economies

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The Contribution of Green, Blue, and Energy Sources to Economic Development in Central Asia

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Abstract: Central Asia (CA) is a young integrated region formed after the collapse of the Soviet Union, with most of its infrastructure based on fossil fuels. The traditional energy and water infrastructure is facing huge inefficiency and technical losses. This study investigates the transition of the green, blue, and energy economies in Central Asia using a small-dimensional panel dataset on five countries, Uzbekistan, Kazakhstan, Kyrgyzstan, Tajikistan, and Turkmenistan, over the period 1995–2018. The authors analyze the impact of ecological footprint, water withdrawal, and energy consumption on gross domestic product. In applying the Panel Vector Error Correction Model, evidence was found supporting the long-running association between variables. Furthermore, the adjustment coefficients suggest that only GDP growth will adjust toward equilibrium. Overall, the findings suggest a more effective role of green transition compared to blue and energy transitions.

Keywords: energy; water; green growth; Central Asia

Citation: Caporin, Massimiliano, Bekhzod Kuziboev, Ergash Ibadullaev, Elbek Khodjaniyazov, Peter Marty, and Olimjon Saidmamatov. 2024. The Contribution of Green, Blue, and Energy Sources to Economic Development in Central Asia. *Economies* 12: 251. https://doi.org/10.3390/economies12090251

Academic Editor: George Halkos

Received: 16 July 2024
Revised: 1 September 2024
Accepted: 11 September 2024
Published: 17 September 2024

1. Introduction

Green, blue (water), and energy resources are commonly discussed in the context of Central Asia (Wang et al. 2020; Mohsin et al. 2022; Li et al. 2023). Each of the three resources can be analyzed and discussed separately, but their interactions and interconnections present a particularly interesting and relevant research question. Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan compose the Central Asia area (CA). It is a diversified region with a mix of upper-, middle-, and low-income countries that hold substantial strategic significance due to their geographic location and natural resource endowments. For instance, the upstream countries (i.e., Tajikistan, Kyrgyzstan) have strong hydropower potential, while the downstream countries (i.e., Uzbekistan, Turkmenistan) have agriculture potential. In the region, water remains a key strategic resource to control agriculture and energy industries among the five countries.

The growth of the economic system at the expense of green resources can be defined as green growth. Green growth has been regarded as the most suitable approach for emerging nations to reach sustainable economic growth that is more inclusive and committed to environmental preservation (Houssini and Geng 2021). The initial papers (OECD 2011; UNEP 2011) attempted to suggest some measures for gauging green growth. One definition of green growth was an approach to economic expansion based on the sustainable use of natural resources (Abramovay 2015; Bagheri et al. 2018). In particular, green energy growth has gained increased significance in recent years as politicians have advocated for and issued warnings about the necessity for economic growth and development based on environmental protection measures (Bagheri et al. 2018). Conversely, areas with abundant natural resources could have a difficult time transitioning and changing their economy in the direction of green energy growth (Cheng et al. 2020). Needless to say, natural resources must be managed according to certain standards to keep regional ecosystems in balance (Castro Oliveira et al. 2021).

Water is intricately linked in Central Asia. The hydrologic interlinkages are determined by nature: several transboundary rivers, including the Amu Darya and Syr Darya of the Aral Sea basin, connect the Central Asian Republics and Afghanistan (Central Asia Water & Energy Program 2024). A worrisome array of challenges lies ahead in Central Asia. Few know about the impact of water consumption for irrigation on the Aral Sea, and one of the major challenges is to ensure an equitable supply of water to meet both economic and environmental needs (Dobrescu 2022). Due to their heavy need of irrigation due to the paucity of rainfall, Central Asian nations are also significant producers of agriculture, especially cotton and other water-intensive crops. Three times the size of Belgium, the five countries have an irrigated area of at least 100,000 km^2, which necessitates massive water withdrawals from rivers. As agriculture is the largest user of water in Central Asia and given that water for irrigation represents the major use, it is not surprising that, relative to the CA population, per capita water usage in Central Asia is very high compared to that of European countries (Russell 2018). Accordingly (Wang et al. 2022), Central Asian countries are one of the hardest hit areas in the world with regard to water scarcity; this evidence has seriously restricted efforts toward achieving Sustainable Development Goals (SDGs).

Furthermore, energy consumption has a major role in the economies of CA countries. According to the Central Asia Regional Economic Cooperation Program (CAREC) (Abdullaev and Akhmedov 2023), CA countries' energy demand in 2020 was 204 million tons of oil equivalent (toe), excluding the PRC (People's Republic of China). In building on electricity consumption, which is one of the primary sources of energy source consumption, the energy demand is predicted to rise to 254–290 million tons by 2030, with an average increase of roughly 32%. In addition, given its prominent role as a fuel in the production of electricity and for direct consumption in homes and business activities, natural gas usage is likely to rise further in the energy mix. If the People's Republic of China is factored into the forecast, the total projected energy demand is expected to increase from 2.3 billion tons in 2020 to 2.4–2.7 billion tons by 2030 (Asian Development Bank 2023). Energy policies, economic expansion, and the adoption of energy-saving technologies will all have an impact on the rising demand.

Given these premises, the evaluation of the impact of green, blue, and energy resources in CA countries' gross domestic product (GDP) would provide insightful information for the identification and the implementation of sustainable growth policies. This study will thus contribute to the literature as a pioneering study in the investigation of the joint impact of green, blue, and energy resources on economic development in Central Asia. The authors utilized the ecological footprint, which is expressed in global hectares (gha) per person, as a stand-in for green resources in the analysis. Differently, water withdrawal, measured in billion cubic meters, was used to measure the usage of blue resources, and finally, the use of energy resources was approximated using the amount of energy consumed per person, expressed in kilowatt-hours. The outcome of our analysis will provide relevant insights for the design of regional, sustainable, and coordinated development policies. From a methodological perspective, a panel dataset was used, covering the five CA nations from 1995 to 2018.

The purpose of this study was to verify that there exists a long-running relation between economic development and green, blue, and energy resources. Furthermore, our research reveals that environmentally friendly actions and renewable energy transition must be encouraged since economic development relies on green and energy resources. The research hypothesis is that sustainable consumption patterns of water should be adopted as the consumption of blue resources is not sustainable in the Central Asian region.

This is how the rest of this paper is structured: The literature is reviewed in Section 2, the data sources and research techniques are introduced in Section 3, the empirical results are analyzed in Section 4, and the conclusion is presented in Section 5.

2. Literature Review

2.1. Economic Development and Green Resources

The literature focusing on green growth is scarce. Studies (Kararach et al. 2017; Pan et al. 2019) examine the relationship between economic development and green resources. Authors (Kararach et al. 2017; Lyytimäki et al. 2017; Yang et al. 2019; Šneiderienė et al. 2020) deal with quantitative perspectives on green growth, but their works do not focus on the estimation of the relationship between economic development and green resources. Instead, they mostly focus on the introduction of green growth indicators rather than econometric analysis on their impact and relation with economic growth or other structural economic indicators. Only Ferreira et al. (2023) used multiple linear regressions to assess how the performance of green growth affects 172 countries' economic development, proving that green growth generally has a good effect on economic development. From a general viewpoint, the knowledge about the impact of green resources on economic development is still scarce and needs further development. In this context, this study applies ecological footprint as a green resources variable.

2.2. Economic Development and Water Resources

It should be noted that water impacts economic development in different ways. The difference between water withdrawal and water consumption has to be highlighted. The term "water withdrawal" describes the process of removing water from its source for use. Consumed water never resurfaces, not even as waste (Martín 2016). Differently, "water consumption" is the amount of withdrawn water that is ultimately lost due to evaporation, transpiration, usage by plants, or consumption by humans or animals; this water is no longer available. Irrigation consumes the most water, accounting for 70% of the water required for agriculture globally, with evaporation or transpiration losing about 50% of this water (Wada et al. 2016). In the literature, the associations among water withdrawal, consumption, and economic development vary. Theoretically, an increase in both water withdrawal and consumption should have a positive influence on economic development (Wada et al. 2016; El Khanji and Hudson 2016; Fant et al. 2016). However, contradicting results also exist. Specifically, GDP is inversely correlated with agricultural water withdrawal (El Khanji 2016) while economic development and water quantity and quality were found to be weakly negatively correlated in the study (Gao et al. 2021). They concluded that increasing water quality and quantity can promote both economic growth and sustainable water consumption. Furthermore, excessive or inefficient water use will probably slow down economic growth (Barbier 2004). The literature (Chen et al. 2018; OECD 2022; Ummalla and Samal 2018) suggests that a positive relationship between water withdrawal and economic development implies sustainable water consumption. Conversely, when the relationship between water withdrawal and economic development turns negative, water consumption becomes unsustainable (Saidmamatov et al. 2020; Mehta et al. 2021; Rasul and Sharma 2015). The latter pattern is more relevant to the Central Asian region. As one of the most valuable and tightly controlled resources in Central Asia, water is crucial for the socioeconomic growth of the region (Bréthaut et al. 2019; Jalilov et al. 2018; Guillaume et al. 2015). Central Asian governments point toward the adoption of new policies to arrive at a more productive and efficient use of this essential resource (Keskinen et al. 2016; Saidmamatov et al. 2024); this is an increasingly relevant need given the rising demand for water as a result of the inherent highly consuming and water-intensive structure of their economies (Abdullaev and Akhmedov 2023). Currently, irrigated agriculture loses between 30% and 60% of the extracted water before it reaches the irrigated plots (Jalilov et al. 2018; Konyeaso et al. 2022). The availability of water resources will significantly influence the aims of sustainable socioeconomic development in Central Asia (Ummalla and Samal 2018; Rasul and Sharma 2015; Guillaume et al. 2015; Vinokurov et al. 2021). The fact that water use in Central Asian countries is relatively high per USD 10,000 of GDP, notwithstanding a notable downward trend, may be seen as a positive (Wang et al. 2020; OECD 2022). However, more efforts are required to boost economic growth (Saidmamatov et al. 2020; Guillaume et al. 2015).

2.3. Economic Development and Energy Resources

The literature focusing on the link between economic development and energy resources is more developed and includes several studies focusing on Asian countries. As the global economy expands, energy becomes one of the most important sources of production and services. Presuming that a high level of energy production is a worldwide necessity, Hsu and Chien (2022) used the NARDL model to analyze the effects of economic variables on China's energy production, with a focus on a sample from 1976 to 2020. These variables included GDP, national income, employment rate, FDI, inflation, and technological advancement. The findings show a substantial positive relationship between China's energy output and every economic metric.

Ummalla and Samal (2019) examined the connection between China's use of hydroelectric electricity and its economic growth between 1965 and 2016. They employ the Auto Regressive Distributed Lag (ARDL) bound testing approach for cointegration to show the positive association between renewable energy and economic growth. Additionally, their study's application of the Granger causality test demonstrates a unidirectional causal link between the use of hydropower energy and economic growth.

Ummalla and Samal (2019) studied China and India, the two biggest rising market economies in the world, and examined the effects of natural gas and renewable energy use on economic growth between 1965 and 2016. Ummalla and Samal (2019) investigate the long-run and causative relationship between natural gas consumption, renewable energy consumption, coal petroleum use, CO_2 emissions, and economic growth, using the ARDL bounds testing approach to cointegration and the vector error correction model (VECM). According to their findings, China's economic growth is a direct result of natural gas use, whereas there is no short-term causal relationship in India.

A total of 32 African nations were chosen by Konyeaso et al. (2022) based on their wealth levels and division between oil-rich and non-oil-rich countries between 1996 and 2018. The findings indicate a noteworthy positive correlation between renewable energy and economic growth across all categories. The research by Khan et al. (2020) advances our knowledge of the connection between Pakistan's energy supply and economic growth. Utilizing data from 1980 to 2016, they employ both linear and non-linear ARDL models to investigate the relationship between Pakistan's GDP per capita and the usage of conventional and renewable energy.

They conclude that renewable energy asymmetrically affects Pakistan's economic growth over the long run (Jafri et al. 2021). Among the nations with the highest production of renewable energy are the G7 economies (Behera and Mishra 2019). Okumus et al. (2021) looked at the G7 economies from this perspective and discovered a favorable long- and short-term correlation between the use of renewable and non-renewable energy and economic growth. However, it is discovered that the use of non-renewable energy resources has a greater and more significant impact on economic growth when the coefficients of these two variables are analyzed.

In 14 selected emerging economies, Zangoei et al. (2021) examine the relationship between economic development, foreign direct investment, and fossil and alternative energy sources using data from the 1986–2016 time frame and an apparently unrelated regression (SUR) model. Their findings suggest that the GDP is positively impacted by both fossil fuels and alternative energy. Oil rents have no bearing on economic growth. Examining FDI led to the same conclusions.

3. Data and Methodology

3.1. Data

Using a balanced panel dataset that includes the five Central Asian nations of Uzbekistan, Kazakhstan, Kyrgyzstan, Tajikistan, and Turkmenistan, the study aims to objectively examine the relationship between economic development and green, blue, and energy resources. Using annual data, the authors concentrate on the years 1995–2018. The dependent variable in our study is GDP (gross domestic product, a proxy for economic development), which is measured in billions of dollars USD. The independent variables are energy consumption per capita (measured in kWh), water (measured in billions of cubic meters), and ecological footprint (global hectare per person, a proxy for the green economy). These variables are selected as they best demonstrate the dynamic relationship between economic development and green, blue, and energy resources in the Central Asia region. Macrotrends was the source of GDP data. Additionally, data on water extraction were retrieved from World Bank Data, data on energy use per capita were collected from Our World in Data, and data on the ecological footprint were downloaded from the Global Footprint Network. Every dataset is accessible on an annual basis. Table 1 provides the sources and definitions of the variables used.

Table 1. Definition and sources of the variables. (Macrotrends 2024; Global Footprint Network 2024; World Bank Data 2024; Our World in Data 2024).

Variable	Description and Unit	Sources
GDP	Gross domestic product (in USD 1 billion).	(Macrotrends 2024)
EF	Ecological footprint measured in global hectares (gha) per person. Using current technology and resource management techniques, the amount of biologically productive land and water that a person, population, or activity needs in order to produce all the resources they use and absorb the waste they make is measured.	(Global Footprint Network 2024)
WATER	Annual freshwater withdrawals, total (billion cubic meters).	(World Bank Data 2024)
EC	The amount of energy consumed per person, measured in kilowatt-hours (kWh), includes both renewable and non-renewable energy. Energy is used not only for cooking, heating, and transportation, but also for other purposes such as electricity.	(Our World in Data 2024)

The variables' descriptive statistics are shown in Table 2. It can be noted that the GDP of Central Asian nations from 1995 to 2018 was, on average, USD 32.53 billion. Each nation's ecological footprint (EF) was 2.72 hectares per person. Each nation's average share of water withdrawal, or WATER, was 24.37 billion cubic meters. Throughout the period under consideration, the average person in the Central Asian region consumed 23.89 kilowatt-hours (EC). In contrast to the ecological footprint (EF), whose standard deviation is modest and almost nil, the GDP, water extraction (WATER), and energy consumption (EC) all have substantial standard deviations. Ecological footprint (EF), water extraction (WATER), energy consumption (EC), and GDP (leptokurtic) all have positively biased data. As per the results of the Jarque–Bera normality test, not all variables exhibit a normal distribution.

Table 2. Descriptive statistics.

	GDP	***EF***	***WATER***	***EC***
Mean	32.53	2.72	24.37	23.89
Median	9.91	2.19	22.45	20.19
Maximum	236.63	6.78	58.90	62.04
Minimum	0.86	0.79	7.70	7.33
Std. Dev.	51.58	1.71	15.76	14.27
Skewness	2.34	0.57	0.82	0.79
Kurtosis	7.88	1.90	2.43	2.69
Jarque–Bera	229.66	12.49	15.13	13.27
p-value	0.00	0.00	0.00	0.00
Sample size ($T \times N$)	120	120	120	120

3.2. Methodology

This research looks into how green, blue, and energy sources affect the economic development of Central Asian nations. Panel Vector Error Correction Model is taken into consideration in order to investigate the long-run equilibrium, with the following general representation:

$$\Delta Y_{i,t} = \alpha\left(\beta' Y_{i,t-1}\right) + \Gamma \Delta Y_{i,t-1} + \varepsilon_{i,t} \quad (1)$$

The modeled variables in $Y_{i,t}$ are country-specific and include $GDP_{i,t}$, $EF_{i,t}$, $WATER_{i,t}$, $EC_{i,t}$, $\varepsilon_{i,t}$ (the model error, which may be further detailed with the specification of unobserved heterogeneity), and Δ (first difference operator). Since our dataset contains yearly data and the sample size is small, a single lag is also incorporated. Moreover, it can be emphasized that the cointegrating equation coefficients β, the adjustment coefficients α, and the short-term parameters Γ are constant among all the participants (countries) in our sample. Finally, the term $\beta' Y_{i,t-1} = \mu_t$, enclosed in parentheses, is also known as the error correction term or cointegration residual. From an economic point of view, it is noted that the parameters in the β' vector are also defined as long-run multipliers. Notably, a two-step estimation approach may be used (Sims 1980). In the first stage, the long-run parameters, or the β vector, are estimated using suitable methods (e.g., Dynamic OLS or Fully Modified OLS). Given the stationarity of the cointegration residuals, the short-term dynamic parameters and the adjustment coefficients are estimated using least squares methods. The formulation of more adaptable long-run equations is made possible by this two-step process.

The authors will assess if unit roots exist for the variables of interest and whether cointegration occurs between them in the empirical study. The study looks into the ADF-Fisher-Chi-square (Maddala and Wu 1999), the PP-Fisher-Chi-square (Choi 2001) (for individual unit root process), the Levin, Chin and Chu t*-test (for common unit root process) (Levin et al. 2002), the Pesaran and Shin W-stat (Im et al. 2003), and the panel unit root tests ADF-Fisher-Chi-square (Maddala and Wu 1999). The Fisher (or combined Johansen) cointegration test is another tool to determine whether the variables have a long-term relationship (Maddala and Wu 1999). Another method to conclude the studies is the Dumitrescu and Hurlin causality test (Dumitrescu and Hurlin 2012), which determines whether there are causal relationships between the variables.

The above-discussed two-step process for model estimation is benefited. Using the DOLS approach (Saikkonen 1991), the cointegration relation of the equation is first estimated (2).

$$GDP_{i,t} = \gamma_1 + \gamma_2 EF_{i,t} + \gamma_5 WATER_{i,t} + \gamma_6 EC_{i,t} + \mu_{i,t} \quad (2)$$

In the second step, lagged residuals series of the cointegration equation (obtained using DOLS) are added as an exogenous variable to a Vector Auto Regressive (VAR) model for the first differences. Given that our interest is limited only to the equation where GDP is the dependent variable, it is reported below (note that a full VAR model is estimated but only the parameters of this equation are considered):

$$\Delta GDP_{i,t} = \alpha_1 \hat{\mu}_{i,t-1} + \vartheta_{1,1}\Delta GDP_{i,t-1} + \vartheta_{1,2}\Delta EF_{i,t-1} + \vartheta_{1,3}\Delta WATER_{i,t-1} + \vartheta_{1,3}\Delta EC_{i,t-1} + \varepsilon_{1,i,t} \quad (3)$$

Our focus for this second stage will be on the numerous variables in the short-term dynamic model and their relevance, along with the adjustment coefficients. The conclusions of the previously described causality test will be read with the full model results.

4. Empirical Results

First, it is assessed if unit roots exist for the variables under consideration; Table 3 presents the findings. There are convincing empirical indications that a unit root exists for GDP, EF, WATER, and EC. The ADF-Fisher-Chi-square, PP-Fisher-Chi-square, W-stat (Im et al. 2003), and t* statistic (Levin et al. 2002) are the methods used to identify unit roots. Once taken into account for the first differences, all the variables are stationary.

Table 3. Unit root tests.

	GDP		*EF*		*WATER*		*EC*	
	Level	**1st Dif.**	**Level**	**1st Dif.**	**level**	**1st Dif.**	**Level**	**1st Dif.**
Null: Unit root (assumes common unit root process)								
Levin, Lin and Chu t*	0.83	0.00 *	0.37	0.00 *	0.01	0.00 *	0.67	0.00 *
Null: Unit root (assumes individual unit root process)								
Im, Pesaran and Shind W-stat	0.99	0.00 *	0.74	0.00 *	0.22	0.00 *	0.94	0.00 *
ADF-Fisher-Chi-square	0.99	0.00 *	0.68	0.00 *	0.07	0.00 *	0.90	0.00 *
PP-Fisher-Chi-square	0.99	0.00 *	0.63	0.00 *	0.04	0.00 *	0.89	0.00 *

* represents statistical significance at 1% level.

The study only presents the *p*-values for each test (Levin, Lin and Chu t*, Im, Pesaran and Shind W-stat, ADF-Fisher-Chi-square, and PP-Fisher-Chi-square). The SIC was used to choose the lags; in every case, the lag was set to 1, and only the individual intercept was taken into account. There is a unit root, which supports the null hypothesis. The rejection of the null at the 1% confidence level is indicated by the symbol *. The Fisher (combined Johansen) cointegration test can be used to determine whether cointegration is present given the evidence that the variables are integrated. Table 4 presents the findings.

Table 4. Johansen Fisher panel cointegration test.

Hypothesized No. of CE(s)	Fisher Stat. (from Trace Test)	Prob.	Fisher Stat. (from Max-Eigen Test)	Prob.
None	53.86	0.00 ***	38.35	0.00 ***
At most 1	24.56	0.00 ***	15.81	0.10
At most 2	16.68	0.08 *	15.92	0.10
At most 3	11.39	0.32	11.39	0.32

* and *** represent statistical significance at 1% and 10% levels, respectively.

The Johansen Fisher maximum and trace eigenvalue tests for panel cointegration are displayed in the table along with the corresponding *p*-values. The number of cointegrating relations, or cointegration rankings, reported over the rows of column 1 is linked to the null hypothesis. In terms of statistical significance, asterisks stand for *** at the 1% level and * at the 10% level. Authors use SIC to set the latency to 1. Results from the maximum eigenvalue and trace tests are inconsistent. For the most part, the trace test is constructed, but it is conjectured that there is only one cointegrating equation. As a result, further movement with Panel VECM estimation can be made. Before estimating the model, the Dumitrescu–Hurlin causality test is used to examine the relationship between the variables in our panel. The results are in Table 5. The dependent variable, GPD, is subject to the causal effects of *EF* and *WATER*, although energy consumption (*EC*) is not subject to this impact. Based on theoretical grounds, this variable is utilized since it is impossible to ignore the impact of energy consumption on GDP.

Table 5. Dumitrescu–Hurlin panel causality tests.

Null Hypothesis:	**Level**
EF does not homogeneously cause GDP	0.00 ***
GDP does not homogeneously cause EF	0.00 ***
$WATER$ does not homogeneously cause GDP	0.00 ***
GDP does not homogeneously cause $WATER$	0.00 ***
EC does not homogeneously cause GDP	0.11
GDP does not homogeneously cause EC	0.00 ***
$WATER$ does not homogeneously cause EF	0.00 ***
EF does not homogeneously cause $WATER$	0.02 **
EC does not homogeneously cause EF	0.46
EF does not homogeneously cause EC	0.81
EC does not homogeneously cause $WATER$	0.06 *
$WATER$ does not homogeneously cause EC	0.05 *

* represents 10% significance level, ** represents 5% significance level, and *** represents 1% significance level.

The Dumitrescu–Hurlin panel causality test p-values are shown in the table. At the 1%, 5%, and 10% levels, respectively, asterisks denote statistical significance ***, **, and *. SIC has been used to determine the ideal latency.

Table 6 reports the estimation results of the long-run relation between variables. In all cases, the coefficients estimated using the DOLS method are statistically significant, validating the existence of a long-run relation among the variables (GDP, EF, $WATER$, and EC). More specifically, ecological footprint (EF) and energy consumption (EC) positively impact economic development (GDP), whereas water withdrawal ($WATER$) has a negative effect on GDP. Therefore, it emerges that an increase in water withdrawals is detrimental to GDP growth while a positive association between ecological footprint and energy consumption is observed. Admittedly, the Central Asian region is suffering from water stress due to conflict among neighboring countries, even though water withdrawal is at a sufficient level. More precisely, Kyrgyzstan and Tajikistan are "energy-poor but water-rich" countries, whereas Kazakhstan, Turkmenistan, and Uzbekistan are "energy-rich but water-poor" countries (Jalilov et al. 2018; Saidmamatov et al. 2024; European Parliament 2015). As a result, Tajikistan built Rogun Hydropower Station to generate electricity. This caused a water crisis, particularly decreasing irrigation benefits in Turkmenistan and Uzbekistan, as the Rogun Dam is situated on the Amu Darya River that flows across Tajikistan, Turkmenistan, and Uzbekistan (Guillaume et al. 2015; Keskinen et al. 2016; Bekchanov et al. 2015). Our findings confirm the negative correlation between water withdrawal and economic development, which we attribute to national conflicts and priorities. In contrast, the availability of energy resources in almost all of the region's countries accounts for the positive relationship between economic development and energy resources. Furthermore, our results confirm that green resources and economic development have a positive link. This could be explained by the fact that agriculture is one of the primary sources of employment and wealth in Central Asian nations due to their abundance of agricultural resources. Agriculture is a major source of resources for the CA countries' industrial sector as well.

Table 6. DOLS estimation results of cointegration equation.

	Dependent Variable=*GDP*
Variables	DOLS (lag and lead: fixed, optimal lag and leads = 1, linear trend)
EF	23.94 *** (4.13)
WATER	−3.68 ** (1.61)
EC	2.20 *** (0.78)

Standard errors are in parentheses. Asterisks represent statistical significance ** and *** for 5% and 1% levels, respectively.

Finally, authors estimate the VECM in which the error correction term, that is, the lagged residual series of equation (2), is included in the system. The adjustment coefficients are reported; full results are available upon request.

According to Table 7, only the GDP adjustment coefficient is statistically significant. As a result, the GDP will adjust after short-run disequilibrium, while no adjustment will take place in water, energy, and green resources. On the contrary, these variables might impact at the contemporaneous level on the GDP, as shown in the long-run equation.

Table 7. The results of VECM—adjustment coefficients.

Estimated Alphas (*p*-Values)	**Coefficient**
GDP	−0.43 *** (0.13)
EF	0.00 (0.00)
WATER	0.00 (0.01)
EC	0.33 (0.29)

Standard errors are in parentheses. Asterisks represent statistical significance *** for 5% level.

5. Conclusions and Policy Implications

In this study, the authors assess the impact of ecological footprint, water withdrawal, and energy consumption on economic development in the Central Asian region, applying a two-step VECM approach over the period 1995–2018. Our results reveal that a good ecological footprint, utilizing green resources for their energy, positively impacts economic development, whereas water withdrawal, which damages blue resources, has a negative effect on economic development in Central Asia. The long-run relation among the employed variables was estimated using DOLS method and further supported by the Fisher (combined Johansen) cointegration technique. Moreover, the coefficient of error correction model of the equation of GDP in VECM is statistically significant, validating the adjustment of disequilibrium in the long-run.

The research hypothesis is confirmed by the positive association of ecological footprint with economic development that might be explained as the economy's reliance on green resources. The findings are in line with the results of the studies (Ummalla and Samal 2019; Khan et al. 2020; Okumus et al. 2021; Zangoei et al. 2021). Ecosystem services cannot be neglected in Central Asia, and it can be postulated that currently a green transition is happening. Since ecological footprint might represent resource endowment, our results are consistent with those (Behera and Mishra 2019; Li et al. 2019) who find that there is a positive relation from the efficiency of employing natural resources to the green growth of the economy in Central Asia. Central Asian economies rely on agriculture and agriculture industries, which are resource-based sectors. Central Asian governments should pay attention to supporting green technologies and innovations, for instance by imposing environmental taxes.

The negative impact of water withdrawal shows that water consumption is not sustainable in Central Asia. More specifically, the research observes a decrease in economic development after an increase in water withdrawals, most likely as the water is not reaching the required destinations, leading to an unsustainably high consumption. Climate change in Central Asia has significantly impacted the region's water supplies, and excessive human activity has resulted in an overuse of the region's water resources, thereby elevating the risk of water contamination. Countries in Central Asia must now increase the efficiency of their water usage and encourage the transformation of their water use structure.

This work makes a significant contribution to the existing literature. The positive association of energy resources with economic development in Central Asia is double-faceted: on the one hand, it is a consequence of the economic growth path started in the countries, while on the other hand, fossil fuel energy dependence remains very high. As a result, the consumption of energy resources cannot be considered sustainable in the region. On this occasion, the renewable energy transition should be enhanced. However, due to less developed infrastructure, ongoing ineffective energy policy and, presumably, the knowledge gap, the transition to renewable energy has not happened yet in Central Asia. Policymakers should thus put more efforts toward those aspects to further strengthen economic growth.

Our research also has some limitations, as the authors exclude a possible role coming from a digitization factor. On the one hand, this pertains to data availability constraints, but it also signifies a potential future direction for investigation.

Author Contributions: Conceptualization, B.K. and E.K.; methodology, B.K.; software, B.K.; validation, E.I., P.M. and O.S.; formal analysis, E.K.; investigation, E.I.; resources, O.S.; data curation, E.I.; writing—original draft preparation, E.K.; writing—review and editing, M.C.; visualization, O.S.; supervision, M.C.; project administration, M.C.; funding acquisition, P.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data supporting the results can be obtained by request.

Conflicts of Interest: The authors declare no conflicts of interest.

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