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EXAMINING THE LINK BETWEEN ENVIRONMENTAL TAX VOLATILITY AND THE SHIFT TO RENEWABLE ENERGY IN UKRAINE

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A B S T R A C T

Environmental taxes are increasingly used as fiscal instruments to internalize environmental externalities and finance renewable energy investments. Environmental taxes are increasingly utilized as fiscal instruments to internalize environmental externalities and finance renewable energy investments. This study examines the nonlinear, regime-dependent relationship between environmental tax volatility and the renewable energy transition in Ukraine, aiming to identify stable tax regimes that effectively support renewable energy development. The study employs annual time-series data from the World Development Indicators covering the period 1980-2023. Preliminary analyses include descriptive statistics, unit root tests (ADF and PP), OLS estimation, and non-linearity diagnostics (BDS and CUSUM tests). Ordinary Least Squares results indicate that a 1% increase in environmental tax revenue increases renewable energy transition by 0.8329% ($p < 0.01$). Markov switching results identify two distinct regimes. Regime 2 records a higher coefficient (0.7812) and stronger persistence ($P22 = 0.970$) compared to Regime 1 (0.7016; $P11 = 0.909$). Regime 2 demonstrates lower volatility, higher mean values (0.9337), and a longer duration of approximately 33 years, indicating a stable and sustained environmental tax regime that effectively supports renewable energy transition. Maintaining stable, consistent environmental tax regimes should be the top priority for policymakers to ensure stable, consistent funding for renewable energy investments, build greater public trust, and accelerate the achievement of SDG 7 in Ukraine.

INTRODUCTION

It is undoubtedly true that environmental taxes are increasingly recognized and can internalize the costs associated with the consumption of fossil fuels, thereby encouraging businesses and households to invest in renewable energy sources. Environmental taxes are recognized as one of the policy measures to reduce global warming and facilitate a transition to renewable energy sources. By promoting environmental quality (Avagyan, 2021), this pathway could help mitigate the effects of climate change and achieve Sustainable Development Goal 7, affordable and clean energy (Kamalu & Wan Ibrahim, 2024; Global Energy Outlook, 2025). It is noted that there is a pursuit goal between environmental taxes and renewable energy transition, which tends to influence environmental policy outcomes such as reducing ecological footprint, combating energy emissions and pollution (Shahbaz et al., 2022; Fang et al., 2022), and contributing to Sustainable Development Goals. The adequacy of environmental taxes ensures sustainable earnings, thereby increasing earnings capacity and facilitating the transition to renewable energy, thereby improving the achievement of SDG 7. However, environmental taxes such as carbon taxes exhibit an undulating trend, are inherently vulnerable, and remain volatile due to geopolitical shocks and policy uncertainty, hindering the renewable energy transition. This research assertion has received

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limited attention in Ukraine, especially in the context of using the Markov regime-switching model (Hamilton, 1989) to investigate the thresholds of change in environmental tax revenue that facilitate the renewable energy transition in Ukraine. Despite fluctuations in environmental tax revenue, it remains a crucial buffer for advancing sustainable energy reforms amid economic volatility. Theoretically, environmental taxes are a strong source of financing, derived from activities that harm the environment, and are primarily used to meet a nation's environmental budgetary controls. These funds create environmental wealth to drive lasting success and promote practices for the renewable energy transition. However, the behavior of environmental taxes can fluctuate drastically, leading to abrupt shifts in environmental management decisions. Fluctuations in environmental taxes could negatively impact the renewable energy transition, ultimately affecting renewable energy reforms and programs due to earnings volatility (Jenkins et al., 2025). Reducing environmental taxes could limit the nation's budget for implementing environmental initiatives, undermine sustainable practices, and hinder reductions in greenhouse gas emissions. This study aims to enrich the knowledge base in accounting and finance by using the Markov-switching technique to examine the nonlinear behavior (Hamilton, 1989) of Ukraine's environmental taxes to explain renewable energy transitions and achieve SDG 7. While parametric estimation methods have been used in previous studies, this study uses financial time-series data on environmental taxes and renewable energy to analyze their nonlinear relationships using a Markov switching model.

Empirical studies have documented the decline in environmental taxes and the barriers they pose to renewable energy transitions. Factors that affect environmental regulations include strict regulations, limited understanding of the interlinkages of environmental taxes for efficient, sustainable reform policies, taxpayers' attitudes, fluctuating environmental tax rates, and failure to account for the nonlinear effects of green taxation (Chien et al., 2023). Ukraine is a nation with significant geopolitical and economic volatility, yet it has historically relied on carbon-intensive energy sources. Its environmental taxation system provides both opportunities and challenges for managing sustainable energy reforms and for policy directives (Ukraine Energy Report, 2025). To reduce pollution and encourage decarbonization (Article 234), Ukraine's environmental tax rates have increased, leading to a 70% increase in carbon emissions (Ukraine Energy Report, 2025). Ukraine has initiated a green transition to align with EU best practices, such as the EU Green Deal, to support the implementation of obligatory environmental tax payment targets. Despite this move, the contribution of environmental taxes has not been markedly pronounced in Ukraine's government-led renewable energy transition reforms, thereby inhibiting the attainment of SDG 7. The paradigm nature of environmental taxes provides time-series data, characterizing the establishment of varying regimes, due to abrupt economic recessions, which could create pronounced panic conditions and thereby constrain Ukraine's energy transition. Ukraine's environmental tax framework (Global Energy Outlook, 2025) may include different regimes that reflect high- and low-commitment phases. The ongoing conflict with Russia has exacerbated the decline in environmental taxes in Ukraine, negatively affecting these earnings and hindering the promotion of a renewable energy transition, leading to unpredictable economic setbacks. The results indicate that Regime 2 is persistent and optimal, providing a sufficient and stable environmental tax to support the renewable energy transition effectively. Moreover, the out-of-sample prediction for regime 2 shows an upward yield for a resilient environmental tax to promote the renewable energy transition, thereby providing reasonable assurance of achieving sustainable development.

This study deals with theoretical and empirical issues in Section 2. The research design and materials are presented in Section 3, and Sections 4 and 5 address the empirical results, discussion, and concluding remarks, respectively.

LITERATURE REVIEW

This literature review section synthesizes the theoretical basis and the extant empirical evidence to cogently contextualize the study topic. The theoretical review addresses Pigouvian tax theory, the snowball effect of environmental taxes, the financial outlook for Ukraine under environmental taxes, and the accounting for ecological taxes under the International Public Sector Accounting Standards (IPSAS).

Pigouvian Tax Theory

This theory asserts that environmental taxes can confer a strategic competitive advantage by improving the path of the renewable energy transition, specifically by addressing negative externalities from ecological pollution. The strong predictive power of the nation's environmental taxes can be leveraged to achieve and sustain strategic competitive advantages, reduce environmental externalities, and enhance revenue resilience. The Ukrainian government can benefit from this resilience revenue path to achieve SDG 7. Structural changes are imminent in regime switches in environmental taxes, which persistently facilitate the use of nonlinear Markov methods in the context of the correlation between environmental taxes and Ukraine's renewable energy transition sector.

Snowball Effects of Environmental tax

Snowball's theory of environmental taxation explains that tax revenues can build momentum to have substantial impacts over time. The current situation is gradually creating a perception of the costs of polluting activities, leading companies to switch to cleaner alternatives and reduce emissions (Kamalu & Wan Ibrahim, 2024). However, the unstable nature of environmental taxes, defined by unplanned shifts and volatility, raises issues in different regimes, compounding revenue risks. According to this viewpoint, an unobserved state can be used to forecast the legal system that best guarantees environmental tax support for the transition to renewable energy. Environmental taxes could create a snowball effect, boosting earnings power to support Ukraine's shift to renewable energy.

Environmental tax revenue outlook and the Financial Sector of Ukraine

Scholarly studies have proposed environmental taxes as a viable means of supporting the transition to renewable energy. For instance, several prior studies have shown that ecological taxes related to the renewable energy transition pathway are beneficial: Fang et al. (2022), Zhang and Zheng (2023), Sharma et al. (2021), and Rehman et al. (2025) support this assertion. Such a possibility could be ascribed to the respective nation's resilient financial sector. Since 1990, Ukraine has proactively aligned its environmental decision-making with EU and OECD Best Practices, perhaps with the primary aim of securing strategic carrots and, for instrumental reasons, easier market access and greater autonomy in EU climate governance, leading to improved environmental outcomes. Air and water pollution, waste, and radioactive waste are the four theme areas that Ukraine recognizes for environmental taxation. Due to externalities and the ongoing Russian invasion, environmental taxes, which account for about 2% of Ukraine's GDP (OECD, 2012), have stagnated. Over the years, this invasion has reduced their influence across a range of financial metrics, causing severe harm to Ukraine's infrastructure, natural resource base, and environment (Pata et al., 2024).

The introduction of environmental taxes is hindered by persistent challenges that may create financial vulnerabilities, slowing the transition to renewable energy and ultimately hindering progress towards fulfilling the Sustainable Development Goals (SDGs) (Xia et al., 2023). The war in Ukraine has exacerbated fragility, including weak financial support for public environmental programs, thereby compounding environmental risks and increasing threats to the renewable energy transition, which affects the attainment of sustainable development goals.

To increase coordinated efforts to address environmental tax issues, including high energy prices, several white papers and debates have been launched, most notably the 2014 European Union-Ukraine Association Agreement. Firms avoid paying environmental taxes due to higher energy prices, making it more expensive for firms that use carbon in their production, affecting earnings and hindering support for the renewable energy transition. There is a high likelihood that post-war reconstruction will further exacerbate environmental tax challenges. This trend of environmental taxes exhibits undulating patterns that threaten the earnings power needed to advance the renewable energy transition and boost SDG No. 7 in Ukraine. This trend of conditions necessitates the application of the Markov Switching model.

Environmental Tax within IPSAS Effect

International Public Sector Accounting Standard (IPSAS) 23 addresses the accounting for revenues from Non-Exchange Transactions – taxes and transfers. Accounting for environmental taxes and their treatment is guided by these standard guidelines: incomes or revenues obtained from environmental activities such as pollution, carbon emissions, and mineral extraction. This type of tax revenue or income is recognized as earned, measurable, and collectible in the government or covered entity's financial accounts. Tax revenues from carbon emissions and mineral extraction activities often exhibit unusual fluctuations and a random walk pattern, which suggests the application of the Markov Regime Switching model.

Empirical Analysis

Environmental taxes are identified as an important tool for supporting the adoption of renewable energy, which, in turn, could help mitigate environmental pollution and enhance sustainable development. Environmental taxes are recognized in part to mitigate climate change. It is widely accepted that there is an interdependence between environmental tax pathways and renewable energy consumption, which can unleash integrated approaches to achieving sustainable development. Prior studies confirm a positive association between environmental taxes and renewable energy adoption across contexts, including the European Union and OECD nations. The prior study by Alper et al. (2025) demonstrates the efficacy of environmental taxes in contributing to net earnings through investment in cleaner technology (Dradra, 2024); their link to stable, resilient financial access drives the critical role in enhancing the renewable energy transition (Rehman et al., 2025). However, the fluctuating pattern of environmental taxes influences the extent of the energy transition pathway, casting doubt on their ability to support sustainable renewable development (Rahmane et al., 2024). This study examines the extent to which environmental taxes support the implementation of renewable energy to achieve sustainable development in Ukraine, given its middle-income status. Despite this, the complexities of the tax system and corporate governance issues pose challenges to achieving optimal tax earnings to facilitate the renewable energy transition (Sugihyanty & Faisal, 2024). Thus, we therefore posit that:

H_1: There is a likelihood that Ukraine's renewable energy transition will be influenced by shifts in environmental tax regimes, amidst increased volatility.

MATERIALS AND METHODS

Several prior studies have established the U-shaped nature and nonlinear outcomes of environmental tax revenues, including energy and greenhouse gas taxes, and the potential for social equity in achieving the SDGs (Chien et al., 2023). Given the sustained, unpredictable nature of environmental tax revenues, the Markov-switching model of time variation is appropriate for this study (Hamilton, 1989; Engel & Hamilton, 1990; Chien et al., 2023). The parameters of the Markov Switch model capture the judicious application of environmental taxes associated with each regime to measure their contribution to the renewable energy transition. This study would reveal novel insights into Ukraine's situation in the post-Russia-Ukraine war period. Findings could be compared with those obtained using nonlinear time-series tools, such as ARMA (Box & Jenkins, 1970). World Bank's (2023) World Development Indicators provided data for this study of Ukraine, covering the period from 1980 to 2023.

Measuring Variables

This paper investigates how far Ukraine's environmental tax explains the transition to renewable energy to achieve the SDGs. The dependent variable is renewable energy, while environmental taxes serve as the independent variable and the focal unit of this study. This analysis uses natural logarithms to mitigate bias from variable transformations. (see Table 1).

Table 1. Variable Definition and Measurement

Variable	Meaning	Label	Source	Support theory	Sign
Dep. var: Renewable energy trans.	Natural log of renewable energy	LNETAX	WDI, 2023	sustainable energy transition theory	?
Ind. Var: Environmental tax	Natural log of environmental tax	LNRNGY	WDI, 2023	Pigouvian tax theory	--/+

Source(s): Author estimation

Model Specification

Stochastic conditions can cause random variables to undergo fundamental changes in behavior and can prompt Markov switching via standard principles (Hansen, 2000). The mean and variance parameters associated with the normal distribution within the Markov regime take this specification:

$$x_t = \mu_t + \delta_t + \varepsilon_{t-1} \quad t = 1,\ldots,T, \qquad (1)$$

With $\varepsilon_t + N(0,1)$ the Z-scores.

The random walk movements of the Markov-switching model drive the state variable (St) between regimes, enabling the recognition of signals in the unobservable value within the financial time-series dataset. This time-series dataset would exhibit unplanned, volatile conditions that are uncontrollable, and the discrete states would enhance the creation of feasible states for a Markov process with time (t) and regimes (M) (Hansen, 2000). The inherent regime parameters from the Markov switch attain identified states with shift probabilities given as:

$$\Pr(s_t = j\text{I}S_{t-1} = i) = P_{ij} \ldots\ldots. i, j \in \{1, 2\}$$

Z_t = an exogenous variable, where Z_t may be X_t

$s_t = i$ is the state variable

i = regimes 1 and 2

P_{ij} = probability that State i follows State j

A point to note for 2 hidden states in the unobserved regime condition of time and State in accordance with a first-order Markov chain, as portrayed in this equation:

$$\Pr(s_t = j\text{I}S_{t-1} = i) = P_{ij} \ldots\ldots. i, j \in \{1, 2\} \qquad (2)$$

It can be noted that transition probabilities (Hansen, 2000) derive State 1 at time t-1 to State j at time t, from State j at time t t, from equation (2). Density functions from regimes do create transition probabilities to uphold the assumptions unchanged over time $Pij(t_t) = Pij$ for all t (equation 1). The shift probabilities provide reasonable assurance of identifying regimes that maintain optimal performance, with filtered and smoothed probabilities for regime-parameter maximization.

This study identified a dataset from the WDI database for the period 1980-2023. We performed the fundamental econometric procedures, which serve as basic tests for financial time series. In the broader context, environmental taxes are resources the nation collects through levies on carbon emissions to promote renewable energy transitions and environmental quality (Chien et al., 2023) and to support the attainment of the SDGs. Environmental tax can be referred to as a policy instrument within the ambit of reaping 'double dividend' with inherent merits in both economic and environmental yields. Environmental taxes exhibit unexpected behavior, which may ultimately lead to declining tax revenues and hinder supportive measures for Ukraine's renewable energy transition. This assertion can be exacerbated by the Russia-Ukraine war. This condition would weaken support for the renewable energy transition pathway in Ukraine, slowing progress toward the SDGs, particularly the goal of achieving net-zero carbon emissions by 2050. Notwithstanding this, other inherent factors may be accounting for the decline in environmental taxes.

RESULTS AND DISCUSSIONS

Table 2 presents the descriptive statistics for the fundamental values of both dependent (renewable energy transition, LNRNGY) and independent (environmental tax, LNETAX) variables used in this study. The environmental tax and renewable energy transition have mean scores of 6.9027 and 0.9485, respectively, as shown in Table 2. The LNETAX percentiles showed higher scores than the LNRNGY percentiles during the same study period. Therefore, the study can draw an inference that environmental tax could contribute to explaining Ukraine's renewable energy transition, within the abject undulating trends or patterns that environmental tax may exhibit (see Figure 1)

Table 2. Descriptive analysis

Var	mean	Std dev	Variance	25%	50%	75%
LNETAX	6.9027	0.9193	0.8452	5.8494	6.6881	7.8223
LNRNGY	0.9485	0.7976	0.6363	0.1823	0.9932	1.7047

Source(s): Author estimation

Figure 1 illustrates trends in financial data on environmental taxes and the renewable energy transition in Ukraine from 1994 to 2023. The values of renewable energy (LNRNGY) displayed random movements with a gradual upward trend around 0.5, 1.0, and 1.8 on the y-axis, showing an average annual decrease of 8.9%. On the other hand, environmental tax (LNETAX) shows an upward trend in 2021, 2022, and 2023 to counter random movements and fluctuations, but achieved an annual growth rate of 16.5% in 2023, when LNETAX was stable at the tail end. The faster trend in the random walk of environmental taxes (see Figure 1) signals the realization of sufficient earnings, a promising step toward accelerating renewable energy investments to attain SDG 7.

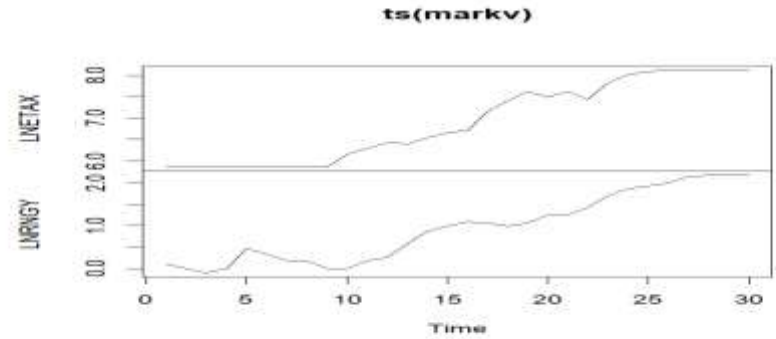


Figure 1. Line graph: Trends of LNETAX and LNRNGY

The capacity of environmental taxes highlights their efficacy and reliability in uncertain conditions, which affords the use of the Markov model in this study. In the two-regime dataset, both trends demonstrate the cyclical nature of the time series, with irregular time intervals and comparable movements.

Table 3 displays the unit root test findings for environmental tax (LNETAX) and renewable energy transition (LNRNGY) via the Dickey-Fuller and Philip–Perron approaches. Findings from ADF and PP indicated no stationarity at the levels, perhaps due to the variables' seasonality. Moreover, the trends and random walks of the study variables warrant the application of a Markov model. The environmental tax was stationary at first difference under both the ADF and PP techniques, whereas renewable energy was not, and the results may exhibit spurious or invalid inferences. According to Table 2, the diagnostic test outcomes do not support the null hypothesis. This suggests that the models are correctly specified and well-suited for use.

Table 3. Stationarity test and residual results

TEST: ADF	**Intercept**	**Trend & intercept**	**Joint tests**	**Statistics**	**Prob.**	**Dec.**
Variable	*levels*	*1st Diff*	Joint tests			
LNRNGY	0.3274 (0.9756)	-3.4076 (0.0706)	Normality J. B.	3.6302	0.1628	Normally dist.
LNETAX	0.3585 (0.9774)	-5.0360 (0.0019)	Serial correlation	10.7065	0.0004	No correlation
TEST: PP			Ramsey RESET	3.7967	0.0008	No missp.
LNRNGY	1.3096 (0.9981)	-3.3424 (0.0801)	Heterosdasticity: B-P Godfrey ARCH	 5.8613 3.7749	 0.0222 0.0625	000000 No homo Volatility
LNETAX	0.4206 (0.9804)	-5.0947 (0.0016)	Anova F-test	1.328	0.4492	No significant effect

Source(s): Author estimation

This analysis outlines the OLS findings for the variables involved (see Table 4). The result reveals that a 1% significant increase in environmental tax is associated with a 0.8329 increase in the coefficient for renewable energy transition. This finding implies that a substantial increase in LNETAX could provide reasonable assurance of ameliorating public funding for the renewable energy transition in Ukraine, thereby supporting government renewable projects to improve SDG No. 7. Furthermore, the wavering pattern of environmental tax and the likely impact of the war on tax revenue realization command the swift usage of the Markov model. The OLS results (Table 4) provide the best-fit estimate by minimizing the sum of squared residuals and yield the most efficient, unbiased outcome, but may yield spurious results due to deceptive high R-squared values (98.6%) in some cases.

Table 4. OLS test result (dep=LRNGY)

Variable	Estimate	Std. error	T-value	Pr(>|t|)
_Cons	-4.8003	0.3201	-15.00	6.55e-15***
LNETAX	0.8329	0.0459	18.11	<2e-16***
Adj. R-sq=0.986, F-Stat=382.2, Prob(F-stat)=<2.2e-16, Residual std error =0.2276, residuals: min=0.477, max=0.398, med=0.014, 1Q=0.155, 3Q=0.214				

Note(s): ***p<0.01
Source(s): Author estimation

The OLS results indicated that environmental taxes have a high capacity to drive the adoption of renewable energy in Ukraine. The adjusted R-square for the OLS model is 8.6.7%, while the overall probability value measured 0.000. However, due to unexpected changes within the administration of environmental tax from economic shocks of the Ukrainian economy, alterations in the government regulation, declining earnings margins due to underperforming energy lines, and sudden challenges in fulfilling OLS requirements, this paper utilizes the Markov model to ascertain a specific remarkable regime that contributes to renewable energy transition in Ukraine. In addition, the justification for switching to the Markov switching model is not limited to: the OLS recognizes and assumes a single constant relationship across the entire sample, the biased nature of OLS during a major policy introduction, and the presence of heteroskedasticity of residuals of OLS, of which the Markov switching model incorporates to solve these fundamental problems. With these, the Markov-switching technique becomes feasible for analyzing the renewable energy transition and environmental tax policies.

Markov Switching Model Results

Table 5 displays the Brock-Dechert-Scheinkman (Brock et al., 1987) test and the structural break test results from the CUSUM of squares test for explaining the non-linearity of environmental tax. This test assumes that data switches between varying regimes, accounting for residuals from environmental taxes and changes in both the mean and the variance (Engel & Hamilton, 1990). The BDS results affirm the applicability and appropriateness of the Markov-switching model using a financial time-series dataset.

Table 5. BDS Test for LNETAX

Dimension	BDS statistics	Std error	z-stats	Prob.
2	0.152357	0.008787	17.33930	0.0000***
3	0.239771	0.014197	16.88876	0.0000***
4	0.291957	0.017189	16.98544	0.0000***
5	0.312332	0.018223	17.13973	0.0000***
6	0.323333	0.017885	18.07840	0.0000***

Note(s):***p<0.01
Source(s): Author estimation

The study confirms the non-linearity of BDS results for environmental taxes, as the series are linearly dependent at the 0.05 level, suggesting a complete rejection of the null hypothesis. In addition, the BDS result incorporates an inbuilt association by assessing the probability of variance in states (S) across varying intervals at the end, allowing it to detect misspecification in recurring and frequent signal segments (Brock et al., 1987). Furthermore, the CUSUM of squares results evidence a reasonable part of the cumulative sum of squares lies inside the 5% critical boundary (see Figure 2), indicating a reasonable stability outcome. Therefore, this combined effect drives demand for the Markov model, suggesting adherence to the time-series pattern.

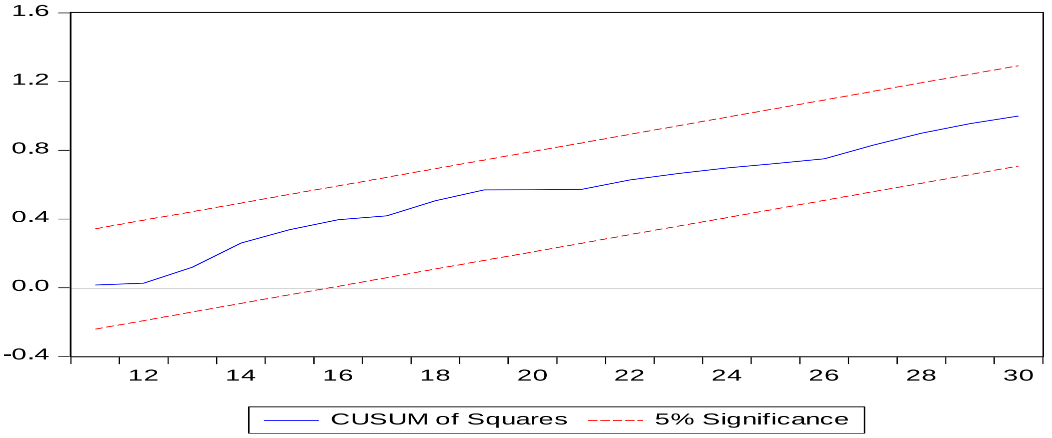


Figure 2. CUSUM of Squares Stability Test

This study applies a Markov-switching model in a regression, using standard distribution theory to define mean and variance boundaries to capture regime shifts in a financial time-series dataset. Considering that this study recognizes the renewable energy transition and environmental tax in its contexts, this estimation technique sets the tone for the dynamic relationships among the study variables, allowing for switches between different regimes or states (St) with their own associated parameters. This study proposes two regimes: regime 1, a low-renewable energy transition, and regime 2, a high-energy transition (see Table 6). This switch confirms nonlinear relationships, providing insights into the dynamics of both the renewable energy transition and environmental taxation across different regimes, which, in turn, leads to the evaluation of the efficacy of these revenues in promoting the renewable energy transition in the Ukrainian economy. Transition probabilities and the unobserved state variable (St) inherently capture the Markov chain's states, leveraging filtered and smoothed possibilities associated with the observed regime value to estimate the expected duration of regime selection.

Table 6. Markov results and descriptive analysis

Test statistics	**Regime 1**		**Regime 2**	
	LNETAX	INTERCEPT	LNETAX	INTERCEPT
Est	0.7016	-4.1362	0.7812	-4.2751
Std error	0.0475	0.3175	0.0327	0.2420
T-value	-14.771	-13.027	23.890	-17.666
Pr(>|t|)	< 2.2e-16	<2.2e-16	< 2.2e-16	< 2.2e-16
Std residuals:				
Mean		0.0662		0.9337
Median		0.0487		0.9512
Max		0.3138		0.9629
Min		0.0370		0.6861
R-squared		0.9510		0.9765

Note(s):***p<0.01

Source(s): Author estimation

The Markov model results for both regimes are presented in Table 6, showing that the environmental tax could explain the renewable energy transition in Ukraine. The coefficient for Regime 1 is 0.7016 at the 1% significance level, while Regime 2 achieves a higher value of 0.7812. Furthermore, Regime 2's mean score was 0.9337, surpassing Regime 1's score of 0.0662. Standard error estimates are used to measure the efficiency and accuracy of the mean score appropriately. Regime 1 had a greater standard error (0.0475) than Regime 2 (0.0327), suggesting that Regime 2's mean standard error is preferable due to its lower volatility, which typically translates to greater stability across contexts and is more desirable because it implies reduced risk. Regime 2 displays a median value of 0.9512, as compared to Regime 1's lower value (0.0487). This suggests that LNETAX volatility (regime 2) within Ukraine's renewable energy transition has greater capacity to deliver key benefits to Ukraine's energy transformation, beyond the point at which financial resilience supports renewable energy needs and capacity, thereby accelerating renewable energy generation. The regime's unleashed ability provides sufficient assurance that environmental taxes can influence the renewable energy transition to achieve SDG 7. Regime 2 exhibits low volatility, maintaining the Markov model's stability over time, suggesting a more stable outcome for a risk-averse nation like Ukraine. The outcomes of regime 2 show notable changes in the mean and variance, mainly driven by the dynamic traits of the environmental tax, which encourage Ukraine's transition to safe renewable energy pathways.

Regime shifts reveal the transition probabilities: P11 = 0.909, P12 = 0.091, P21 = 0.029, and P22 = 0.970. Governing the transformation of latent variables. The transition probability P22 of 0.970 indicates that Regime 2 is highly persistent, pointing to a prolonged period of stability, but with a relatively lower chance (3%) of switching from Regime 2 to Regime 1, indicating a phase with reduced risk of transitioning into another regime. The Markov switching model for Regime 1 to Regime 1 appears to show a more stable, but lower, probability of persistence than Regime 2 to Regime 2, as shown in the one-step predicted and filtered regime probability graphs across the study periods **(**see Figures 3 & 4**).** Regime 2 dominates the graphs, leading to a prolonged period of stability that significantly reduces the availability of sufficient environmental tax revenues to support a renewable energy transition and achieve SDG 7. Regime 2 is quite stable, with a low likelihood of switching to regime 1's persistence probability.

On the other hand, Figure 3 shows the one-step-ahead predicted regime probabilities, which indicate the model's best guess of which regime the system is in and which regime it switches to in the next time (t) steps, based on the previous and current information available at time t+1. It indicates that the model may be in either regime 1 or regime 2, in the sense of the likely future State of the system. Figure 4 presents a recursive algorithm for the Hamilton Filter to calculate the filtered probabilities of being in each regime, given the available information up to time t. Regime 2 of the filtered probabilities showed a persistent transition, enabling the use of reliable, accurate data to analyze the financial time series, as compared with Regime 1.

Figure 5 shows the results of filtered/smothered probabilities under regime 2. According to the test results, regime 2 has a higher probability than regime 1, as it is more likely to be the correct regime at that time. Moreover, regime 2 demonstrates that a threshold of more than 0.5 is required to be considered a valid State.

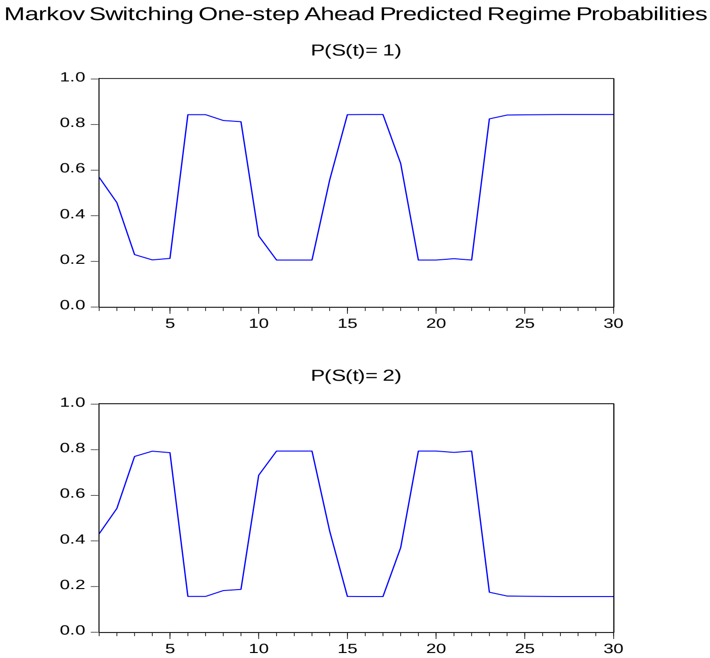


Figure 3. Markov Switching One-step Ahead Predicted Regime Probabilities

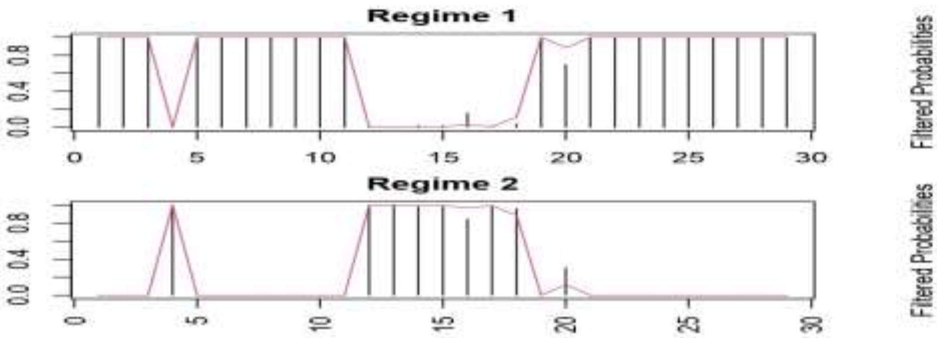


Figure 4. Filtered Probabilities of Regime 1 and 2

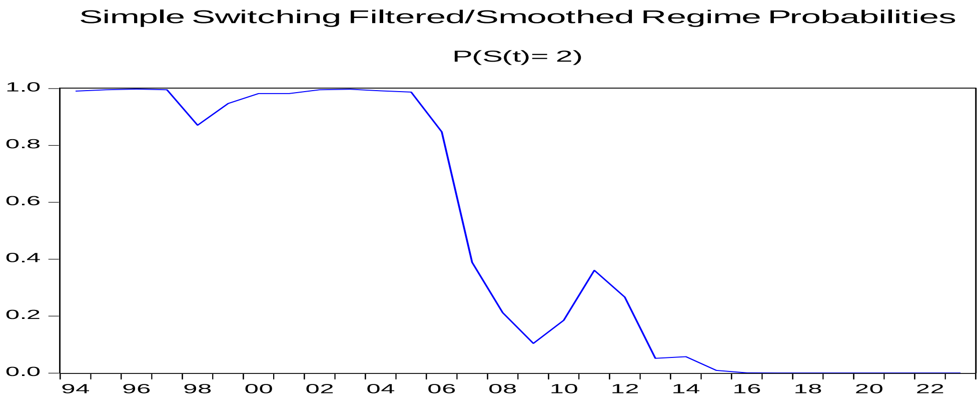


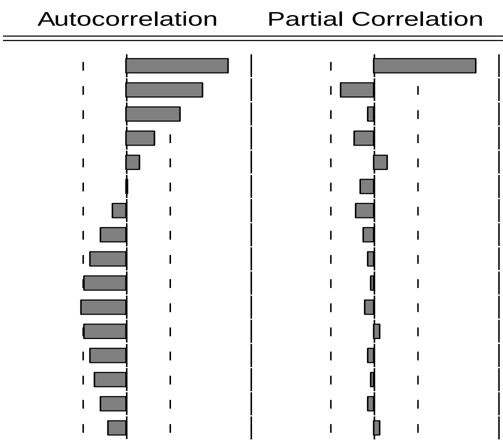
Figure 5. Filtered/Smothered Regime 2 Probabilities

The result (Figure 5) shows that Regime 2 achieves a significantly longer filtered persistent duration of more than 33 years during the total study period, suggesting a more enduring trend than Regime 1, which lasts around 11 years. Regime 2 depicts a higher-threshold dynamic for switching to Regime 1, exhibiting greater stability and a longer-lasting regime. This finding suggests that Regime 2 stays longer to postulate an environmental tax revenue realization to motivate and support renewable energy pathways for achieving SDG 7

Environmental tax is undoubtedly one of the most effective forms of funding to reduce pollution and encourage the transition to renewable energy, especially at higher persistence and lower volatility, associated with Regime 2, for more stable outcomes. The test results clearly showed Regime 2 as the optimal point for environmental tax realization, providing the Ukrainian government with reasonable assurance of meeting its renewable energy targets of 27% in total final consumption. Regime 2 demonstrated potential to generate environmental tax revenue, in contrast with Regime 1, thereby mitigating the high capital costs that tend to cast doubt on the viability of renewable energy initiatives in Ukraine.

Diagnostic for autocorrelation checks

Figure 6 depicts correlograms of the Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) for a graphical representation of time lags in financial time-series analysis of the autocorrelation structure. Both ACF and PACF measure the correlation between a time series and its lagged version. The results in Figure 6 indicate that the observed test results are highly statistically significant, suggesting the rejection of the null hypothesis. Figure 6 reveals clear common patterns, such as sudden drops, gradual declines, and prominent peaks, in both the ACF and PACF, suggesting autocorrelation and seasonality. This result indicates a high level of misspecification in the series and could therefore distort the study's meaningful conclusions.



	AC	PAC	Q-Stat	Prob*
1	0.849	0.849	23.837	0.000
2	0.641	-0.283	37.919	0.000
3	0.443	-0.055	44.911	0.000
4	0.243	-0.167	47.098	0.000
5	0.110	0.114	47.561	0.000
6	0.005	-0.112	47.561	0.000
7	-0.110	-0.155	48.069	0.000
8	-0.212	-0.097	50.036	0.000
9	-0.295	-0.052	54.025	0.000
10	-0.347	-0.017	59.792	0.000
11	-0.369	-0.080	66.669	0.000
12	-0.346	0.046	73.069	0.000
13	-0.304	-0.047	78.299	0.000
14	-0.259	-0.026	82.334	0.000
15	-0.210	-0.044	85.168	0.000
16	-0.151	0.042	86.721	0.000

*Probabilities may not be valid for this equation specification.

Figure 6. ACF residuals and PACF plots of Auto Correlation

Out-of-sample of regime 2 prediction

Regime 2 outlined a successful environmental tax to support Ukraine's renewable energy transition. In the same manner, Figure 2 depicts out-of-sample prediction of the log variance in Regime 2 between 2024 and 2029. The result indicates a lower value, suggesting less volatility (lower uncertainty) in the years 2015 onwards than in regime 1. This can be explained as a low risk associated with environmental tax over the next six years, providing reasonable assurance that sufficient environmental tax will be available to support investment in the renewable energy project in Ukraine, all things being equal. This is due to appreciable out-of-sample forecast yield (see Figure 7), supporting model validation, providing insights into the sufficiency of yield from environmental taxes under the renewable energy transition, and providing assurance to policymakers about tax earnings to support renewable energy adoption in Ukraine.

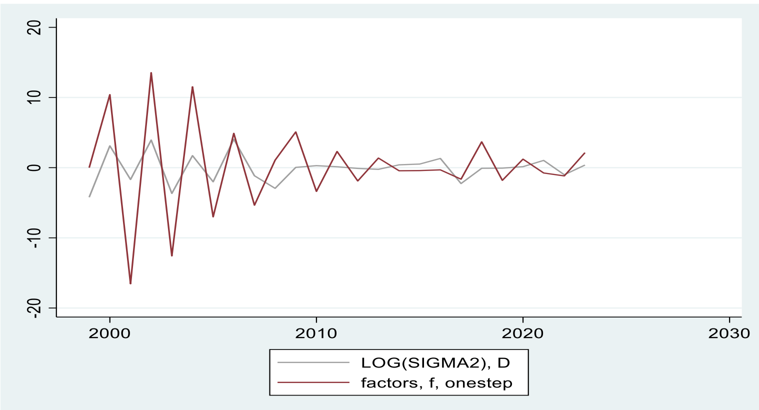


Figure 7. Regime 2's out-of- sample forecast yields

CONCLUSIONS

This study aims to provide insights into the undulating, unplanned dynamics of volatility as environmental taxes mitigate high capital costs to support Ukraine's renewable energy transition. Using a sample of a financial time-series dataset for Ukraine from WDI, Markov switching is employed to capture time-varying effects to aid policymakers' decisions. The results confirmed the existence of persistent, distinct regimes in environmental taxes within a time-invariant environment with extensive volatilities. The analysis of results confirmed that Regime 2 maintained long, persistent environmental taxes to generate sufficient earnings to support a renewable energy transition and accelerate energy initiatives (Fang et al., 2022), in contrast to Regime 1.

In other indicators of outcome, Regime 2 earnings are more relevant for the reasonable allocation of scarce resources. The financial numbers of mean and standard error of Regime 2 fit suitably and appropriately with lower volatility in environmental taxes (LNETAX) to enhance explanatory power in supporting renewable energy transition (Zhang & Zheng, 2023), which facilitates the attainment of SDG No.7, compared with Regime 1. Nevertheless, Regime 1 shows evidence of releasing moderating environmental taxes but highly volatile reactions to support renewable energy investment initiatives. Even though this moderating effect is significant, it is relatively weak, with a highly volatile response and a short duration, resulting in undulating LNETAX and scant renewable energy efficiency, and less motivation to drive the SDG clean target in Ukraine.

To conclude, this study investigates the extent the application of the Markov switching model disentangle environmental tax revenue within two regimes in a defined period to cause a persistent sustained long-lasting duration to support renewable energy investments for achieving the SDGs No.7. Our results highlight that Regime 2 demonstrated affirmative and more appreciable mean and standard deviation values of high magnitude in contrast with lower values of Regime 1 of the same information. The descriptive statistics exhibited higher values of Regime 2. Regime 2 demonstrated lower volatility, with persistent, sustained tax revenues to support renewable energy transition initiatives, consistent with the application of Pigouvian theory.

Regime 2 reveals that a long-lasting duration in this regime provides reasonable assurance of accurate, reliable predictive power to realize the potential to promote renewable energy use, which would serve as the bedrock of energy technologies consistent with sustainable energy transition theory.

The findings of Regime 2 demonstrate a predictive power for appreciable tax revenue to enhance effective energy transition in support of energy transition theory. This move mitigates capital costs and increases investment in Ukraine's renewable energy transition. This evidence shows that persistent fluctuations in environmental taxes, amid volatility, could support Ukraine's renewable energy transition targets (sustainable energy transition theory) within the Markov-switching framework. The out-of-sample results for predicting the variance of regime 2 provide reasonable assurance of the sustainability of environmental taxes over the six-year forecasting period. This study is relevant in disentangling and capturing regime shifts in the environmental tax revenue crises. Furthermore, this study is relevant to the government regarding the study variables and the application of the Markov model to facilitate optimal forecasting and enable promising steps toward meeting SDG No.7.1 - sustainable modern energy for Ukrainians at a given time. This study makes a significant contribution to our understanding of the relationship between environmental taxes and the renewable energy transition, and to the ultimate potential of these taxes to support renewable energy investment in Ukraine. Environmental tax management aims to correct failures pursued by polluters to encourage more socially optimal behavior.

This study has several limitations, which serve as a platform for future research. The context of managing environmental taxes is complex and influenced by environmental policy goals, varying international environmental agreements, potential economic instability in Ukraine, and adjustments to tax rates and policy bases. However, this study ignores these factors to evaluate the pernicious effects of environmental taxes. The final results would have been compromised if the majority of these factors had been recognized in our dataset analysis. In view of this, we pre-empt that future research studies should recognize crucial variables such as the tax base, tax rate, tax regulatory frameworks, and the level of citizen support to ensure the resilience of future findings. This would aid Ukraine's governance in making a judicious evaluation of environmental taxes to identify and disentangle regime periods that could mark a persistent, long-lasting period of sustainable taxation for policy directives and regulatory implementation across Ukraine as a whole.

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