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PATHWAYS TO SUSTAINABLE ENERGY TRANSITION IN UZBEKISTAN AND THE ROLE OF POLICY AND INVESTMENT MECHANISMS (INPUT-OUTPUT-CGE MODEL)

Gulmuxamedova Dilbar

Independent PhD Researcher at Westminster International University in Tashkent

Email: gulmukhamedova@gmail.com

ORCID: 0009-0001-0239-5566

Abstract. Uzbekistan's energy transition over the 2000–2025 period is assessed using a combination of empirical and structural models. Descriptive statistics, correlation analysis, linear regression, and Structural Equation Modeling (SEM) are applied to analyze the relationships among energy-transition variables and identify potential mediation mechanisms. The results indicate a significant decline in energy intensity and demonstrate that energy investment has a substantial impact on energy efficiency. In addition, a combination of the Input–Output (I–O) model and the Computable General Equilibrium (CGE) model is proposed to assess future energy-transition scenarios in Uzbekistan.

Keywords: energy transition, energy efficiency, SEM path modeling, Input–Output (I–O) model, energy investment.

Annotatsiya. O'zbekistonda 2000–2025-yillardagi energiya o'tishi empirik va strukturaviy modellar kombinatsiyasi asosida baholangan. Energiya o'tishi o'zgaruvchilari o'rtasidagi bog'liqliklarni tahlil qilish va mumkin bo'lgan vositachilik mexanizmlarini aniqlash uchun tavsifiy statistika, korrelyatsiya tahlili, chiziqli regressiya va strukturaviy tenglamalarni modellashtirish (SEM) usullaridan foydalanilgan. Natijalar energiya intensivligining sezilarli darajada pasayganini hamda energetika sohasiga yo'naltirilgan investitsiyalar energiya samaradorligiga sezilarli ta'sir ko'rsatishini ko'rsatgan. Bundan tashqari, O'zbekistonda energiya o'tishining kelajakdagi stsenariylarini baholash uchun «Input–Output» (I–O) va hisoblanadigan umumiy muvozanat (CGE) modellarining kombinatsiyasi taklif etilgan.

Kalit so'zlar: energiya o'tishi, energiya samaradorligi, SEM yo'l modeli, «Input–Output» (I–O) modeli, energiya investitsiyalari.

Аннотация. Энергетический переход в Узбекистане за 2000–2025 годы оценен на основе комбинации эмпирических и структурных моделей. Для анализа взаимосвязей между переменными энергетического перехода и определения возможных механизмов опосредования использованы методы описательной статистики, корреляционного анализа, линейной регрессии и моделирования структурными уравнениями (SEM). Результаты показали значительное снижение энергоёмкости, а также существенное влияние инвестиций в энергетику на энергоэффективность. Кроме того, для оценки будущих сценариев энергетического перехода в Узбекистане предложена комбинация модели «затраты–выпуск» (I–O) и модели вычислимого общего равновесия (CGE).

Ключевые слова: энергетический переход, энергоэффективность, путевое моделирование SEM, модель «затраты–выпуск» (I–O), инвестиции в энергетику.

INTRODUCTION

Uzbekistan's energy sector has undergone substantial structural transformation over the past two decades, driven by growing energy demand, economic modernization, industrial development, and the increasing need to improve energy efficiency. Between 2000 and 2025, the country's energy transition became an increasingly important component of sustainable economic development, particularly in the context of reducing energy intensity and improving the efficiency of energy use. Despite Uzbekistan's historically high dependence on conventional energy resources, recent changes in energy investment, technological development, and resource efficiency have created new opportunities for accelerating the transition toward a more sustainable



energy system. Understanding the relationships among energy investment, energy efficiency, energy intensity, and broader economic development is therefore essential for evaluating the progress and future direction of Uzbekistan's energy transition.

Against this background, the present study examines the dynamics and structural relationships underlying Uzbekistan's energy transition during 2000–2025 using a combination of descriptive statistics, correlation analysis, linear regression, and Structural Equation Modeling (SEM). The empirical results indicate a substantial decline in energy intensity over the study period, suggesting a significant improvement in the efficiency of energy use, while energy investment emerges as an important factor influencing energy efficiency. The study further investigates potential mediation mechanisms through which energy-related factors affect the transition process. To complement the empirical assessment and provide a forward-looking perspective, an integrated Input–Output (I–O) and Computable General Equilibrium (CGE) modeling framework is proposed to evaluate alternative future energy-transition scenarios for Uzbekistan.

LITERATURE REVIEW

Energy transition is taking place in Uzbekistan with the aim of increasing energy efficiency, diversifying the energy structure, enhancing energy security, and promoting sustainable economic development [1]–[3]. The historically high share of natural gas in the energy structure, combined with increasing energy demand and environmental considerations, highlights the importance of renewable energy development, technological modernization, and investment in the energy sector [1], [4]. The country's green economy strategy identifies renewable energy capacity and energy efficiency as key elements of sustainable economic development [5]. These transformations are not limited to the energy sector; energy transitions influence not only industrial production but also transport, agriculture, services, household well-being, trade, and investment in the country's economy [6], [7].

In this context, an appropriate methodological framework is necessary to understand the economic consequences of the energy transition. Input–Output (I–O) analysis can help identify intersectoral linkages and demonstrate how changes in energy demand and supply lead to changes in intermediate consumption, output, and the structure of production [8]. The I–O approach is based on the assumption of fixed technological coefficients; therefore, complementary methodological approaches can be used to account for behavioral responses to significant changes [9], [10].

Furthermore, the structure of the relationships affecting the energy transition should be examined empirically. Structural Equation Modeling (SEM) offers a suitable approach for testing direct and indirect relationships among policy, investment, energy transition, and efficiency outcomes [11]. By integrating SEM methods with Input–Output and CGE analyses, it is possible to combine empirical evidence on the energy transition with a prospective evaluation of policy impacts on the national economy. An integrated perspective appears to be particularly useful in the case of Uzbekistan, where rapid economic development necessitates the simultaneous consideration of multiple issues, such as energy security, economic growth, environmental sustainability, and economic restructuring. Therefore, the current research focuses on analyzing the energy transition in Uzbekistan from 2000 to 2025 and developing an integrated methodology that incorporates empirical evidence from SEM and prospective applications of I–O and CGE approaches.

RESEARCH METHODOLOGY

This research uses a mixed quantitative methodology to analyze Uzbekistan's energy transition between 2000 and 2025. Descriptive statistics and correlation analysis are first used to understand the nature of the relationships and associations among the selected variables. Multiple linear regression is used to establish the statistical relationships between these variables and energy intensity. Structural Equation Modeling (SEM) is used to examine both direct and indirect effects, particularly the potential mediating effect of energy investment. Finally, an Input–Output (I–O) approach is used to explore the economic consequences.

ANALYSIS AND RESULTS

Table 1 presents the descriptive statistics of the variables used in the empirical analysis for the period 2000–2025, consisting of 26 observations. The average value of energy intensity is 8.298, with a minimum value of 6.472 and a maximum value of 9.421; the standard deviation is 0.819, suggesting a gradual improvement in energy efficiency. The share of renewable energy averages 12.996%, ranging from 10.8% to 22.5%; the share of natural gas averages 81.862%, ranging from 75% to 84.2%, thus indicating the



predominant role of natural gas in Uzbekistan's energy structure. The average value of energy investment is 3.185, with a minimum value of 2 and a maximum value of 6, indicating the gradual growth of investment in the energy sector (Table 1).

Table 1. Descriptive statistics of the model¹

Variable	Obs	Mean	Std. Dev.	Min	Max
Year	26	2012.5	7.649	2000	2025
Energy intensity	26	8.298	.819	6.472	9.421
Renewable share	26	12.996	2.793	10.8	22.5
Natural gas share	26	81.862	2.441	75	84.2
Energy investment	26	3.185	1.105	2	6
Green policy index	26	26.577	22.102	5	82

The dynamics of the main energy-transition indicators in Uzbekistan between 2000 and 2025 are presented in Figure 1. The level of energy intensity declines over time, falling from approximately 9.4 to 6.5, indicating a general improvement in energy efficiency. At the same time, the share of renewable energy remains relatively stable during the earlier period and increases significantly from 2018 onward, reaching approximately 22.5%. The share of natural gas demonstrates an opposite trend: it remains above 80% until 2018 and subsequently decreases to approximately 75%. The level of energy investment increases continuously, from 2% to 6%, particularly from 2018 onward.

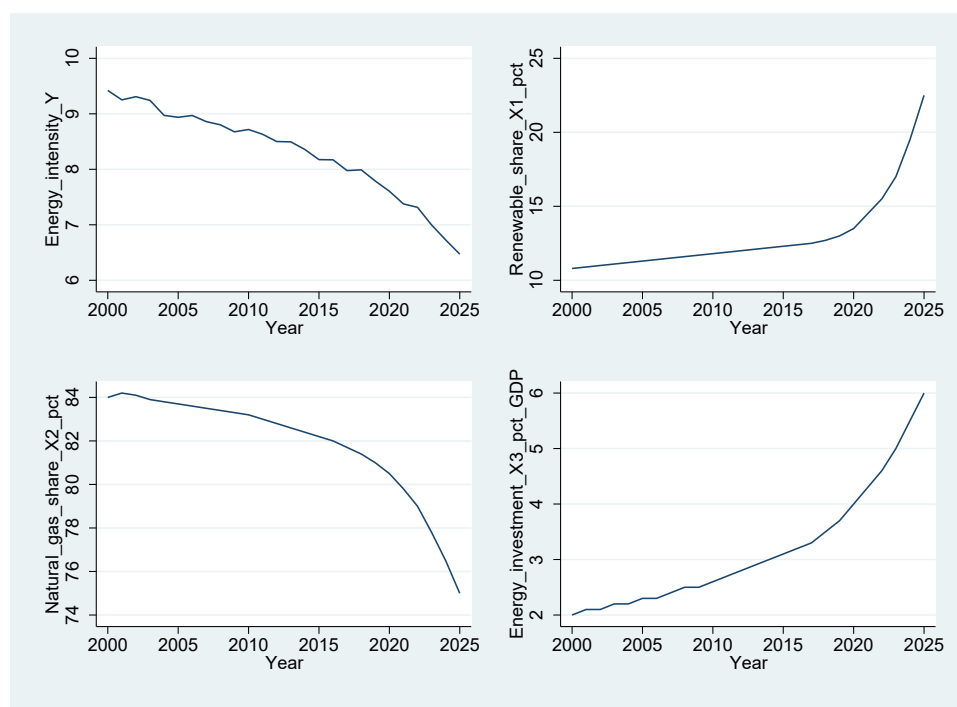


Figure 1. Trends in energy transition indicators in Uzbekistan (2000–2025)²

Figure 2 presents the bivariate relationships between energy intensity and four major energy-transition variables. According to the estimated regression lines, there is an inverse relationship between energy intensity and the share of renewable energy, indicating that higher levels of renewable energy use are associated with lower energy intensity. In contrast, there is a positive relationship between energy intensity and the share of natural gas, indicating that higher levels of reliance on natural gas are associated with higher levels of energy intensity. Energy investment and the green policy index also demonstrate inverse relationships with energy intensity.

¹ Source: Developed by the author.

² Source: Developed by the author.

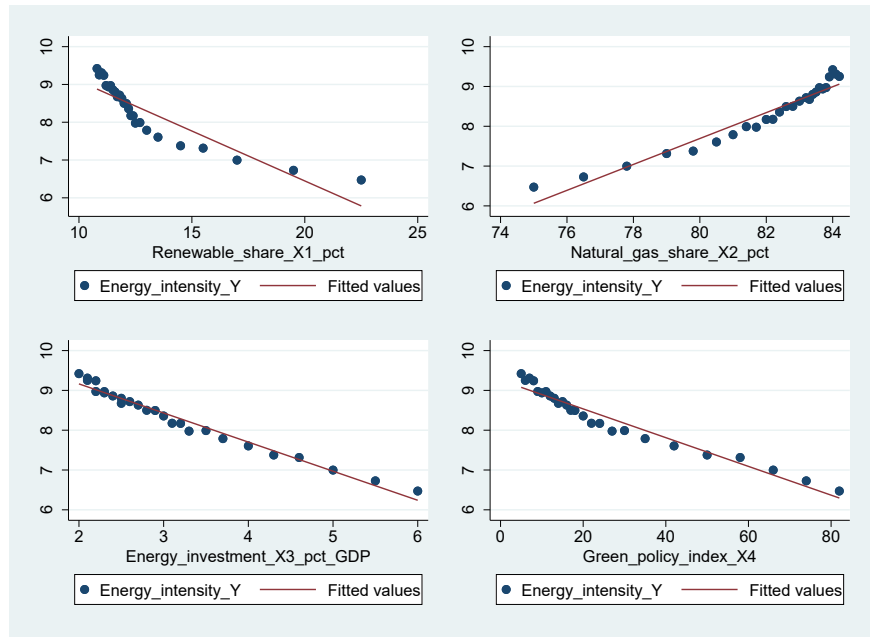


Figure 2. Bivariate Relationships Between Energy Intensity and Energy-Transition Indicators in Uzbekistan (2000–2025)³

Figure 3 illustrates the distributions of energy intensity, the share of renewable energy, the share of natural gas, and the green policy index for the period 2000–2025. Energy intensity is more concentrated between 8 and 9, while the share of renewable energy is predominantly concentrated at lower levels, with the distribution extending to the right, corresponding to its recent increase. The share of natural gas is more concentrated at levels between 82% and 84%, while its distribution gradually shifts to the left.

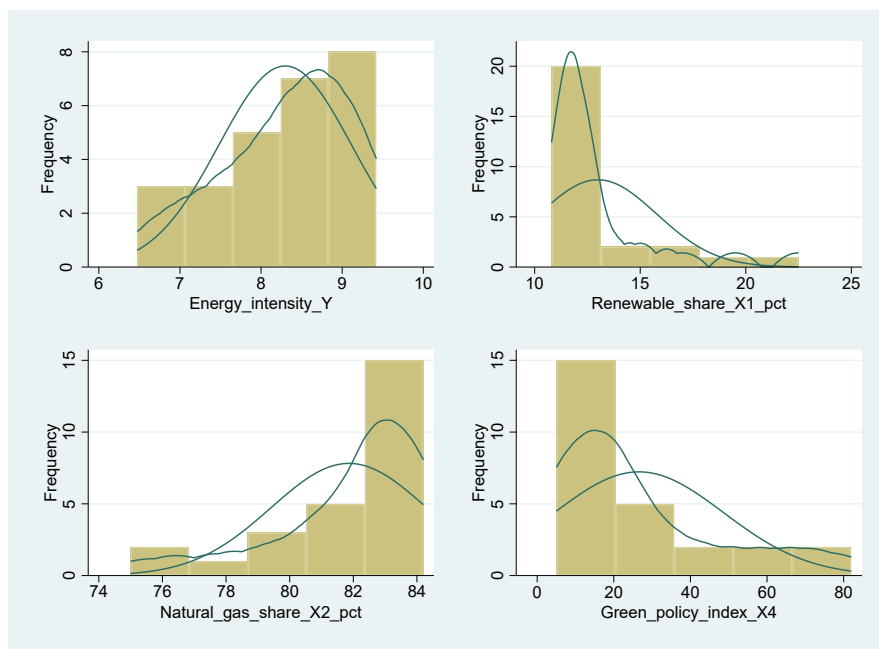


Figure 3. Distribution of Energy-Transition Indicators in Uzbekistan⁴

Table 2 presents the pairwise correlation coefficients between the variables included in the regression analysis. There is a strong negative correlation between energy intensity and the share of renewable energy

³ Source: Developed by the author.

⁴ Source: Developed by the author.



($r = -0.902$, $p < 0.01$), energy investment ($r = -0.987$, $p < 0.01$), and the green policy index ($r = -0.975$, $p < 0.01$), whereas there is a strong positive correlation between energy intensity and the share of natural gas ($r = 0.970$, $p < 0.01$). The predictor variables are also highly correlated with one another, with correlation coefficients ranging from -0.995 to 0.996 .

Table 2. Pearson Pairwise Correlations Among Energy-Transition Indicators⁵

Variables	(1)	(2)	(3)	(4)	(5)
(1) Energy_intensity	1.000				
(2) Renewable_share	-0.902* (0.000)	1.000			
(3) Natural_gas_share	0.970* (0.000)	-0.974* (0.000)	1.000		
(4) Energy_investment	-0.987* (0.000)	0.949* (0.000)	-0.995* (0.000)	1.000	
(5) Green_policy index	-0.975* (0.000)	0.954* (0.000)	-0.994* (0.000)	0.996* (0.000)	1.000

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

The results of the linear regression analysis of the determinants of energy intensity presented in Table 3 are based on a sample of 26 annual observations. Overall, the regression model is statistically significant ($F = 485.017$, $p < 0.001$), and its explanatory power ($R^2 = 0.789$) is approximately 78.9%. Energy investment is statistically significant with a negative coefficient ($\beta = -1.527$, $p < 0.001$), indicating that higher investment is associated with improved energy efficiency, while the green policy index has a positive and statistically significant coefficient ($\beta = 0.022$, $p = 0.042$). The share of renewable energy ($\beta = 0.064$, $p = 0.291$) and the share of natural gas ($\beta = -0.092$, $p = 0.676$) are not statistically significant in the multiple regression model.

Table 3. Linear Regression Results for Energy Intensity in Uzbekistan⁶

Energy_intensity_	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
Renewable_share	.064	.059	1.08	.291	-.059	.186	
Natural_gas_share	-.092	.216	-0.42	.676	-.541	.358	
Energy_investment	-1.527	.335	-4.56	0	-2.224	-.83	***
Green_policy	.022	.01	2.17	.042	.001	.044	**
Constant	19.233	19.382	0.99	.332	-21.074	59.54	

Mean dependent var	8.298	SD dependent var	0.819
R-squared	0.789	Number of obs	26
F-test	485.017	Prob > F	0.000
Akaike crit. (AIC)	-45.596	Bayesian crit. (BIC)	-39.306

*** $p < .01$, ** $p < .05$, * $p < .1$

The Linktest results used to determine whether the linear regression model is correctly specified are presented in Table 4. The model is statistically significant (F-test, $p < 0.001$) and has a high R^2 of 0.990 and a Root MSE of 0.087. The coefficient for the fitted value ($\hat{_}$) is not statistically significant ($\beta = 0.630$, $p = 0.169$), and the coefficient for the square of the fitted value ($\hat{_}^2$) is also not statistically significant ($\beta = 0.023$, $p = 0.412$). If $\hat{_}^2$ were statistically significant, it could indicate model misspecification or nonlinear relationships; therefore, the insignificance of $\hat{_}^2$ provides support for the adequacy of the estimated model specification.

⁵ Source: Developed by the author.

⁶ Source: Developed by the author.

Table 4. Linktest Specification Test for Model Adequacy⁷

Source	SS	df	MS	Number of obs =26
Model	16.580	2	8.290	Prob > F=0.000
Residual	0.174	23	0.008	R-squared = 0.990
Total	16.754	25	0.670	Root MSE = 0.087

energy_int~y	Coefficient	Std. err.	t	P>t	[95% conf. interval]
_hat	0.630	0.444	1.420	0.169	-0.288 1.548
_hatsq	0.023	0.028	0.830	0.412	-0.034 0.080
_cons	1.464	1.763	0.830	0.415	-2.183 5.110

Table 5 presents the estimation results of the proposed Structural Equation Model (SEM), examining the associations among energy investment, energy intensity, renewable energy, the green policy index, and the share of natural gas over the 2000–2025 period, based on 26 observations. In the energy-intensity equation, energy investment has a statistically significant negative association with energy intensity ($\beta = -1.355$, $p < 0.001$), indicating that higher investment is associated with greater energy efficiency. Meanwhile, the share of renewable energy ($\beta = 0.041$, $p = 0.478$) and the share of natural gas ($\beta = -0.239$, $p = 0.240$) are not statistically significant in explaining energy intensity when the other variables are controlled for.

Table 5. SEM Path Model Results for Energy-Transition Pathways in Uzbekistan⁸

Number of observations = 26

Endogenous variables:

Observed: energy_intensity_y, energy_investment

Exogenous variables:

Observed: renewable_share, green_policy, natural_gas_share

Fitting target model:

Iteration 0: log likelihood = -72.392009

Iteration 1: log likelihood = -72.392009

Structural Equation Model

Estimation method: ML

Log likelihood = -72.392009

	OIM					
	Coefficient	std. err.	z	P>z	[95% conf. interval]	
Structural						
energy_intensity_y						
energy_investment	-1.355	0.324	-4.190	0.000	-1.990	-0.721
renewable_share	0.041	0.058	0.710	0.478	-0.072	0.154
natural_gas_share	-0.239	0.204	-1.170	0.240	-0.639	0.160
_cons	31.683	18.403	1.720	0.085	-4.386	67.751
energy_investment						
renewable_share	-0.137	0.021	-6.400	0.000	-0.180	-0.095
green_policy	0.007	0.006	1.240	0.214	-0.004	0.019
natural_gas_share	-0.538	0.070	-7.720	0.000	-0.675	-0.402
_cons	48.838	6.076	8.040	0.000	36.929	60.746
mean(renewable_share)	12.996	0.537	24.200	0.000	11.944	14.049
mean(green_policy)	26.577	4.250	6.250	0.000	18.246	34.907
mean(natural_gas_share)	81.862	0.470	174.350	0.000	80.941	82.782

LR test of model vs. saturated: $\chi^2(1) = 5.25$

Prob > $\chi^2 = 0.0220$

⁷ Source: Developed by the author.

⁸ Source: Developed by the author.

Equation 1. Energy Investment

$$\text{Energy Investment} = 48.838 - 0.137 \text{ Renewable Share} + 0.007 \text{ Green Policy} - 0.538 \text{ Natural Gas Share} + \varepsilon_1$$

Equation 2. Energy Intensity

$$\text{Energy Intensity} = 31.683 - 1.355 \text{ Energy Investment} + 0.041 \text{ Renewable Share} - 0.239 \text{ Natural Gas Share} + \varepsilon_2$$

Mediation Effect

The estimated indirect effect of renewable energy on energy intensity through energy investment is:

$$-0.137 \times -1.355 = +0.1856$$

In the energy-investment equation, the renewable energy share has a statistically significant negative association with energy investment ($\beta = -0.137$, $p < 0.001$). This indicates that, within the estimated model, an increase in the renewable energy share is associated with lower energy investment. The green policy variable has a positive but statistically insignificant association with energy investment ($\beta = 0.007$, $p = 0.214$), indicating that the estimated association between green policy and energy investment is not statistically distinguishable from zero. The natural gas share has a statistically significant negative association with energy investment ($\beta = -0.538$, $p < 0.001$).

Therefore, the SEM results indicate that energy investment represents the primary statistically significant channel associated with variations in energy intensity. The coefficient of -1.355 indicates that a one-unit increase in energy investment, while holding the shares of renewable energy and natural gas constant, is associated with an approximately 1.355-unit decrease in energy intensity. At the same time, the negative coefficient estimated for the relationship between renewable energy and energy investment should be interpreted within the structure of the estimated model. This relationship may reflect strong time trends and the high correlations among the variables, as demonstrated by the correlation analysis, and therefore does not independently establish a causal relationship.

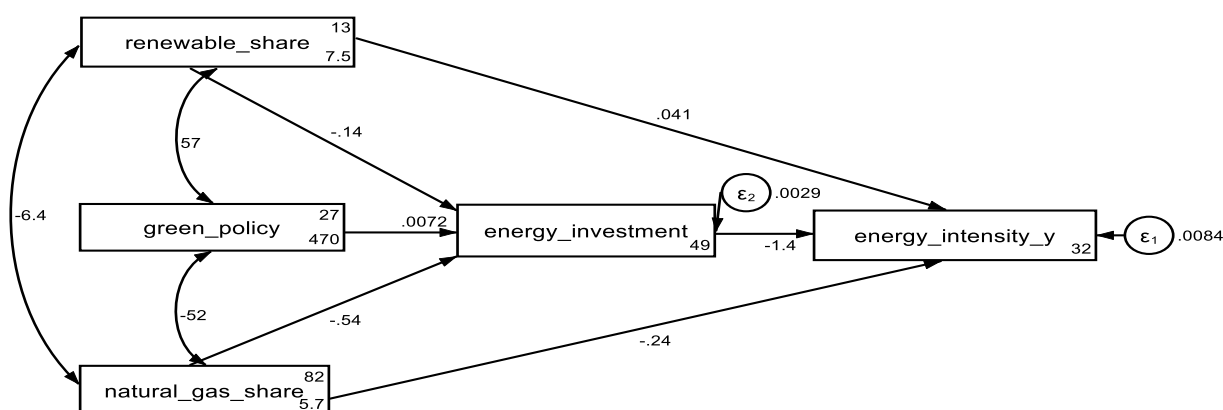


Figure 4. SEM Path Model Results for Energy-Transition Pathways in Uzbekistan⁹

Finally, the LR test comparing the fitted model with the saturated model is statistically significant ($\chi^2(1) = 5.25$, $p = 0.022$), indicating differences between the fitted and saturated models. Given the sample size ($N = 26$) and the high correlations among the predictors, the results provide an exploratory empirical basis for interpreting the identified relationships, while causal interpretations require additional evidence.

The findings provide important insights into Uzbekistan's evolving energy transition and its implications for sustainable development. The descriptive results demonstrate a gradual decline in energy intensity alongside increasing renewable energy participation and energy investment, suggesting a structural movement toward greater energy efficiency. The regression and SEM results consistently identify energy investment as an important factor associated with lower energy intensity. This finding implies that investment in modern infrastructure, energy-saving technologies, and technological modernization may contribute substantially to improving energy efficiency.

The estimated direct effect of renewable energy indicates that increases in renewable capacity may be accompanied by complementary investments and institutional measures to further strengthen improvements in energy intensity. The SEM results also indicate that the relationship between renewable energy and energy

⁹ Source: Developed by the author.



investment is complex, highlighting the importance of considering broader structural conditions. From an Input–Output perspective, these findings imply that energy-transition policies can generate significant intersectoral effects because changes in energy supply influence production costs, intermediate consumption, and sectoral output. Therefore, combining SEM evidence with I–O analysis and CGE simulations could provide a more comprehensive assessment of future transition scenarios, including impacts on economic growth, trade, employment, welfare, and emissions.

CONCLUSION AND SUGGESTIONS

The empirical findings indicate that Uzbekistan's energy transition is increasingly associated with improvements in energy efficiency, supported particularly by rising energy-sector investment and the gradual expansion of renewable energy. The SEM results show that energy investment has a statistically significant negative effect on energy intensity, highlighting the importance of capital allocation toward modern energy infrastructure, technological upgrading, and efficiency-enhancing projects. From an Input–Output (I–O) perspective, these findings suggest that energy investment should be assessed not only within the energy sector itself but also through its intersectoral effects on manufacturing, construction, transport, agriculture, and services. An updated I–O framework can therefore identify how changes in the energy mix propagate through production chains, intermediate demand, household consumption, imports, exports, and sectoral energy requirements.

Looking forward, integrating I–O accounting with a Computable General Equilibrium (CGE) model would provide a stronger prospective framework for evaluating Uzbekistan's energy-transition scenarios. The I–O system can establish structural relationships and energy requirements across sectors, while the CGE model can simulate alternative policy scenarios, such as accelerated renewable energy deployment, increased energy-efficiency investment, reduced dependence on natural gas, and stronger green-policy implementation. Such an integrated framework would allow policymakers to evaluate not only reductions in energy intensity and emissions but also potential effects on GDP, sectoral output, employment, household welfare, trade, imports, and investment. Consequently, the I–O–CGE approach can support evidence-based planning for a more efficient, diversified, and environmentally sustainable energy transition in Uzbekistan.

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Musahhih: Zokir ALIBEKOV

Sahifalovchi va dizayner: Hasan MAQSUDOV

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