-fired. In 1999, emissions of Kazakhstan slumped into the lowest at 7.803 metric tons per capita. CO_2 emissions in both Kazakhstan and Turkmenistan are growing rapidly compared with the other three countries. Yet, emissions from Tajikistan are the lowest, below 1.0 metric ton per capita. Figure 3 displays the trends of per capita real GDP. As the richest countries in Central Asia, per capita real GDP of Kazakhstan is 10,369 in 2013, 10 times higher than the Kyrgyz Republic (984 US$) and Tajikistan (855 US$). Figure 4 presents the trends of per capita use of renewable energy. From the figure, the use of renewable energy in Tajikistan is on a decrease, obviously. In 2012, the Kyrgyz Republic, exceeding Tajikistan, became the country with the highest per capita renewable energy use. However, renewable energy use in Turkmenistan was not popular, only 2 metric ton per capita in 2013. Most of Central Asian countries are at an early stage in exploiting and utilizing the renewable energies. Urbanizations of five Central Asian countries are shown in Fig. 5. The highest urban rate is Kazakhstan, more than 50%, following with Turkmenistan between 45 and 50%, while urbanization in Tajikistan is below 30%. The regional urbanization is lower than the world's average, 55%. Compared with the rest of the world, Central Asian countries have much lower population growth rates. Table 2 summarizes the selected variables.

[5] Would Development Indicator, 2017. World Bank, 2017. https://data.worldbank.org/. The latest data of energy use in Uzbekistan is in 2013, while the oldest data of CO_2 emissions is in 1992. In order to unify the data in these five Central Asian Countries, we choose the time period from 1992 to 2013.

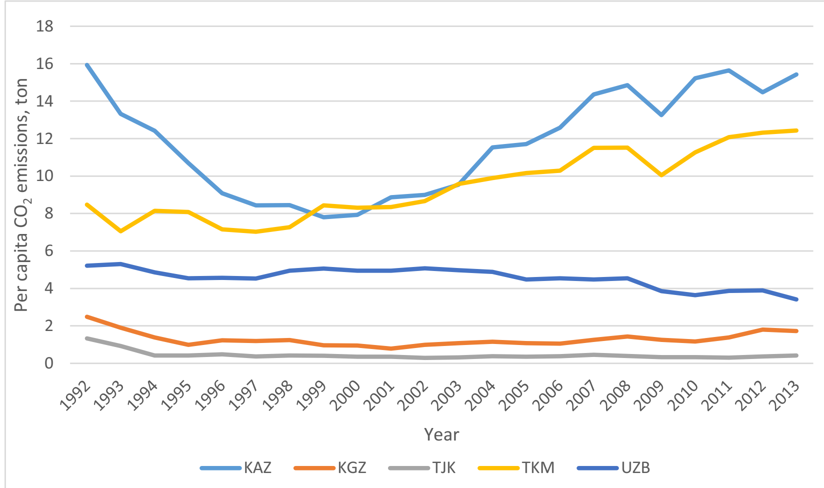

Fig. 2 Plots of per capita CO_2 emissions in CAC-5

Empirical results and discussion

Panel stationary tests

Pesaran's cross-sectional dependence (CD) test is reported in Table 3. The result shows that there is cross-sectional dependence in each selected panel variables.

The empirical findings of LLC, IPS, and CADF unit root tests, under the assumption of cross-section independence in the series, are displayed in Table 4. The first group is in level with no significance, indicating that all variables have unit root. The second group is in the first difference, showing that each of the examined variables is stationary with no unit root, strongly rejecting the null hypothesis, in the 1% level of significance. Such results indicate that the time series data have the same order of integration. Namely, the next step, co-integration test, can be carried out significantly based on the stationary of selected data.

Panel co-integration tests

"Panel stationary tests" section confirms that the selected variables are stationary in first difference. Thus, the Pedroni and Westerlund panel co-integration tests are employed to test the long-run equilibrium linkage between the mentioned variables. The findings of the Pedroni residual and Westerlund co-integrating tests are presented in Tables 5 and 6, respectively. The first part in Table 5, based on within-dimension, shows that panels PP-Statistic and ADF-Statistic are significant at the 5% level, while the second part shows that groups PP-Statistic and ADF-Statistic are of significance in the 1% level. Namely, four out of seven are of significance, which rejects the null hypothesis of no co-integrating linkage between emissions, real GDP, renewable energy, and urbanization in CAC-5. Such results indicate that the considered variables are significantly co-integrated with the full sample of CAC-5. Moreover, the results of the Westerlund co-integration test in Table 6 suggest that there is co-integrating

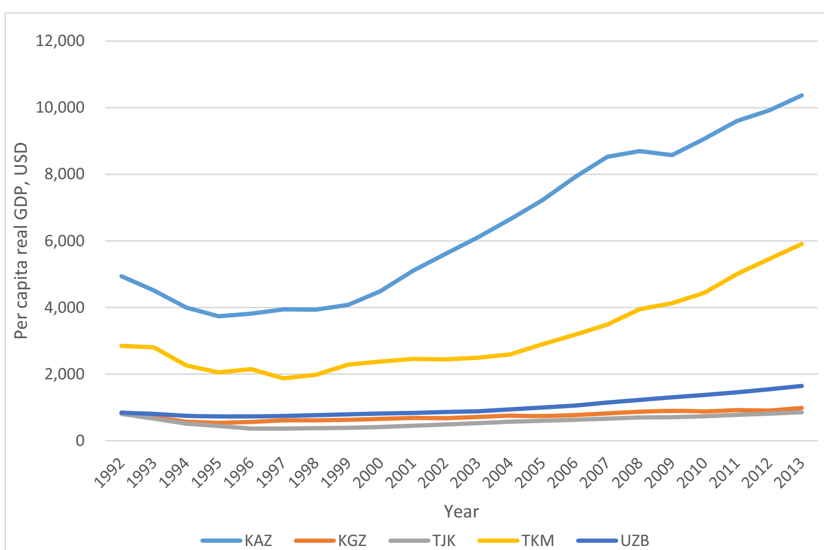

Fig. 3 Plots of per capita real GDP in CAC-5

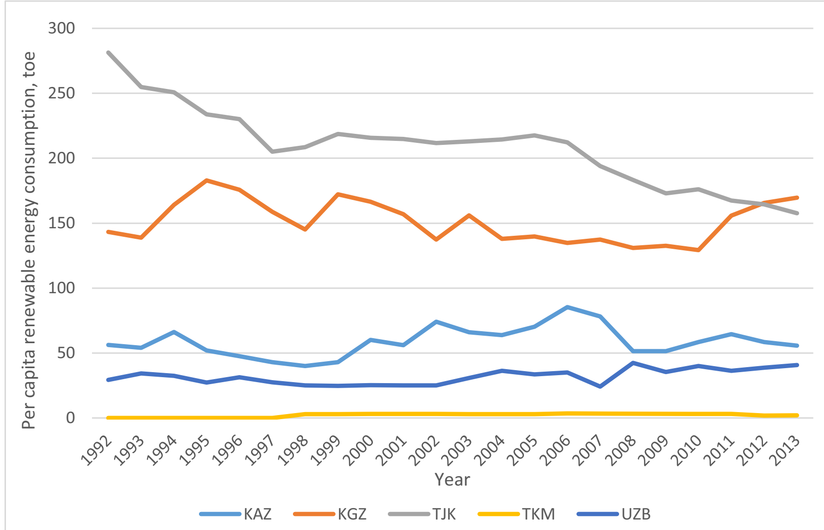

Fig. 4 Plots of per capita renewable energy consumption in CAC-5

relationships between the selected variables. Based on such findings, the following sections make sense.

Estimations of long-run parameters

The long-run equilibrium linkage is found between the variables from "Panel co-integration tests" section, but the positive or negative effects have not been determined. Therefore, this step is to confirm the parameters from independent variables to the dependent variable based on Eq. (1). For robustness checking, three different estimator techniques are employed. The results of the long-run estimated coefficients, based on Panel FMOLS, DOLS, and OLS, are presented in Table 7. The results of these three methodologies are exactly similar to their values of coefficients significantly. Moreover, R^2 and adjusted R^2, nearly 0.90, suggest that the regressions are well fitted with the data. Additionally, the negative sign of real GDP and the positive sign of the square of real GDP suggest no hypothetical inverted U-shaped EKC between CO_2 emissions and economic growth in CAC-5. Such a result may depend on the current status of the development of countries and regions. Indeed, Central Asian countries are developing on top speed nowadays with 5.2% average economic growth rate in 2016, which may depend on more energy input, the main source of emissions. Therefore, CO_2 emissions may augment, along with economic growth for a long term in Central Asian countries. Green economy is needed to shorten the period of hypothetical EKC without affecting the regional economy. The findings are supported by Liu et al. (2017a), which also reject the EKC hypothesis in ASEAN countries, and are not in line with Zhang et al. (2017a, b), Zhang (2018), and Dogan and Seker (2016). The invalidity of EKC is similar with Hafeez et al. (2018) for panel of One Belt and One Road (OBOR) countries (including Kazakhstan, Kyrgyz Republic, Tajikistan, and so on) based on DOLS and FMOLS, and Halicioglu and Ketenci (2016) for Kyrgyz Republic and Turkmenistan by generalized method of moments regression. FMOLS (DOLS and OLS) estimates suggest that CO_2

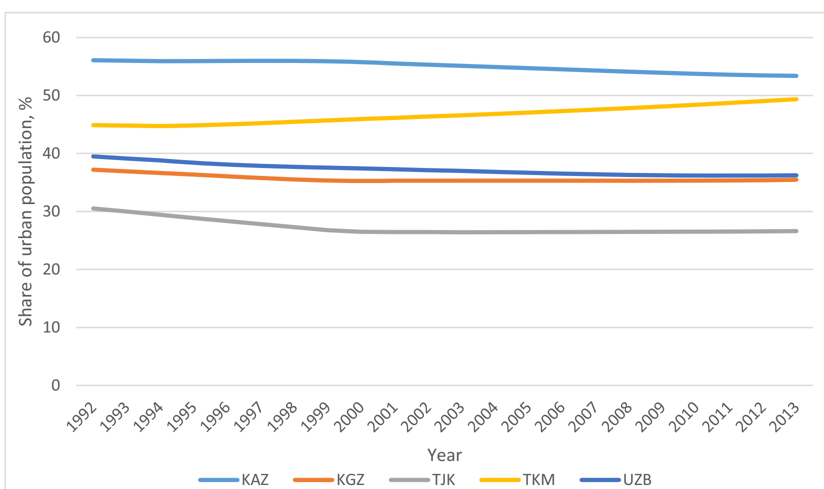

Fig. 5 Plots of share of urban population in total population in CAC-5

Table 2 Summary of selected variables in CAC-5 from 1992 to 2013

	LCO	LGDP	$LGDP^2$	LRE	LURB
Mean	1.106	7.302	54.209	3.576	3.669
Median	1.517	6.837	46.746	4.049	3.615
Maximum	2.769	9.247	85.499	5.640	4.027
Minimum	− 1.232	5.901	34.823	− 3.058	3.273
Std. Dev.	1.289	0.949	14.332	2.063	0.243
Skewness	− 0.478	0.514	0.644	− 1.688	− 0.098
Kurtosis	1.795	1.956	2.119	5.534	1.954
Jarque-Bera	10.853	9.846	11.167	81.678	5.191
Probability	0.004	0.007	0.004	0.000	0.075
Sum	121.616	803.207	5962.986	393.353	403.573
Sum Sq. Dev.	181.207	98.066	22,389.4	463.858	6.450
Observations	110	110	110	110	110

emissions with respect to economic growth amount to *0.495 gdp − 3.839* (*0.489 gdp − 3.591* and *0.479 gdp − 3.604*). Moreover, 1% increase of renewable energy use decreasing 0.190–0.290% of per capita CO_2 emissions suggests that Central Asian countries should enlarge the renewable energy consumption to achieve carbon emissions reduction. Such findings are supported by Liu et al. (2017b) for BRICS countries. Actually, in Central Asia, despite the excellent growth potential, the share of renewable energy in electricity generation is very low, between 1 and 3%.[6] Reassuringly, each country makes many accounts of renewable energy, such as holding the World Expo Exhibition "Future Energy" in Kazakhstan in 2017 and exempting a series of taxes for renewable energy producers in Uzbekistan.

Compared with negative influence from renewable energy to emissions, 1% increase of urbanization increases 4.122–4.487% of emissions. Thus, on the one hand, cities can give opportunities to businesses and people to develop Central Asian economy. On the other hand, with the rapid expansion of cities, urban infrastructure, incongruity with demand, can lead to a deterioration of living conditions, such as environmental degradation. Therefore, the control of the urban population or reasonable city planning should be put into effect in Central Asian Countries. The finding is different from Long et al. (2017) and Meng et al. (2018).

The Dumitrescu-Hurlin Granger causality tests

The findings of the directional panel Granger causality based on Dumitrescu-Hurlin are displayed in Table 8. Table 8 reveals feedback linkage of emissions and real GDP. Thus, any change in these countries' output may affect the environment, and vice

[6] Renewable Energy and Energy Efficiency in Central Asia: Prospects for German Engagement. http://www.succow-stiftung.de/tl_files/pdfs_downloads/MDF%20Working%20Paper/MDF%20Paper_RE%20and%20EE%20in%20Central%20Asia_Kominla%20Nabiyeva_2015.pdf

Table 3 The Pesaran CD test

	LCO	LGDP	$LGDP^2$	LRE	LURB
Statistic	1.669*	13.402***	13.409***	− 2.193**	2.303**
p value	0.095	0.000	0.000	0.028	0.021

***, **, and * denote the 1%, 5%, and 10% significant levels, respectively

versa. The findings are consistent with Shahbaz et al. (2017), also reporting two-way causality linkage of emissions and output in France and Italy, and not supported by Liu and Bae (2018) in China. Moreover, unidirectional causal relationship exists from emissions to renewable energy. In Central Asia, the main used energy is non-renewable energy, the main source of emissions. Meanwhile, economic growth does heavily depend on energy consumption. Thus, increasing the proportion of renewable energy in total energy consumption, is a sustainable way to improve the regional economy andenvironment. The findings are dissimilar with Danish et al. (2017) for Pakistan and Zhang and Liu (2019) for 10 Asian countries, but in accordance with Zrelli (2017) for 14 selected Mediterranean countries and Jebli et al. (2016) in the panel of 25 OECD[7] countries. Causal influence is found between urbanization and emissions which differs from by Ouyang and Lin (2017), indicates that the Central Asian Countries should pay closer attention to the environment brought by urbanization, such as urban poor infrastructure and the inefficient energy use.

Causal linkages are found between real GDP and renewable energy use, bidirectionally. Thus, any change in economic growth would accelerate the development of renewable energy. These findings are dissimilar with Liu et al. (2018) for the Asia-Pacific region and Liu (2018) for China, and similar with Dogan (2016) for Turkey. Investment on renewable energy can boost the development of the economy. Simultaneously, economic growth may change the habit of energy use and prompt the government to develop renewable energy or less pollution energy. Granger causal linkages exist between urbanization and GDP, which is in line with Destek et al. (2016). Obviously, urbanization brings convenience to life and work and makes economy intensive. Two ways causal influence between urbanization and renewable energy reveal that the development of urbanization can affect the use of renewable energy, and vice versa, in Central Asian countries. Such results may depend on the governments, attaching great importance to the urban environment. Smart urban, with large-scale renewable energy use, may improve the technology to reduce the emissions and make energy use more efficient, eco-friendly, cost-effective, accessible, and sustainable, while overurbanization may cause energy shortages, thus affecting the investment on the energy industry, especially renewable energy.

[7] OECD: Organization for Economic Cooperation and Development.

Table 4 Unit root tests

	LCO	LGDP	$LGDP^2$	LRE	LURB
Level					
LLC	− 0.682	0.449	0.805	− 0.514	5.075
IPS	− 0.902	2.390	2.628	− 0.234	0.444
Pesaran's CADF	− 1.678	− 2.267	− 2.271	− 1.572	− 1.945
First difference					
LLC	− 4.328***	− 4.186***	− 4.058***	− 9.674***	− 4.694***
IPS	− 4.180***	− 3.848***	− 3.739***	− 9.074***	− 2.971***
Pesaran's CADF	− 4.359***	− 3.058***	− 2.891***	− 2.787***	− 3.036***

*** denotes the 1% significant level

Conclusions and implications

Notwithstanding lots of studies examining the nexus of energy-urbanization emissions, few pay attention to renewable energy, as well as the main body of Central Asian countries. On account of hypothetical EKC, the present paper examines the relationships among per capita CO_2 emissions, real GDP, renewable energy, and urbanization in CAC-5 from 1992 to 2013. By employing panel unit root tests, panel co-integration test, FMOLS, DOLS, OLS estimation, and the Dumitrescu-Huilin Granger causality, the empirical results of three estimators' techniques indicate that no evidence of inverted hypothetical U-shaped EKC exists in the panel of five selected countries. In addition, under the estimation methodologies, 1% increase of renewable energy use reduces 0.190–0.290% of per capita CO_2 emissions. Moreover, urbanization plays a positive role in emissions significantly, 1% increase of urbanization increasing 4.122–4.487% of emissions. The findings of the Dumitrescu-Huilin Granger causality show that there are evidences of bidirectional causalities between selected variables except no causality from emissions to renewable energy.

On account of the econometric results, the unsupported inverted EKC suggests that the green economic growth should be pushed by Central Asian governments to accelerate the existence of turning point of EKC. One way to achieve the goal is to strive to develop renewable energy, which can lead to CO_2 emissions reduction. Although there are abundant renewable energies in this region, such as wind power in Kazakhstan, solar energy in Uzbekistan, small hydropower in Kyrgyzstan, solar and hydropower in Tajikistan, and solar in Turkmenistan, investments from public and private in this sector are very scarce. In 2011, the subsidies of energy consumption in Uzbekistan and Turkmenistan are 28% and 23% of its GDP, respectively.[8] Therefore, rationalization of energy price is important. Thus, Central Asian countries should increase the investment and subsidy in renewable energy and reduce them in non-renewable energy, as well as foster private investment on renewable energy. As indispensable parts of new Silk Road, proposed by China, Central Asian countries usher in more opportunities to strengthen in-regional and out-regional cooperation, such as technology exchange and talent exchange, and experience sharing, as well as make full use of the Silk Road Fund in the renewable energy field. Meanwhile, the quality of population should be improved to protect the regional environment.

In addition, the development of Central Asian countries' economy cannot be achieved without urbanization, which transfers excess manpower from the countryside to the cities. What followed is pollution, such as air pollution, land

Table 5 The Pedroni residual co-integration test

Alternative hypothesis: common AR coefs. (within-dimension)		
	Statistic	Prob.
Panel v-Statistic	− 0.796	0.787
Panel rho-Statistic	0.330	0.629
Panel PP-Statistic	− 2.046**	0.020
Panel ADF-Statistic	− 2.746***	0.003
Alternative hypothesis: individual AR coefs. (between dimension)		
	Statistic	Prob.
Group rho-Statistic	1.286	0.901
Group PP-Statistic	− 4.483***	0.000
Group ADF-Statistic	− 4.768***	0.000

*** and ** denote the 1% and 5% significant levels, respectively

Table 6 The Westerlund co-integration test

Statistic	Value	*Z*-value	*p* value
Gt	− 5.477	− 6.443***	0.000
Ga	− 2.887	3.745	1.000
Pt	− 7.710	− 1.836**	0.033
Pa	− 3.599	2.672	0.996

*** and ** denote the 1% and 5% significant levels, respectively

[8] http://www.worldbank.org/en/news/press-release/2013/06/25/world-bank-calls-for-europe-and-central-asia-to-move-from-brown-to-green-growth

Table 7 Results of panel FMOLS, DOLS, and OLS

Variable	Dependent variable: LCO Panel FMOLS	Panel DOLS	Panel OLS
LGDP	− 3.839*** (− 6.942)	− 3.591*** (− 11.154)	− 3.604*** (− 10.604)
LGDP2	0.247*** (8.833)	0.240*** (11.949)	0.239*** (13.933)
LRE	− 0.209*** (− 5.561)	− 0.290*** (− 3.899)	− 0.190*** (− 8.494)
LURB	4.487*** (6.391)	4.125*** (14.950)	4.122*** (9.534)
R^2	0.884	0.997	0.881
Adjusted R^2	0.881	0.993	0.878

*** denotes the 1% significant level; the values in parentheses represent t-statistics

Table 8 Results of the Dumitrescu-Huilin Granger causality

Null hypothesis:	W-Stat.	Zbar-Stat.	Prob.	Results
LGDP/LGDP^2 → LCO	8.51254	5.14859***	3.00E-07	Bidirectional causality
LCO → LGDP/LGDP^2	6.56626	3.53363***	0.0004	
LRE → LCO	5.47377	2.62711***	0.0086	Unidirectional causality
LCO → LRE	1.59048	− 0.59512	0.5518	
LURB → LCO	10.0006	6.38336***	2.00E-10	Bidirectional causality
LCO → LURB	6.59543	3.55784***	0.0004	
LRE → LGDP/LGDP^2	4.37227	1.71312*	0.0867	Bidirectional causality
LGDP/LGDP^2 → LRE	5.8697	2.95565***	0.0031	
LURB → LGDP/LGDP^2	20.3399	14.9626***	0.0000	Bidirectional causality
LGDP/LGDP^2 → LURB	4.89125	2.14376**	0.0321	

***, **, and * denote the 1%, 5%, and 10% significant levels, respectively

pollution, and noise pollution. According to the results of the econometric calculation, traditional urbanization may lead to the expansion of carbon dioxide. Therefore, developing sustainable urbanization would not only promote economic prosperity in this region but also restrain CO_2 emissions. Nearly 75% of power generated is consumed in cities, so city-integrated renewable energy should be taken seriously by the government (Kammen and Sunter 2016). Renewable energy, such as small solar and wind energy, should be popularized in communal and household facilities (Amini et al. 2018). High-quality urbanization, reasonably planned infrastructure, and to improve population's quality should be considered by the government. Building environmental protection materials, garbage sorting, as well as low-carbon transportation, should be widely spread. Additionally, rapid urbanization leads to substantial challenges related to transportation and housing. Urbanization should be synchronized with the cities' infrastructure. Infrastructure should be improved, especially small- and medium-sized cities in this region. According to one report of the United Nations,[9] all countries suffer from failing infrastructure. For example, 73% of electrical grids should be repaired in Kazakhstan and more than 50% of gas distribution networks are beyond service life in Uzbekistan. Therefore, governments should increase financial allocation and encourage investment from domestic and foreign capitals, either private funds or public funds. Thus, nearly 21 billion dollars would be implemented to support about 62 projects in this regional urban infrastructure.

Moreover, interaction between emissions and urbanization reveals the feasibility of emissions reduction to ensure steady urbanization in Central Asian countries. If global best practices are adopted, emerging economies in Central Asia are likely to save 50% of their current energy consumption without reducing production. Therefore, introducing foreign advanced technologies can lead to energy conservation and emissions reduction. Meanwhile, Central Asian countries should strengthen their own innovations and technologies on renewable energy, so as to reduce the cost and popularize the use of renewable energies.

There are several limitations to this paper. For example, the statistic of urbanization is only the permanent population in the urban area, not including the floating population, which also affects the local environment. Moreover, CO_2 emissions, the main air pollution, are used to measure the environment, while other air pollutions are not considered. This paper only reveals the linkage of renewable energy and emissions on the

[9] Urbanization in Central Asia: Challenges, Issues and Prospects. Economic and Social Commissions for Asia and the Pacific, United Nations. https://www.unescap.org/sites/default/files/Urbanization-in-CA-ENG.pdf

aggregated level, but disaggregated renewable energies are not investigated. Additionally, these five Central Asian countries have different preponderant resources of renewable energy. Future research may focus on individual countries and individual renewable energy sources, and investigate the relationship between different renewable energies and various kinds of urban energy sources on urban environment in Central Asian countries.

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References

Abdouli M, Hammami S (2017) Economic growth, FDI inflows and their impact on the environment: an empirical study for the MENA countries. Qual Quant 51:121–146. https://doi.org/10.1007/s11135-015-0298-6

Ahmad N, Du L, Lu J et al (2017) Modelling the CO2emissions and economic growth in Croatia: is there any environmental Kuznets curve? Energy 123:164–172. https://doi.org/10.1016/j.energy.2016.12.106

Al-Mulali U, Fereidouni HG, Lee JYM, Sab CNBC (2013) Exploring the relationship between urbanization, energy consumption, and CO2 emission in MENA countries. Renew Sust Energ Rev 23:107–112. https://doi.org/10.1016/j.rser.2013.02.041

Al-Mulali U, Ozturk I (2015) The effect of energy consumption, urbanization, trade openness, industrial output, and the political stability on the environmental degradation in the MENA (Middle East and North African) region. Energy 84:382–389. https://doi.org/10.1016/j.energy.2015.03.004

Ali HS, Abdul-Rahim A, Ribadu MB (2017) Urbanization and carbon dioxide emissions in Singapore: evidence from the ARDL approach. Environ Sci Pollut Res 24:1967–1974. https://doi.org/10.1007/s11356-016-7935-z

Amini H, Boroojeni KG, Iyengar SS et al (2018) Sustainable interdependent networks. Springer

Bakirtas T, Akpolat AG (2018) The relationship between energy consumption, urbanization, and economic growth in new emerging-market countries. Energy 147:110–121. https://doi.org/10.1016/j.energy.2018.01.011

Bekhet HA, Othman NS (2017) Impact of urbanization growth on Malaysia CO2emissions: evidence from the dynamic relationship. J Clean Prod 154:374–388. https://doi.org/10.1016/j.jclepro.2017.03.174

Bekun FV, Alola AA, Sarkodie SA (2019a) Toward a sustainable environment: Nexus between CO2 emissions, resource rent, renewable and nonrenewable energy in 16-EU countries. Sci Total Environ 657:1023–1029. https://doi.org/10.1016/j.scitotenv.2018.12.104

Bekun FV, Emir F, Sarkodie SA (2019b) Another look at the relationship between energy consumption, carbon dioxide emissions, and economic growth in South Africa. Sci Total Environ 655:759–765. https://doi.org/10.1016/j.scitotenv.2018.11.271

Belke A, Czudaj R (2010) Is euro area money demand (still) stable? Cointegrated VAR versus single equation techniques. Appl Econ 56:285–315. https://doi.org/10.3790/aeq.56.4.285

Ben Mbarek M, Saidi K, Rahman MM (2018) Renewable and non-renewable energy consumption, environmental degradation and economic growth in Tunisia. Qual Quant 52:1105–1119. https://doi.org/10.1007/s11135-017-0506-7

Bloom DE, Canning D, Fink G (2008) Urbanization and the wealth of nations. Science 80(319):772–775. https://doi.org/10.1126/science.1153057

Brown A (2012) Scenario analysis: urbanization emissions. Nat Clim Chang 2:394–394. https://doi.org/10.1038/nclimate1569

Cetin M, Ecevit E, Yucel AG (2018) The impact of economic growth, energy consumption, trade openness, and financial development on carbon emissions: empirical evidence from Turkey. In: Environ Sci Pollut Res, vol 25, pp 36589–36603

Danish ZB, Wang B, Wang Z (2017) Role of renewable energy and non-renewable energy consumption on EKC: evidence from Pakistan. J Clean Prod 156:855–864. https://doi.org/10.1016/j.jclepro.2017.03.203

Destek MA, Balli E, Manga M (2016) The relationship between CO2 emission, energy consumption, urbanization and trade openness for selected CEECs. Res World Econ 7:52–58. https://doi.org/10.5430/rwe.v7n1p52

Destek MA, Ulucak R, Dogan E (2018) Analyzing the environmental Kuznets curve for the EU countries: the role of ecological footprint. Environ Sci Pollut Res 25:29387–29396. https://doi.org/10.1007/s11356-018-2911-4

Dogan E (2016) Analyzing the linkage between renewable and non-renewable energy consumption and economic growth by considering structural break in time-series data. Renew Energy 99:1126–1136. https://doi.org/10.1016/j.renene.2016.07.078

Dogan E, Inglesi-lotz R (2017) Analyzing the effects of real income and biomass energy consumption on carbon dioxide (CO2) emissions: empirical evidence from the panel of biomass-consuming countries. Energy. 138:721–727. https://doi.org/10.1016/j.energy.2017.07.136

Dogan E, Ozturk I (2017) The influence of renewable and non-renewable energy consumption and real income on CO2emissions in the USA: evidence from structural break tests. Environ Sci Pollut Res 24:10846–10854. https://doi.org/10.1007/s11356-017-8786-y

Dogan E, Seker F (2016) Determinants of CO2emissions in the European Union: the role of renewable and non-renewable energy. Renew Energy 94:429–439. https://doi.org/10.1016/j.renene.2016.03.078

Dogan E, Taspinar N, Gokmenoglu KK (2019) Determinants of ecological footprint in MINT countries. Energy Environ 0958305X1983427. https://doi.org/10.1177/0958305X19834279

Dogan E, Turkekul B (2016) CO2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA. Environ Sci Pollut Res 23:1203–1213. https://doi.org/10.1007/s11356-015-5323-8

Dorian JP, Wigdortz B, Gladney D (1997) Central Asia and Xinjiang, China: emerging energy, economic and ethnic relations. Centr Asian Surv 16:461–486. https://doi.org/10.1080/02634939708401008

Dumitrescu EI, Hurlin C (2012) Testing for Granger non-causality in heterogeneous panels. Econ Model 29:1450–1460. https://doi.org/10.1016/j.econmod.2012.02.014

Effiong EL (2017) On the urbanization-pollution nexus in Africa: a semiparametric analysis. Qual Quant 52:1–12. https://doi.org/10.1007/s11135-017-0477-8

Emir F, Bekun FV (2018) Energy intensity, carbon emissions, renewable energy, and economic growth nexus: new insights from Romania. Energy Environ 30:427–443. https://doi.org/10.1177/0958305X18793108

Farhani S, Ozturk I (2015) Causal relationship between CO2 emissions, real GDP, energy consumption, financial development, trade openness, and urbanization in Tunisia. Environ Sci Pollut Res 22:15663–15676. https://doi.org/10.1007/s11356-015-4767-1

Fu B, Wu M, Che Y, Yang K (2017) Effects of land-use changes on city-level net carbon emissions based on a coupled model. Carbon Manag 8:245–262. https://doi.org/10.1080/17583004.2017.1314704

Hafeez M, Chunhui Y, Strohmaier D, Ahmed M, Jie L (2018) Does finance affect environmental degradation: evidence from One Belt

and One Road Initiative region ? In: Environ Sci Pollut Res, vol 25, pp 9579–9592
Halicioglu F, Ketenci N (2016) The impact of international trade on environmental quality: the case of transition countries. Energy 109:1130–1138. https://doi.org/10.1016/j.energy.2016.05.013
Hao Y, Wang LO, Lee CC (2018) Financial development, energy consumption and China's economic growth: new evidence from provincial panel data. Int Rev Econ Financ. https://doi.org/10.1016/j.iref.2018.12.006
Im KS, Pesaran MH, Shin Y (2003) Testing for unit roots in heterogeneous panels. J Econom 115:53–74. https://doi.org/10.1016/S0304-4076(03)00092-7
Jebli MB, Youssef SB, Ozturk I (2016) Testing environmental Kuznets curve hypothesis: the role of renewable and non-renewable energy consumption and trade in OECD countries. Ecol Indic 60:824–831. https://doi.org/10.1016/j.ecolind.2015.08.031
Kammen DM, Sunter DA (2016) City-integrated renewable energy for urban sustainability. Science 80(352):922–928. https://doi.org/10.1126/science.aad9302
Karakaya E, Özçağ M (2005) Driving forces of CO2 emissions in Central Asia: a decomposition analysis of air pollution from fossil fuel combustion. Arid Ecosyst J 11:49–57
Kasman A, Duman YS (2015) CO2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: a panel data analysis. Econ Model 44:97–103. https://doi.org/10.1016/j.econmod.2014.10.022
Levin A, Lin CF, Chu CSJ (2002) Unit root tests in panel data: asymptotic and finite-sample properties. J Econom 108:1–24. https://doi.org/10.1016/S0304-4076(01)00098-7
Lin B, Zhu J (2019) The role of renewable energy technological innovation on climate change: empirical evidence from China. Sci Total Environ 659:1505–1512. https://doi.org/10.1016/j.scitotenv.2018.12.449
Lin T, Ge R, Zhao Q, Zhang G, Li X, Ye H, Liao J, Yin K (2016) Dynamic changes of a city's carbon balance and its influencing factors: a case study in Xiamen, China. Carbon Manag 7:149–160. https://doi.org/10.1080/17583004.2016.1180587
Liu X (2018) Aggregate and disaggregate analysis on energy consumption and economic growth nexus in China. Environ Sci Pollut Res 25:26512–26526
Liu X, Bae J (2018) Urbanization and industrialization impact of CO2emissions in China. J Clean Prod 172:178–186. https://doi.org/10.1016/j.jclepro.2017.10.156
Liu X, Zhang S, Bae J (2017a) The impact of renewable energy and agriculture on carbon dioxide emissions: investigating the environmental Kuznets curve in four selected ASEAN countries. J Clean Prod 164:1239–1247. https://doi.org/10.1016/j.jclepro.2017.07.086
Liu X, Zhang S, Bae J (2017b) The nexus of renewable energy-agriculture-environment in BRICS. Appl Energy 204:489–496. https://doi.org/10.1016/j.apenergy.2017.07.077
Liu X, Zhang S, Bae J (2018) Renewable energy, trade, and economic growth in the Asia-Pacific region. Energy Sources, Part B Econ Plan Policy 13:96–102. https://doi.org/10.1080/15567249.2017.1327994
Liu Y, Yan B, Zhou Y (2016) Urbanization, economic growth, and carbon dioxide emissions in China: a panel cointegration and causality analysis. J Geogr Sci 26:131–152. https://doi.org/10.1007/s11442-016-1259-2
Long X, Ji X, Ulgiati S (2017) Is urbanization eco-friendly? An energy and land use cross-country analysis. Energy Policy 100:387–396. https://doi.org/10.1016/j.enpol.2016.06.024
Mark NC, Sul D (2003) Cointegration vector estimation by panel DOLS and long-run money demand. Oxf Bull Econ Stat 65:655–680. https://doi.org/10.1111/j.1468-0084.2003.00066.x
Meng L, Crijns-Graus WHJ, Worrell E, Huang B (2018) Impacts of booming economic growth and urbanization on carbon dioxide emissions in Chinese megalopolises over 1985–2010: an index decomposition analysis. Energy Effic 11:203–223. https://doi.org/10.1007/s12053-017-9559-7
Mirza FM, Kanwal A (2017) Energy consumption, carbon emissions and economic growth in Pakistan: dynamic causality analysis. Renew Sust Energ Rev 72:1233–1240. https://doi.org/10.1016/j.rser.2016.10.081
Oh J, Yun C (2014) Environmental Kuznets curve revisited with special reference to Eastern Europe and Central Asia. Int Area Stud Rev 17:359–374. https://doi.org/10.1177/2233865914553518
Ouyang X, Lin B (2017) Carbon dioxide (CO2) emissions during urbanization: a comparative study between China and Japan. J Clean Prod 143:356–368. https://doi.org/10.1016/j.jclepro.2016.12.102
Pedroni P (1999) Critical values for cointegration tests in heterogeneous panels with multiple regressors. Oxf Bull Econ Stat 61:653–670. https://doi.org/10.1111/1468-0084.0610s1653
Pedroni P (2004) Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. Economic Theory 20:597–625. https://doi.org/10.1017/S0266466604203073
Perelet R (2007) Central Asia: background paper on climate change. UNDP hum dev rep 2007/2008 1–24
Pesaran MH (2007) A simple panel unit root test in the presence of cross-section dependence. J Appl Econ 22:265–312. https://doi.org/10.1002/jae.951
Pesaran MH (2004) General diagnostic tests for cross section dependence in panels
Phillips PCB, Hansen BE (1990) Statistical inference in instrumental variables regression with I(1) processes. Rev Econ Stud 57:99–125. https://doi.org/10.2307/2297545
Ponce De Leon Barido D, Marshall JD (2014) Relationship between urbanization and CO2 emissions depends on income level and policy. Environ Sci Technol 48:3632–3639. https://doi.org/10.1021/es405117n
Poumanyvong P, Kaneko S (2010) Does urbanization lead to less energy use and lower CO2 emissions? A cross-country analysis. Ecol Econ 70:434–444. https://doi.org/10.1016/j.ecolecon.2010.09.029
Ramaswami A, Russell AG, Culligan PJ, Sharma KR, Kumar E (2016) Meta-principles for developing smart, sustainable, and healthy cities. Science (80-) 352:940–943. https://doi.org/10.1126/science.aaf7160
Reyer CPO, Otto IM, Adams S, Albrecht T, Baarsch F, Cartsburg M, Coumou D, Eden A, Ludi E, Marcus R, Mengel M, Mosello B, Robinson A, Schleussner CF, Serdeczny O, Stagl J (2017) Climate change impacts in Central Asia and their implications for development. Reg Environ Chang 17:1639–1650. https://doi.org/10.1007/s10113-015-0893-z
Riti JS, Song D, Shu Y, Kamah M, Atabani AA (2017) Does renewable energy ensure environmental quality in favour of economic growth? Empirical evidence from China's renewable development. Qual Quant 1–24. https://doi.org/10.1007/s11135-017-0577-5, 2007, 2030
Sadorsky P (2014) The effect of urbanization on CO2 emissions in emerging economies. Energy Econ 41:147–153. https://doi.org/10.1016/j.eneco.2013.11.007
Saidi K, Hammami S (2015) Economic growth, energy consumption and carbon dioxide emissions: recent evidence from panel data analysis for 58 countries. Qual Quant 50:361–383. https://doi.org/10.1007/s11135-014-0153-1
Saidi K, Mbarek MB (2017) The impact of income, trade, urbanization, and financial development on CO2emissions in 19 emerging economies. Environ Sci Pollut Res 24:12748–12757. https://doi.org/10.1007/s11356-016-6303-3
Saidi S, Shahbaz M, Akhtar P (2018) The long-run relationships between transport energy consumption, transport infrastructure, and economic growth in MENA countries. Transp Res Part A Policy Pract 111:78–95. https://doi.org/10.1016/j.tra.2018.03.013

Saikkonen P (1991) Asymptotically efficient estimation of cointegration regressions. Economic Theory 7(1):1–21. https://doi.org/10.1017/S0266466600004217

Sarkodie SA (2018) The invisible hand and EKC hypothesis: what are the drivers of environmental degradation and pollution in Africa? Environ Sci Pollut Res 25:21993–22022. https://doi.org/10.1007/s11356-018-2347-x

Sarkodie SA, Adams S (2018) Renewable energy, nuclear energy, and environmental pollution: accounting for political institutional quality in South Africa. Sci Total Environ 643:1590–1601. https://doi.org/10.1016/j.scitotenv.2018.06.320

Sarkodie SA, Strezov V (2019a) A review on environmental Kuznets curve hypothesis using bibliometric and meta-analysis. Sci Total Environ 649:128–145. https://doi.org/10.1016/j.scitotenv.2018.08.276

Sarkodie SA, Strezov V (2019b) Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries. Sci Total Environ 646:862–871. https://doi.org/10.1016/j.scitotenv.2018.07.365

Shahbaz M, Loganathan N, Muzaffar AT, Ahmed K, Ali Jabran M (2016) How urbanization affects CO2emissions in Malaysia? The application of STIRPAT model. Renew Sust Energ Rev 57:83–93. https://doi.org/10.1016/j.rser.2015.12.096

Shahbaz M, Shafiullah M, Papavassiliou VG, Hammoudeh S (2017) The CO2–growth nexus revisited: a nonparametric analysis for the G7 economies over nearly two centuries. Energy Econ 65:183–193. https://doi.org/10.1016/j.eneco.2017.05.007

Sharif Hossain M (2011) Panel estimation for CO2emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries. Energy Policy 39:6991–6999. https://doi.org/10.1016/j.enpol.2011.07.042

Stock JH, Watson MW (1993) A simple estimator of cointegrating vectors in higher order integrated systems. Econometrica 61:783. https://doi.org/10.2307/2951763

Tookey DL (2007) The environment, security and regional cooperation in Central Asia. Communist Post-Communist Stud 40:191–208. https://doi.org/10.1016/j.postcomstud.2007.03.004

Ulucak R, Bilgili F (2018) A reinvestigation of EKC model by ecological footprint measurement for high, middle and low income countries. J Clean Prod 188:144–157. https://doi.org/10.1016/j.jclepro.2018.03.191

Wang S, Li G, Fang C (2018) Urbanization, economic growth, energy consumption, and CO2 emissions: empirical evidence from countries with different income levels. Renew Sust Energ Rev 81:2144–2159. https://doi.org/10.1016/j.rser.2017.06.025

Wang Y, Chen L, Kubota J (2016a) The relationship between urbanization, energy use and carbon emissions: evidence from a panel of Association of Southeast Asian Nations (ASEAN) countries. J Clean Prod 112:1368–1374. https://doi.org/10.1016/j.jclepro.2015.06.041

Wang Y, Li L, Kubota J, Han R, Zhu X, Lu G (2016b) Does urbanization lead to more carbon emission? Evidence from a panel of BRICS countries. Appl Energy 168:375–380. https://doi.org/10.1016/j.apenergy.2016.01.105

Westerlund J (2007) Testing for error correction in panel data. Oxf Bull Econ Stat 69:709–748. https://doi.org/10.1111/j.1468-0084.2007.00477.x

Xu B, Lin B (2015) How industrialization and urbanization process impacts on CO2emissions in China: evidence from nonparametric additive regression models. Energy Econ 48:188–202. https://doi.org/10.1016/j.eneco.2015.01.005

Xu H, Zhang W (2016) The causal relationship between carbon emissions and land urbanization quality: a panel data analysis for Chinese provinces. J Clean Prod 137:241–248. https://doi.org/10.1016/j.jclepro.2016.07.076

Zhang N, Yu K, Chen Z (2017a) How does urbanization affect carbon dioxide emissions? A cross-country panel data analysis. Energy Policy 107:678–687. https://doi.org/10.1016/j.enpol.2017.03.072

Zhang S (2018) Is trade openness good for environment in South Korea? The role of non-fossil electricity consumption. Environ Sci Pollut Res 22:9510–9522. https://doi.org/10.1007/s11356-018-1264-3

Zhang S, Liu X (2019) The roles of international tourism and renewable energy in environment: new evidence from Asian countries. Renew Energy 139:385–394. https://doi.org/10.1016/J.RENENE.2019.02.046

Zhang S, Liu X, Bae J (2017b) Does trade openness affect CO2emissions: evidence from ten newly industrialized countries? Environ Sci Pollut Res 24:17616–17625. https://doi.org/10.1007/s11356-017-9392-8

Zrelli MH (2017) Renewable energy, non-renewable energy, carbon dioxide emissions and economic growth in selected Mediterranean countries. Environ Econ Policy Stud 19:691–709. https://doi.org/10.1007/s10018-016-0170-5