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Energy-Use Inefficiency and Policy Governance in Central Asian Countries

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Abstract: This study aims to examine the energy-use inefficiency in Central Asian (CA) countries by using the analytical framework of the energy-environmental Kuznets curve (EEKC). This study's contribution to the literature, in the first place, is to explicitly target the CA countries in the EEKC analysis. The empirical analyses identified the energy-use inefficiency of Turkmenistan, Uzbekistan, and Kazakhstan, and could demonstrate the contributions of weak policy governance and their natural resource abundance. This analytical result could also be endorsed by the Uzbekistan case. Thus, the policy implication is that there would be much room for these countries to improve their energy-use efficiency by enhancing their performance of energy policies.

Keywords: energy-use inefficiency; policy governance; Central Asia; energy-environmental Kuznets curve; Uzbekistan

JEL Classification: Q4; O53

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1. Introduction

Central Asia (CA) is composed of five countries: the Republic of Kazakhstan (hereafter Kazakhstan), the Kyrgyz Republic (Kyrgyz), the Republic of Tajikistan (Tajikistan), Uzbekistan, and Turkmenistan, which were formed after the disintegration of the Soviet Union in 1991. The CA countries have made significant progress in their market-based economic transformations and in their linkages with the world economy. However, they went through severe hardships in their economic management in the early stages after their independence. All the CA countries now belong to the middle-income group (Kazakhstan and Turkmenistan are classified into the "upper" middle-income group and the others into the "lower" middle-income group). This is based on the World Bank income classification (See the website: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519, accessed on 1 July 2021) (see the profile of the CA countries in Table A1).

Much of the existing literature has treated the CA countries as homogenous. The countries enjoy commonalities of history, geographical closeness, culture, and language: all were historically colonized by Tsarist Russia and were part of the Soviet Union for over 70 years, and are geographically landlocked. However, they vary in terms of population and land size, neighboring countries, and natural resource endowments, as shown in Table A1. Kazakhstan has a large population and territory; it also shares borders with Russia and China and is endowed with oil and coal. Kyrgyz and Tajikistan have relatively smaller population size and land, share borders with China (and Afghanistan in the case of Tajikistan), and are less endowed with natural resources. Turkmenistan, bordering with Afghanistan and Iran, is less populated but well endowed with oil and natural gas, and Uzbekistan has a large population and is also well endowed with natural gas.

One of the key issues in the economic development of CA countries is the problem of energy-use efficiency and the power industry. Table A1 shows that the energy uses in terms of a kilogram of oil equivalent per capita in Kazakhstan, Turkmenistan, and Uzbekistan are far beyond the average found in East Asia and the Pacific, excluding high-income countries. The three countries above are typically classified into resource-rich countries by the World Bank (See the website: https://tcdata360.worldbank.org/indicators/7bc4251b?country=BRA&indicator=28157&viz=choropleth&years=2017 accessed on 1 July 2021). The published literature on energy in Central Asia also focused on the energy resources of the region as in Dorian et al. [1] and Dorian [2]. At the same time, Kaliakparova et al. [3] argued that the CA region is one of the most energy-consuming regions globally, and technical losses of energy resources reach 20% of the volume of electricity production. Thus, studying the energy-use efficiency in the CA regions is of vital significance from the global perspective of achieving the Sustainable Development Goals (SDGs) (doubling the global rate of improvement in energy efficiency by 2030 is one of the targets of SDGs (See the website: https://sdgs.un.org/topics/energy accessed on 1 July 2021)).

This article aims to examine the energy-use inefficiency in CA countries by using the analytical framework of the energy-environmental Kuznets curve (EEKC), focusing on Asian countries. The study takes the following steps: first, developing the EEKC for each Asian country to identify the energy-use-efficiency positions of CA countries; second, estimating the EEKC econometrically with country-specific fixed effects on energy-use efficiency; third, investigating the contributions of the factors of energy abundance and institutional quality to country-specific fixed effects for CA countries; and finally, referring to the case of Uzbekistan as a sample for describing energy-use-inefficiency problems.

The remainder of the paper is structured as follows. Section 2 reviews the literature related to this study and clarifies this study's contribution. Section 3 conducts empirical analyses consisting of the simple EEKC description, its econometric estimation and the sample study in Uzbekistan on its energy-use inefficiency. Section 4 summarizes and concludes the paper.

2. Literature Review and Contribution

The issue of energy-use efficiency has often been discussed in the energy-growth nexus, because energy consumption is correlated with economic growth and income level and thus energy-use efficiency cannot be examined without considering economic growth and income level. Therefore, this section reviews the literature on the energy-growth nexus, the EEKC and the energy-use inefficiency of CA countries clarifying this study's contribution.

2.1. Energy-Growth Nexus

The energy-growth nexus has been at the forefront of energy economics in the last two decades, which was initially proposed by the seminal work of Kraft and Kraft [4]. This nexus has gained the academic attention of many researchers and produced a vast empirical output with the evolution of various types of modeling, econometric methods and variable settings. Menegaki [5] summarizes and arranges the numerous empirical works and argues that there has been no clear consensus on the results due to a lack of mature theoretical underpinning.

With a focus on the works on Asian countries, there have been a number of the energy-growth-nexus studies with a variety of perspectives. Regarding time-series analyses using cointegration and the error-correction model, Asafu-Adjaye [6] examined the causal relationships between energy consumption, energy prices and economic growth for selected Asian economies and rejected the view that energy and income are neutral with respect to each other; and Saboori and Sulaiman [7] investigated the nexus between economic growth, carbon dioxide emissions and energy consumption in selected Association of Southeast Asian Nations (ASEAN) countries and found that carbon emissions and energy consumption are highly interrelated to each other. As for panel cointegration and error-correction approaches, Lee and Chang [8], targeting 16 Asian countries, investigated the causal relationship between energy consumption and economic growth within a multivariate framework including capital stock and labor input, and showed that there is a long-run unidirectional causality running from energy consumption to economic growth; Fang and Chang [9], sampling 16 Asia Pacific countries, examined the nexus between energy consumption and economic growth using the augmented production function containing human capital, and proved that economic growth Granger cause energy use though the relationship varies for individual countries; and Menegaki and Tugcu [10] investigated the energy-growth nexus in selected Asian countries with the covariates being trade, rents, financial development and inflation, and suggested that energy conservation restrains conventional and sustainable growth.

As described above, different estimation approaches with different specifications have produced different research outcomes as Menegaki [5] argued, even if the evidence is confined to Asian economies.

2.2. Energy-Environmental Kuznets Curve (EEKC)

The EEKC is a promising research area with a kind of theoretical underpinning in the energy-growth nexus debate. Menegaki [5] categorized the Kuznets curve approach into simultaneous equation modeling in its classification.

The hypothesis of the environmental Kuznets curve postulating the inverted-U-shaped path between environmental pollution and economic growth was initially proposed by Grossman and Krueger [11]. Suri and Chapman [12] applied this hypothesis to energy consumption as being the cause of environmental pollution (since then, this modified energy consumption-growth nexus has been called the energy-environmental Kuznets curve or EEKC). Using this framework, they argued that import of manufactured goods has contributed to the downward slope of the inverted U curve.

Several empirical studies have since then tried to verify the existence of the EEKC, with inconclusive results. EEKC was confirmed in a sample of countries [13], in EU countries [14], in Middle Eastern countries [15], in Ethiopia [16] and in Romania [17], whereas the hypothesis was not identified in the world-wide samples [18,19], or in Latin American and Caribbean countries [20]. When it comes to the Asian region, which is one of the fastest-growing regions, globally, in terms of economy and energy consumption, Aruga [21] examined the EEKC for 19 Asia-Pacific countries initially and found that the EEKC hypothesis only holds for the high-income groups in that region, while it is not apparent for the low- and middle-income groups.

2.3. Energy-Use Inefficiency of CA Countries

This subsection highlights the studies on the inefficiency of energy use in CA countries. Mehta et al. [22] pointed out that the infrastructure in the Central Asian power sector, set up in the 1980s by the Soviet Union, is now outdated. Dyussembekova [23], focusing on the case of Kazakhstan, also examined the deterioration of its power system inherited from the Soviet Union and proposed strategic adjustments based on global trends such as changes in the structure of demand, the development of renewable energy sources, and digitalization of the power industry. Gomez et al. [24], focusing on the case of Uzbekistan, analyzed the energy efficiency problem on both the supply and demand sides: the obsolescence of power generation plants and facilities on the supply side and the intensity of natural gas usage, particularly in the household sector, on the demand side.

The studies above pointed to energy-use inefficiency in a descriptive way but did not analyze the problem in a quantitative way under the energy-growth-nexus framework. This study chooses the EEKC framework as an analytical tool to examine the energy use-inefficiency in CA countries, since the general frameworks of the energy-growth-nexus have led to no clear consensus in their research outcomes as Menegaki [5] argued. The precious study of the EEKC in Asian countries, Aruga [21], did not contain CA countries in the analytical target, and thus, this study's contribution to the literature, in the first place, is to explicitly target CA countries in the EEKC analysis. The advantage of EEKC application to CA countries is that their energy-use inefficiency could be proxied by their country-specific fixed effect, namely, their EEKC locational positions, while verifying the inverted-U-shaped hypothesis between energy use and economic growth would not be a main research focus in this study.

3. Empirical Studies

The empirical studies in this section are composed of a descriptive analysis of Asian countries' EEKC, their econometric analysis and the case analysis of Uzbekistan.

This study assumes that the energy-use efficiency in each sample country can be represented by the heterogeneity of energy use at the same level of GDP per capita, which is corresponding to the difference in the locations of the EEKC in the descriptive analysis, and the country's time-invariant fixed effect in the EEKC econometric estimation. There has been the discussion in general on whether energy efficiency is time "invariant" or time "variant" as in Zheng and Heshmati [25] (This study defines energy use as the kilogram of oil equivalent per capita as in Aruga [21]. Regarding the concepts of energy efficiency, there have still been a number of debates, for instance, on the choice of single factor efficiency or all-factor energy efficiency (see Zheng and Heshmati [25])). This study supposes that the heterogeneity of energy use that is not explained on the EEKC trajectories originates from a country-specific time-invariant fixed effect as in, e.g., Akram et al. [26] and Song and Yu [27]. This section starts with the EEKC descriptive analysis.

3.1. Descriptive Analysis

Figure 1 displays the EEKCs of selected Asian countries for 1970–2015 (The sample period for the CA countries is 1992–2015). The EEKC is drawn with the vertical axis being the energy use expressed as the kilogram of oil equivalent per capita. The horizontal axis is the gross domestic product (GDP) per capita in terms of US dollars at constant prices in 2015. The data of the energy use is retrieved from the databases of the World Bank Open Data (See the website: https://data.worldbank.org/accessed on 1 July 2021) and that of GDP per capita from the UNCTAD Stat (See the website: https://unctadstat.unctad.org/EN/accessed on 1 July 2021). Here, 12 sample countries are selected as follows: Kazakhstan, Kyrgyz, Tajikistan, Turkmenistan, and Uzbekistan in the CA countries, and China, Indonesia, Japan, Korea, Malaysia, Singapore, and Thailand in the other Asian countries. The 12 sample countries here are chosen for easily visualizing the different trajectories of EEKC by removing the countries with similar trends of GDP per capita, while the subsequent econometric analysis targets 23 Asian countries (it will be explained later).

The important finding from Figure 1 is that the locations of Kazakhstan, Turkmenistan, and Uzbekistan among the CA countries reveal higher positions than the trends commonly seen in the other Asian countries. This finding, together with the simple comparison in Table A1, suggests that the three CA countries have experienced extraordinary energy uses at their levels of GDP per capita, thereby implying energy-use inefficiency.

The subsequent section examines the countries' positions of energy use by the country-specific fixed-effect through an econometric approach and investigates the factors contributing to the difference in the fixed effects.

3.2. Econometric Analysis: Methodology and Data

This section focuses on the EEKC econometric analysis for Asian countries and starts with the description of methodology and data.

This study basically follows the original form of the EEKC presented by Suri and Chapman [12]. Regarding the model specification, this study applies the standard nonlinear model where energy use per capita is explained by GDP per capita and its square, which was shown by Suri and Chapman [12] as the simple version of their models, and by Aruga [21] targeting Asia-Pacific countries. This study also adopts the fixed-effect model for panel-data estimation as in Suri and Chapman [12]. From the statistical perspective, the Hausman test statistic is generally utilized to choose between a fixed-effect model and a random effect one [28] as in Aruga [21]. This study, however, emphasizes presenting a country-specific effect on energy use explicitly, and also a time-specific factor such as economic fluctuations due to external shocks such as the Asian financial crises in 1997–1998 and the global financial crises in 2008–2009. In addition, adopting the fixed-effect model contributes to alleviating the endogeneity problem by absorbing unobserved time-invariant heterogeneity among the sample countries. The EEKC analysis is classified into simultaneous equation modeling by Menegaki [5], thereby requiring a prescription for endogeneity among variables. The fixed-effect model removes the omitted variable bias as a source of endogeneity in panel estimation.

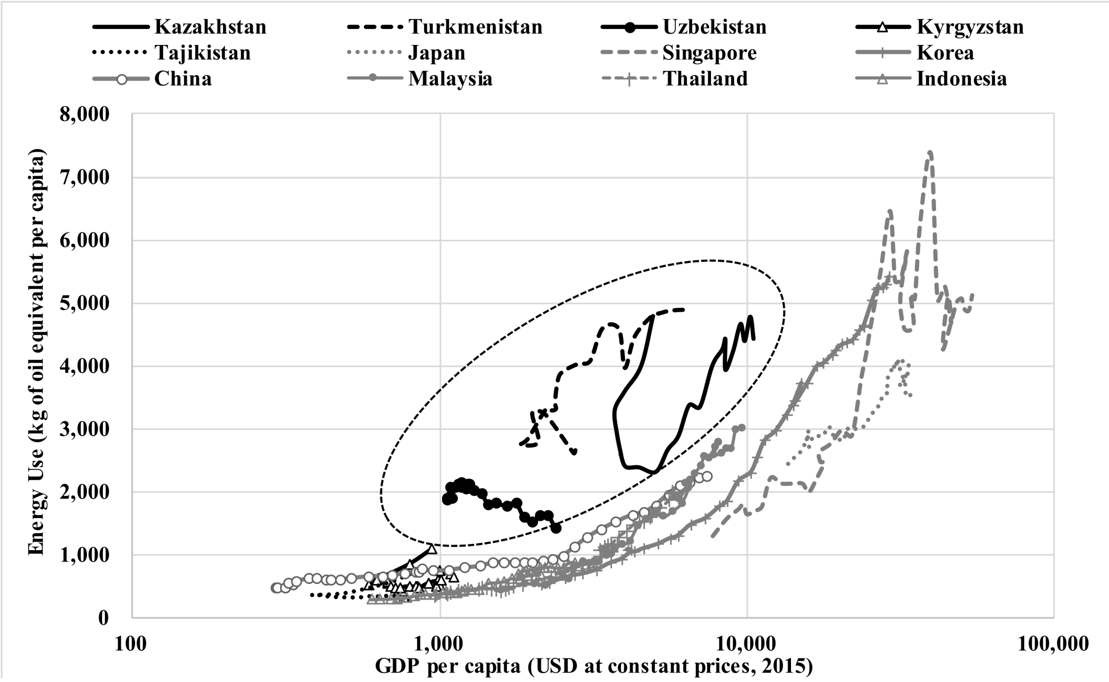


Figure 1. Trends in energy use in selected Asian countries. Sources: Author's calculation based on World Bank Open Data and UNCTAD Stat.

As for the estimation technique, this study applies the ordinary least squares (OLS) estimator for the following Equations (1) and (2) and the Poisson pseudo-maximum likelihood (PPML) estimator for the following Equations (3) and (4) (This study uses EViews 12, as the software for the estimations). The reason for the additional use of the PPML estimator is that the data of energy use might be plagued by the heteroskedasticity problem, in which the OLS estimator leads to a bias and an inconsistency in its estimate. Thus, this study applies both estimators to ensure the robustness of their estimations, following the suggestions as in Santos Silva and Tenreyro [29] and Head and Mayer [30]. Suri and Chapman [12] applied the general least squares (GLS) estimator for addressing the heteroskedasticity problem. This study, however, uses the PPML instead of the GLS considering the property of the nonlinear estimation.

Then, the equations for the estimation are specified as follows:

$$\ln eng_{it} = \alpha_0 + \alpha_1 \ln ypc_{it} + \alpha_2 (\ln ypc_{it})^2 + f_i + f_t + \varepsilon_t \quad (1)$$

$$\ln eng_{it} = \beta_0 + \beta_1 \ln ypc_{it} + \beta_2 (\ln ypc_{it})^2 + \beta_3\, nrr_{it} + \beta_4\, gov_{it} + f_t + \varepsilon_t \quad (2)$$

$$eng_{it} = \exp\,[\alpha_0 + \alpha_1 \ln ypc_{it} + \alpha_2 (\ln ypc_{it})^2 + f_i + f_t\,] + \varepsilon_t \quad (3)$$

$$eng_{it} = \exp\,[\beta_0 + \beta_1 \ln ypc_{it} + \beta_2 (\ln ypc_{it})^2 + \beta_3\, nrr_{it} + \beta_4\, gov_{it} + f_t\,] + \varepsilon_t \quad (4)$$

where the subscripts *i* and *t* denote sample countries and years, respectively; *eng* represents the energy use expressed as the kilogram of oil equivalent per capita; *ypc* shows GDP per capita in terms of US dollars at constant prices in 2015; *nrr* denotes the natural resource rents (sum of oil, natural gas, and coal rents) expressed as a percentage of GDP; *gov* represents the governance indicators; f_i and f_t show a time-invariant country-specific fixed effect and a country-invariant time-specific fixed effect, respectively; ε denotes a residual error term; $\alpha_{0\ldots2}$ and $\beta_{0\ldots4}$ represent estimated coefficients, respectively; ln shows a logarithm form, which is set to avoid scaling issues for the energy use (*eng*) and GDP per capita (*ypc*); and exp shows an exponential form.

The details of the variables and the sample size for the estimation are shown as follows. The data sources for the energy use (*eng*) and GDP per capita (*ypc*) are the same as those in Section 2.1. The data of the natural resources rents (*nrr*) are retrieved from the World Bank Open Data database. The governance indicators (*gov*) are represented by World Governance Indicators (WGI) of the World Bank (For the data acquisition and their definitions, see the website: https://info.worldbank.org/governance/wgi/accessed on 1 July 2021). This study, whose analytical concern is the energy policy performances, selects the following four indicators out of a total of six: effectiveness of government (*gve*), regulatory quality (*rgq*), rule of law (*rol*), and control of corruption (*cor*). Each index takes the number ranging from −2.5 (weak governance) to 2.5 (strong governance), with the world average being approximately zero. As for the sample size, the estimation targets 23 Asian countries: the 12 countries in Section 3.1 and an additional 11 countries (Bangladesh, Brunei Darussalam, Cambodia, India, Mongolia, Myanmar, Nepal, Pakistan, the Philippines, Sri Lanka, and Vietnam). The sample period is 1970–2015 for Equations (1) and (3), and 1996–2015 for Equations (2) and (4) due to the data constraints of WGI. The study then constructs a set of panel data of the sample countries and periods. The study winsorizes the data of all the variables at the 0.01st and 99.9th percentile to remove the outliers. The descriptive statistics for the data of all the variables are displayed in Table A2.

For the subsequent estimation, this study investigates the stationary property of the constructed panel data by employing panel unit root tests: the Levin, Lin, and Chu test (Levin et al. [31]) as a common unit root test; and the Fisher ADF and Fisher PP tests (Maddala and Wu [32]; Choi 2001 [33]) as individual unit root tests. The common unit root test assumes that there is a common unit root process across cross-sections, and the individual unit root test allows for individual unit root processes that vary across cross-sections. These tests are conducted based on the null hypothesis that a level of panel data has a unit root, by including the trend and intercept in the test equations. Table A3 shows that both of the common and individual unit root tests identify the rejection of the null hypothesis of a unit root at the conventional significance levels in all the variables. Therefore, this study uses the level of panel data for the estimation.

The notes on the specifications of the estimation models are described as follows: Equations (1) and (3) apply a fixed-effect model represented by f_i and f_t, respectively, for panel estimation. The estimation sets China as the benchmark country for country-specific effects because China is located in the middle position in the EEKC descriptive analysis in Figure 1. The significantly positive coefficient of the country-specific effect would suggest that the country's energy use is more inefficient than that of China. The ordinary hypothesis of EEKC postulating the inverted-U-shaped path between energy use and GDP per capita would be verified if $\alpha_1 > 0$ and $\alpha_2 < 0$ are significant (in Equations (2) and (4), $\beta_1 > 0$ and $\beta_2 < 0$ are significant).

Equations (2) and (4) replace the country-specific fixed effects above with possible contributors to the fixed effects. This study adopts the natural resource rents (*nrr*) and governance indicators (*gov*) as possible contributors. This is because the lower performance of energy policies has led to inefficient energy use, in particular in CA countries as shown in Mehta et al. [22], Dyussembekova [23], and Gomez et al. [24], while natural resource abundance is supposed to give less incentive to save energy and use energy efficiently. The energy policy performance is represented by the aforementioned four governance indicators. In Equations (2) and (4), each governance indicator is separately inserted as an independent regressor since the indicators have a multicollinearity problem. Table A4 reports the bivariate correlations and the variance inflation factors (VIF), a method of measuring the level of collinearity between the regressors. It shows a high bivariate correlation (around 0.9) in each combination and high values of VIF that are beyond (or close to) the criteria of collinearity, namely, ten points. The natural resource rents (*nrr*) are supposed to have a positive effect on energy use. Each governance indicator is expected to equip a negative coefficient on energy use because better governance leads to more energy-use efficiency.

3.3. Econometric Analysis: Estimation Results

Table 1 reports the results of OLS and PPML estimations in the form of a log-link function. Column (i) displays the outcome of the fixed-effect model of each estimation, and Columns (ii), (iii), (iv), and (v) present the results of the alternative model containing the natural resource rents and the governance indicators instead of the fixed effects. The OLS and PPML estimations show similar results in the sign and significance of each coefficient. Thus, the subsequent description focuses on the result of PPML estimation that adjusts the heteroskedasticity. The findings from the estimation results are summarized as follows.

Table 1. Estimation outcomes.

[OLS Estimation]					
Variables	(i) ln *eng*	(ii) ln *eng*	(iii) ln *eng*	(iv) ln *eng*	(v) ln *eng*
ln *ypc*	1.064 ***	0.982 ***	0.973 ***	0.980 ***	0.999 ***
	(42.152)	(13.923)	(13.982)	(13.707)	(13.378)
(ln *ypc*)^2	−0.018 ***	−0.014 **	−0.013 **	−0.014 ***	−0.017 ***
	(−5.939)	(−2.578)	(−2.589)	(−2.651)	(−2.928)
nrr		0.031 ***	0.029 ***	0.030 ***	0.032 ***
		(10.272)	(10.709)	(10.935)	(11.823)
gve		−0.103 *			
		(−1.796)			
rgq			−0.109 **		
			(−2.235)		
rol				−0.090 *	
				(−1.680)	
cor					−0.050
					(−0.808)
Country fix effects					
Turkmenistan	0.805 ***				
Uzbekistan	0.695 ***				
Kazakhstan	0.215 ***				
Mongolia	0.091 *				
Kyrgyzstan	−0.038				
Myanmar	−0.041				
Nepal	−0.073				
Tajikistan	−0.250 ***				
India	−0.291 ***				
Vietnam	−0.449 ***				
Cambodia	−0.468 ***				
Malaysia	−0.526 ***				
Pakistan	−0.537 ***				
Thailand	−0.605 ***				
Indonesia	−0.605 ***				
Korea	−0.613 ***				
Brunei	−0.626 ***				
Singapore	−0.788 ***				
Japan	−0.844 ***				
Philippines	−0.940 ***				
Sri Lanka	−0.996 ***				
Bangladesh	−1.242 ***				

Table 1. *Cont.*

[OLS Estimation]					
Period fixed effects	Yes	Yes	Yes	Yes	Yes
Redundant VariableTest (F-value)	4299.1 ***	845.4 ***	852.0 ***	838.1 ***	837.8 ***
Number of observation	834	296	296	296	296
[PPML Estimation]					
Variables	(i) ln *eng*	(ii) ln *eng*	(iii) ln *eng*	(iv) ln *eng*	(v) ln *eng*
ln *ypc*	0.998 ***	1.050 ***	0.994 ***	1.021 ***	1.002 ***
	(13.638)	(14.883)	(16.269)	(15.506)	(14.023)
(ln *ypc*)^2	−0.021 ***	−0.020 ***	−0.014 **	−0.017 ***	−0.015 **
	(−2.749)	(−2.752)	(−2.547)	(−2.778)	(−2.254)
nrr		0.021 ***	0.019 ***	0.020 ***	0.020 ***
		(4.926)	(6.106)	(6.286)	(5.727)
gve		−0.181 *			
		(−1.900)			
rgq			−0.248 ***		
			(−3.715)		
rol				−0.214 ***	
				(−3.172)	
cor					−0.233 ***
					(−3.535)
Country fix effects					
Turkmenistan	0.926 ***				
Uzbekistan	0.735 ***				
Kazakhstan	0.424 ***				
Mongolia	0.212				
Brunei	−0.002				
Kyrgyzstan	−0.035				
Nepal	−0.072				
Korea	−0.156				
Malaysia	−0.172				
Myanmar	−0.189				
India	−0.255 *				
Singapore	−0.278				
Tajikistan	−0.285				
Thailand	−0.330 ***				
Japan	−0.387				
Vietnam	−0.411 ***				
Pakistan	−0.442 ***				
Indonesia	−0.455 ***				
Cambodia	−0.520 ***				
Philippines	−0.766 ***				
Sri Lanka	−0.889 ***				
Bangladesh	−1.218 ***				
Period fixed effects	Yes	Yes	Yes	Yes	Yes
Number of observation	834	296	296	296	296

Note: t-statistics are in parentheses. ***, **, and * denote statistical significance at 99, 95, and 90 percent level, respectively. Source: Author's estimation.

First, the EEKC hypothesis, which assumes the inverted-U-shaped relationship between energy use and GDP per capita is confirmed in all the estimations from Columns (i) to (v) because the coefficients of GDP per capita are significantly positive and those of its square are significantly negative. The turning points are, however, far beyond the reasonable range of GDP per capita (The turning point is computed by—$\alpha_1/2\alpha_2$, or—$\beta_1/2\beta_2$.

Using the estimated coefficients in Table 1, the turning points would be beyond 1 million US dollars as GDP per capita). It might come from the observation in Section 2.1 that most sample countries stay at the increasing trends of their EEKC. This finding leads the research to focus on the locations of the EEKC trajectories rather than the EEKC shapes.

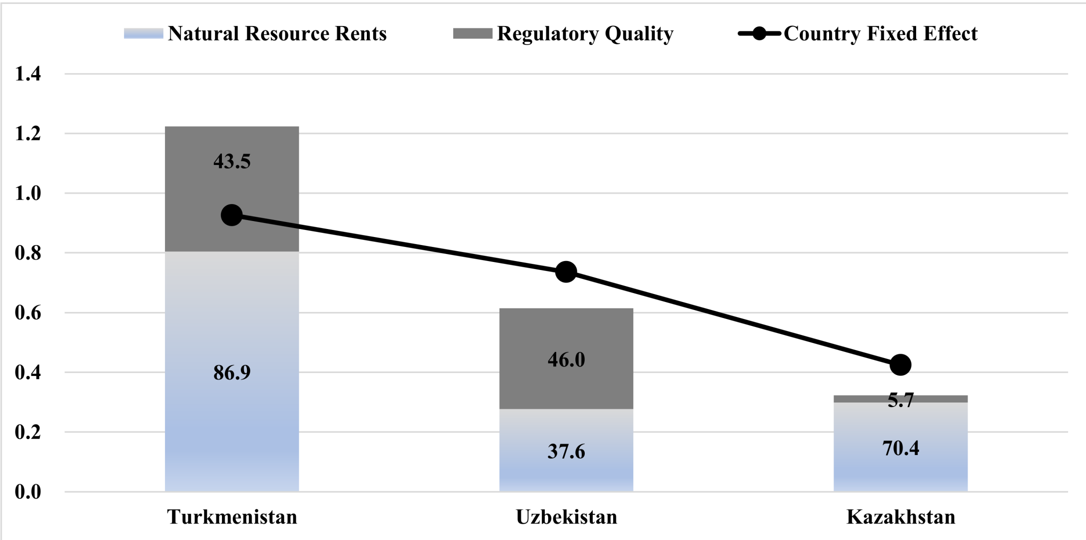
Second, focusing on the fixed-effect model in Column (i), the coefficients of the country-specific dummies are significantly positive in Turkmenistan, Uzbekistan, and Kazakhstan in the CA countries (in common with the OLS estimation), and insignificant or significantly negative in the other sample countries. This means that the energy uses of the three CA countries are inefficient due to their country-specific factors as compared to China, the benchmark country, and this result is consistent with the descriptive analysis in Section 3.1. The degree of the energy-use inefficiency is shown by the magnitude of the coefficient of the country-specific dummy: exp.(0.926) = 2.524 in Turkmenistan (the energy use of Turkmenistan is 2.524 times larger than that of China), exp.(0.735) = 2.085 in Uzbekistan, and exp.(0.424) = 1.528 in Kazakhstan.

Third, turning to the alternative model containing the natural resource rents and the governance indicators in Columns (ii)–(v), the coefficients of the natural resource rents (*nrr*) are significantly positive as expected in all the cases. As for the governance indicators, all the coefficients are significantly negative as supposed: the regulatory quality (*rgq*), the rule of law (*rol*), the control of corruption (*cor*) show robust significance at the 99% level (the rule of law is insignificant in the OLS estimation, though), while the government effectiveness (*gve*) indicate weak significance at the 90% level. This result suggests that energy use is highly correlated with the natural resource abundance and is more importantly affected by policy governance, such as the regulatory quality and the rule of law. The joint estimation outcomes of the country-specific fixed effect and the policy governance effect on energy use lead to the question of the degree of contribution of the policy-governance factors to the country-specific energy use inefficiencies in the CA countries.

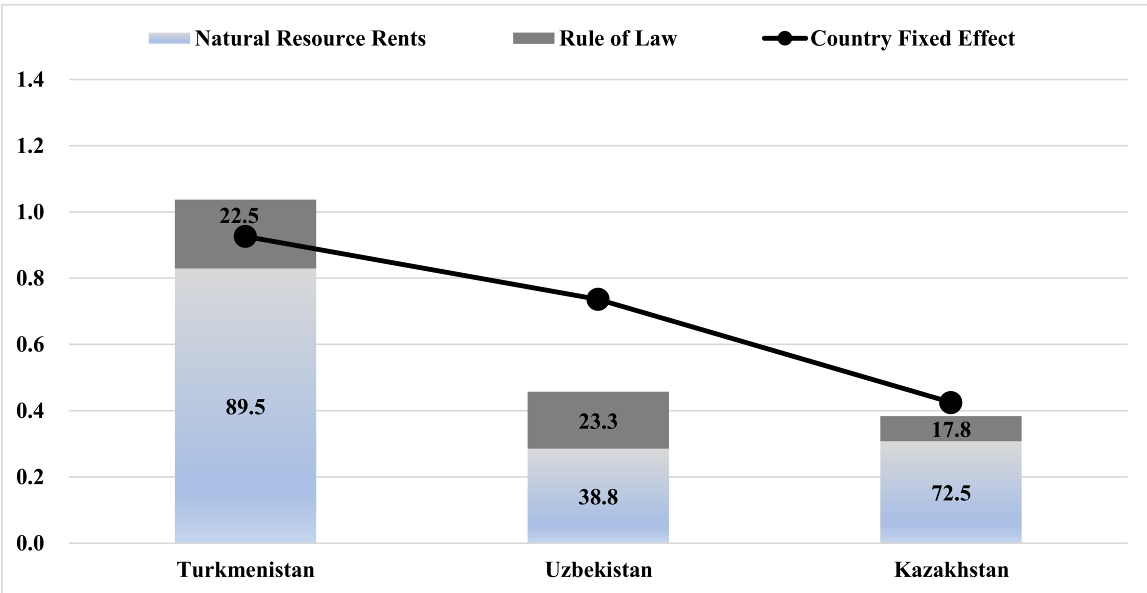
The most critical information extracted from Table 1 is the identification of the energy-use inefficiency with its magnitude in Turkmenistan, Uzbekistan, and Kazakhstan as their country-specific effects in the EEKC framework, and of the statistical linkage of policy governance with energy-use efficiency in the alternative EEKC model.

3.4. Econometric Analysis: Factor Compositions in Energy-Use Inefficiencies

The final step is to examine the contributions of the abundance of natural resources and policy governance to the country-specific energy-use efficiencies in the CA countries (here, also based on the PPML estimation). Table A5 and Figure 2 focus only on the three countries (Turkmenistan, Uzbekistan, and Kazakhstan), since these countries only have significantly positive country-specific fixed-effects representing their energy use inefficiencies in the PPML estimation. Table A5 shows the fixed effects and contributors in the three countries, focusing on two governance indicators: the regulatory quality and the rule of law. Column (a) shows the coefficients of the country-specific fixed-effect dummies; Column (b) presents the period-average natural resource rents (*nrr*); Column (c) computes the *nrr* deviations from China (the benchmark country); Column (d) obtains the *nrr* contributions by multiplying the *nrr* deviations by the estimated *nrr* coefficient in Table 1; Column (e) presents the period-average governance indicators (the regulatory quality, *rgq* and the rule of law, *rol*); Column (f) computes the deviations of *rgq* and *rol* from China; Column (g) obtains the contributions of *rgq* and *rol* by multiplying their deviations by the estimated coefficients in Table 1, respectively; and Column (h) shows the total contributions by summing up each of Columns (d) and (g). In Figure 2, the line displays the country-specific fixed-effects while the bar graphs indicate the contributions of the natural resource rents and the governance indicators in the three CA countries.



[Regulatory Quality]



[Rule of Law]

Figure 2. Decomposition of fixed effects in selected central Asian countries. Note: The number in the bar graph indicates the contribution percentage of each factor (the natural resource rents and governance indicators) to the country fixed effect. Source: Author's calculation.

The analytical results from Table A5 and Figure 2 are summarized as follows. First, the contributions of the natural resource rents (*nrr*) to the country fixed effects account for 37.6–89.5% of the country fixed effects in all the cases. Second, the regulatory quality has contribution rates to the country fixed effects by 46.0% in Uzbekistan, 43.5% in Turkmenistan, and 5.7% in Kazakhstan. Third, the rule of law has contribution rates of 23.3% in Uzbekistan, 22.5% in Turkmenistan, and 17.8% in Kazakhstan. The results suggest that the lack of policy governance is an influential factor that explains energy-use inefficiency in Uzbekistan and Turkmenistan. This outcome is consistent with the argument which points out the lower performance of energy policies in Mehta et al. [22], Dyussembekova [23], and Gomez et al. [24]. Thus, there would be enough room for Uzbekistan and Turkmenistan to improve their energy-use efficiencies by enhancing their performance of energy policies. From the global perspective, the CA countries are considered to be some of the most energy-consuming entities with the greatest loss of energy resources in the world as Kaliakparova et al. [3] argued, while the SDGs require a doubling of the global rate of improvement in energy efficiency by 2030. Therefore, this study's finding demonstrates the significance of enhancing the CA countries' energy policy governance from the world-wide context as well as the regional aspect.

3.5. The Case of Uzbekistan

It was in Uzbekistan that the policy governance mattered to the largest degree in explaining its energy-use inefficiency as shown in the previous subsection. Thus, this subsection picked up the case of Uzbekistan as a sample for describing the detailed energy situation and policies.

The growth of population and the development of the economy in Uzbekistan have induced an increasing demand for energy. The population in Uzbekistan has risen from 20.8 million in 1991 to 33.7 million in 2020. Regarding the economy, the agricultural and industrial sectors are considered the dominant energy users. Thus, Uzbekistan's energy sector has played a significant role; it accounts for 7% of GDP and 72% of the government investment program. Moreover, primary energy demand in Uzbekistan is forecast to increase with an annual growth rate of 1.7% by 2025 (Yuldasheva et al. [34]). Although there are several mines from which gas-oil, coal, and uranium are extracted to produce energy, there is a shortage of energy generation and transmission. Uzbekistan has even resumed imports of electricity from neighboring Central Asian countries, such as Kazakhstan, in 2019, and Turkmenistan, in February 2021, to meet the rising energy demands, especially during the peak load of the winter period.

The question of the factors that caused the shortage of energy generation is crucial in Uzbekistan. First, the technology and management utilized in energy production are outdated and inefficient (e.g., Gomez et al. [6]). Although the energy use intensity in Uzbekistan has decreased by approximately 45% in the last 15 years, it remains 35% higher than that of Kazakhstan and three times higher than that of Germany (See the website: https://www.worldbank.org/en/news/press-release/2018/01/30/industrial-enterprises-to-become-more-energy-efficient-reducing-overall-energy-consumption-in-uzbekistan accessed on 1 July 2021). This is because most of the main energy generators located in a thermal power station that generates 56.5 million kilowatts of electricity, were built fifty years ago and are less productive under an inefficient management system. At the same time, the country's industrial sector, which largely utilizes inefficient and obsolete technology in its production processes, accounts for about 40% of total energy consumption. The government is now on its way to modernizing the energy generation system with the installation of high-end technologies. Second, Uzbekistan still depends on traditional energy resources such as natural gas. Looking at the share of energy sources of electricity generation in 2018, traditional energies such as natural gas account for 90%, whereas hydropower as a renewable energy source accounts for only 10% (See the website: https://www.iea.org/reports/uzbekistan-energy-profile accessed on 1 July 2021). In Uzbekistan, more than 300 days in a year are sunny, and there is considerable room to develop the harvesting of renewable energy resources. In fact, the solar energy potential is almost four times the country's primary energy consumption. Thus, potential solar energy is enough to meet the rising energy demands and a wide range of industrial purposes (See the website: https://www.iea.org/reports/uzbekistan-energy-profile/sustainable-development accessed on 1 July 2021). Its production is expected to be cost-saving and sustainable, thereby contributing to energy-use intensity in the country.

4. Conclusions

This study examined inefficient energy use in CA countries by using the analytical framework of EEKC. This study's primary contribution to the literature is to explicitly target the CA countries in the EEKC analysis.

In the descriptive analysis in Section 3.1, it was found that the EEKC positions of Turkmenistan, Uzbekistan, and Kazakhstan are higher than those of the other Asian countries, thereby implying energy-use inefficiency in the three CA countries. The econometric analysis in Sections 3.2 and 3.3 identified the energy-use inefficiency in the three countries by the country-specific fixed effects, with China being the benchmark country: 2.524 in Turkmenistan, 2.085 in Uzbekistan, and 1.528 in Kazakhstan. The analysis of the factor compositions in Section 3.4 revealed that the contributions of the regulatory quality to the energy-use inefficiency account for 46.0% in Uzbekistan, 43.5% in Turkmenistan, and 5.7% in Kazakhstan; and the contributions of the rule of law account for 23.3% in Uzbekistan, 22.5% in Turkmenistan, and 17.8% in Kazakhstan. In sum, the EEKC analyses identified the energy-use inefficiency of Turkmenistan, Uzbekistan, and Kazakhstan and demonstrated the impact of weak policy governance on their energy-use inefficiency. This study's findings also emphasize the significance of enhancing the CA countries' energy policy governance from the world-wide context. It is because the CA countries are considered to be some of the most energy-consuming entities with the greatest loss of energy resources in the world, while the SDGs require a doubling of the global rate of improvement in energy efficiency by 2030.

The policy implications from the study's findings could be noted as follows. The CA countries, particularly, Turkmenistan, Uzbekistan, and Kazakhstan, should facilitate improving policy governance for energy-use efficiency. Aside from the other emerging market economies, the CA countries belong to economies in transition with immature market-based systems and with a negative legacy from the Soviet Union, as the sample study in Uzbekistan in Section 3.5 described. Thus, they should speed up the reformation of the economic system with strong policy governance.

The limitation of this study is the lack of detailed research on individual countries and thus further research should be conducted so that country-specific policy prescriptions and recommendations for their energy-use efficiency could be extracted, based on scientific evidence.

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Appendix A

Table A1. Profile of Central Asia Countries.

Kazakhstan	Kyrgyzstan	Tajikistan	Turkmenistan	Uzbekistan
		Population (thousand, 2020)		
18,754	6592	9538	6031	34,232
		Surface Area (thousand sq. km)		
2725	200	141	488	447
		GDP per capita (current prices USD, 2020)		
8733	1146	844	7967	1702
		Income Classification (2020)		
upper middle	lower middle	lower middle	upper middle	lower middle

Table A1. *Cont.*

Kazakhstan	Kyrgyzstan	Tajikistan	Turkmenistan	Uzbekistan
Energy Use (kg of oil equivalent per capita, average for 1996–2014)				
3511	552	336	3925	1843
East Asia & Pacific (excluding high income): 1.567				
Oil Rents (% of GDP, average for 1996–2019)				
14.796	0.372	0.130	15.267	4.055
East Asia & Pacific (excluding high income): 1.524				
Natural Gas Rents (% of GDP, average for 1996–2019)				
1.207	0.027	0.050	25.086	11.205
East Asia & Pacific (excluding high income): 0.281				
Coal Rents (% of GDP, average for 1996–2019)				
1.339	0.147	0.115	0.000	0.101
East Asia & Pacific (excluding high income): 1.035				

Sources: Population, Surface Area, Energy Use, and Oil, Natural Gas and Coal Rents: World Bank Open Data, https://data.worldbank.org/accessed on 1 July 2021. GDP per capita: World Economic Outlook Database, IMF, https://www.imf.org/en/Publications/WEO/weo-database/2021/April accessed on 1 July 2021. Income Classification: World Bank, https://datahelpdesk.worldbank.org/knowledgebase/articles/906519 accessed on 1 July 2021.

Table A2. Descriptive statistics.

Variables	Obs.	Mean	Std. Dev.	Min	Max
eng	861	1477	1715	105	7794
ypc	912	6151	10,702	172	49,915
nrr	706	5.993	10.182	0.001	58.319
gve	383	−0.168	0.866	−1.604	2.236
rgq	383	−0.284	0.892	−2.214	2.142
rol	383	−0.355	0.834	−1.648	1.706
cor	383	−0.458	0.840	−1.625	2.229

Sources: Author's calculation. Obs: Observations; Std. Dev.: standard deviation

Table A3. Panel unit root tests.

Variables	Levin, Lin & Chu Test	Fisher ADF Chi-Square	Fisher PP Chi-Square
ln *eng*	−1.798 **	71.693 ***	128.777 ***
ln *ypc*	−1.968 **	91.554 ***	274.895 ***
$(\ln ypc)^2$	−2.060 **	86.051 ***	341.777 ***
nrr	−6.113 ***	320.314 ***	64.189 ***
gve	−7.847 ***	79.188 ***	92.957 ***
rgq	−8.918 ***	95.223 ***	132.251 ***
rol	−6.501 ***	72.084 ***	59.643 *
cor	−6.549 ***	61.532 *	79.343 ***

Note: ***, **, and * denote statistical significance at 99, 95, and 90 percent level, respectively. Sources: Author's estimation.

Table A4. Correlation matrix and variance inflation factors.

	gve	*rgq*	*rol*	*cor*
gve	1.000			
rgq	0.912	1.000		
rol	0.931	0.889	1.000	
cor	0.928	0.872	0.950	1.000
VIF	11.875	6.425	13.032	12.001

Sources: Author's estimation.

Table A5. Fixed effect analysis in selected countries.

	[Regulatory Quality]							
	Fixed Effects	*nrr*	(b)— China *nrr*	(c) × 0.020	*rgq*	(e)— China *rgq*	(f) × −0.248	(d) + (g)
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Turkmenistan	0.926	43.787	40.919	0.805	−1.955	−1.689	0.419	1.224
Uzbekistan	0.736	16.941	14.074	0.277	−1.628	−1.362	0.338	0.615
Kazakhstan	0.425	18.066	15.199	0.299	−0.363	−0.097	0.024	0.323
China	0.000	2.868	-	-	−0.266	-	-	-
	[Rule of Law]							
	Fixed Effects	*nrr*	(b)— China *nrr*	(c) × 0.020	*rol*	(e)— China *rol*	(f) × −0.214	(d) + (g)
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Turkmenistan	0.926	43.787	40.919	0.829	−1.470	−0.973	0.208	1.038
Uzbekistan	0.736	16.941	14.074	0.285	−1.299	−0.802	0.172	0.457
Kazakhstan	0.425	18.066	15.199	0.308	−0.850	−0.353	0.076	0.384
China	0.000	2.868	-	-	−0.497	-	-	-

Source: Author's calculation.

References

1. Dorian, J.P.; Tojiev, U.; Tonkopy, M.S.; Alaibek, O.; Daxiong, Q. Energy in central Asia and northwest China: Major trends and opportunities for regional cooperation. *Energy Policy* **1999**, *27*, 281–297. [CrossRef]
2. Dorian, J.P. Central Asia: A major emerging energy player in the 21st century. *Energy Policy* **2006**, *34*, 544–555. [CrossRef]
3. Kaliakparova, G.S.; Gridneva, Y.E.; Assanova, S.S.; Sauranbay, S.B.; Saparbayev, A.D. International economic cooperation of Central Asian countries on energy efficiency and use of renewable energy sources. *Int. J. Energy Econ. Policy* **2020**, *10*, 539–545. [CrossRef]
4. Kraft, K.; Kraft, A. On the relationship between energy and GNP. *J. Energy Dev.* **1978**, *3*, 401–403.
5. Menegaki, A.N. *A Guide to Econometric Methods for the Energy-Growth Nexus*; Academic Publishing: London, UK, 2020.
6. Asafu-Adjaye, J. The relationship between energy consumption, energy prices and economic growth: Time series evidence from Asian developing countries. *Energy Econ.* **2000**, *22*, 615–625. [CrossRef]
7. Saboori, B.; Sulaiman, J. CO2 emissions, energy consumption and economic growth in association of Southeast Asian nations (ASEAN) countries: A cointegration approach. *Energy* **2013**, *55*, 813–822. [CrossRef]
8. Lee, C.C.; Chang, C.P. Energy consumption and economic growth in Asian economies: A more comprehensive analysis using panel data. *Resour. Energy Econ.* **2008**, *30*, 50–65. [CrossRef]
9. Fang, Z.; Chang, Y. Energy, human capital and economic growth in Asia Pacific countries—evidence from a panel cointegration and causality analysis. *Energy Econ.* **2016**, *56*, 177–184. [CrossRef]
10. Menegaki, A.N.; Tugcu, C.T. Two versions of the index of sustainable economic welfare (ISEW) in the energy-growth nexus for selected Asian countries. *Sustain. Prod. Consum.* **2018**, *14*, 21–35. [CrossRef]
11. Grossman, G.; Krueger, A. Environmental impacts of the North American Free Trade Agreement. In *The U.S.-Mexico Free Trade Agreement*; Garber, P., Ed.; MIT Press: Cambridge, MA, USA, 1993.
12. Suri, V.; Chapman, D. Economic growth, trade and energy: Implications for the environmental Kuznets curve. *Ecol. Econ.* **1998**, *25*, 195–208. [CrossRef]
13. Shahbaz, M.; Mahalik, M.K.; Shahzad, S.J.H.; Hammoudeh, S. Does the environmental Kuznets curve exist between globalization and energy consumption? Global evidence from the cross-correlation method. *Int. J. Financ. Econ.* **2019**, *24*, 540–557. [CrossRef]
14. Pablo-Romero, M.P.; Sanchez-Braza, A. Residential energy environmental Kuznets curve in the EU-28. *Energy* **2017**, *125*, 44–54. [CrossRef]
15. Mahmood, H.; Maalel, N.; Hassan, M.S. Probing the Energy-Environmental Kuznets Curve hypothesis in oil and natural gas consumption models considering urbanization and financial development in Middle East countries. *Energies* **2021**, *14*, 3178. [CrossRef]
16. Hundie, S.K.; Daksa, M.D. Does energy-environmental Kuznets curve hold for Ethiopia? The relationship between energy intensity and economic growth. *J. Econ. Struct.* **2019**, *8*, 21. [CrossRef]
17. Shahbaz, M.; Mutascu, M.; Azim, P. Environmental Kuznets curve in Romania and the role of energy consumption. *Renew. Sustain. Energy Rev.* **2013**, *18*, 165–173. [CrossRef]
18. Chen, P.Y.; Chen, S.T.; Hsu, C.S.; Chen, C.C. Modeling the global relationships among economic growth, energy consumption and CO2 emissions. *Renew. Sustain. Energy Rev.* **2016**, *65*, 420–431. [CrossRef]
19. Luzzati, T.; Orsini, M. Investigating the energy-environmental Kuznets curve. *Energy* **2009**, *34*, 291–300. [CrossRef]
20. Pablo-Romero, M.P.; De Jesus, J. Economic growth and energy consumption: The Energy-Environmental Kuznets Curve for Latin America and the Caribbean. *Renew. Sustain. Energy Rev.* **2016**, *60*, 1343–1350. [CrossRef]

21. Aruga, K. Investigating the Energy-Environmental Kuznets Curve Hypothesis for the Asia-Pacific Region. *Sustainability* **2019**, *11*, 2395. [CrossRef]
22. Mehta, K.; Ehrenwirth, M.; Trinkl, C.; Zörner, W.; Greenough, R. The energy situation in Central Asia: A comprehensive energy review focusing on rural areas. *Energies* **2021**, *14*, 2805. [CrossRef]
23. Dyussembekova, G.; Bayandina, G.; Zakirova, D.; Sartova, R.; Kalmenova, M. The electric energy sector of Kazakhstan: State and vision for the country taking into account the international trends. *Int. J. Energy Econ. Policy* **2019**, *9*, 179–186. [CrossRef]
24. Gomez, A.; Dopazo, C.; Fueyo, N. The future of energy in Uzbekistan. *Energy* **2015**, *85*, 329–338. [CrossRef]
25. Zheng, X.; Heshmati, A. An Analysis of Energy Use Efficiency in China by Applying Stochastic Frontier Panel Data Models. *Energies* **2020**, *13*, 1892. [CrossRef]
26. Akram, R.; Chen, F.; Khalid, F.; Huang, G.; Irfan, M. Heterogeneous effects of energy efficiency and renewable energy on economic growth of BRICS countries: A fixed effect panel quantile regression analysis. *Energy* **2021**, *215*, 119019. [CrossRef]
27. Song, F.; Yu, Y. Modelling energy efficiency in China: A fixed effects panel stochastic frontier approach. *Econ. Political Stud.* **2018**, *6*, 158–175. [CrossRef]
28. Hausman, J. Specification tests in econometrics. *Econometrica* **1978**, *46*, 1251–1271. [CrossRef]
29. Santos Silva, J.M.C.; Tenreyro, S. The log of gravity. *Rev. Econ. Stat.* **2006**, *88*, 641–658. [CrossRef]
30. Head, K.; Mayer, T. Gravity equations: Workhorse, toolkit, and cookbook. In *Handbook of International Economics*; Gopinath, G., Helpman, E., Rogoff, K.S., Eds.; Elsevier: Oxford, UK, 2014.
31. Levin, A.; Lin, C.F.; Chu, C. Unit root tests in panel data: Asymptotic and finite-sample properties. *J. Econom.* **2002**, *108*, 1–24. [CrossRef]
32. Maddala, G.S.; Wu, S. A Comparative Study of Unit Root Tests with Panel Data and a New Simple Test. *Oxf. Bull. Econ. Stat.* **1999**, *61*, 631–652. [CrossRef]
33. Choi, I. Unit Root Tests for Panel Data. *J. Int. Money Financ.* **2001**, *20*, 249–272. [CrossRef]
34. Yuldassheva, O.; Goto, N.; Prescott, L. Assessment of energy transition through "MFA-based energy indicators set" in a transition economy—Uzbekistan. *J. Hum. Environ. Symbiosis* **2016**, *28*, 20–31.