

Article

Does Oil Price Volatility Drive or Hinder the Global Sustainable Energy Transition? Evidence from Oil-Exporting Versus Oil-Importing Countries

Achouak Barguelli¹ and Adel Benhamed^{2,*}

¹ IFGT Research Laboratory, Faculty of Economics and Management of Tunis, University of Tunis, Tunis 1068, Tunisia; achouak.barguelli@fsegt.utm.tn

² Department of Economics, School of Business, King Faisal University, AlAhsa 31982, Saudi Arabia

* Correspondence: abenhamed@kfu.edu.sa

Abstract

This paper examines whether oil price volatility accelerates or decelerates the global sustainable energy transition by analyzing the differential responses of oil exporters and oil importers. Using a Panel Autoregressive Distributed Lag (P-ARDL) estimation on a balanced panel of 30 countries (2002–2023), this study investigates the long-term sustainability of energy shifts under market uncertainty. We find significant asymmetric impacts: oil-exporting countries demonstrate a strong, positive long-run response to volatility, suggesting that price uncertainty acts as a catalyst for economic diversification and sustainable investments in renewables as a strategic risk management tool. Conversely, oil-importing countries show no significant volatility response; their transition toward sustainability is primarily driven by economic growth rather than oil market forces. The error correction mechanisms reveal annual adjustment rates of 35.9% for importers and 21.5% for exporters, confirming stable long-run sustainable development relationships. These findings challenge the hypothesis of a uniform global transition, highlighting that achieving sustainability goals is highly dependent on a nation's position in international oil markets, necessitating tailored policy frameworks for a resilient energy future.

Keywords: energy transition; oil price volatility; renewable energy; panel ARDL; oil-exporting countries; oil-importing countries; cointegration analysis

JEL Classification: Q42; Q43; C23; O13



Academic Editor: Camelia Delcea

Received: 27 December 2025

Revised: 27 January 2026

Accepted: 6 February 2026

Published: 9 February 2026

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1. Introduction

The global energy sector is witnessing a revolution, which includes the gradual shift away from reliance on fossil fuel sources and a switch to renewable and sustainable energy sources [1]. The energy revolution is one of the most critical challenges of the 21st century, especially as it affects the impact of climate change, security, and economic development [2].

Traditionally, the dynamics of international oil markets have significantly contributed to setting energy policies and investment strategies. According to conventional economic theory, a rise in oil prices would trigger a substitution effect, favoring the use of renewable energy resources as these would become more price-competitive [3]. Nevertheless, new facts emerging show that there is a much more complex relationship between oil markets and a green transformation than a price substitution mechanism would lead one to believe.

Recent empirical studies present a mixed and often contradicting picture. For example, Mukhtarov [3] found that oil price increases in China result in a 0.16% increase in renewable energy consumption, thus supporting the substitution hypothesis. Contrarily, Tambari et al. [4] documented asymmetric relationships in African countries, where positive changes in oil prices had negative long-run effects on renewable energy investment, challenging conventional wisdom.

One important gap in the existing literature that this paper intends to fill is the undue emphasis placed on the levels of oil prices, rather than the volatility in oil prices. Whereas price levels are a direct cost factor, volatility is a proxy for market uncertainty. As argued by Real Options Theory, such uncertainty can substantially delay investment in capital-intensive renewable energy projects due to higher risk premiums; see Chen et al. [5]. Private investment may be discouraged by high volatility; on the other hand, it may also act as a strategic driver for energy diversification in an economy's efforts to hedge against fossil fuel shocks. In focusing on volatility, this manuscript extends the empirical research from purely cost-benefit analysis to one embedded in risk-based decision-making.

Apart from that, oil price instability does not have a similar effect on national economies. A second major contribution of this work is the explicit comparative framework between oil-exporting and oil-importing nations. These groups face fundamentally different economic incentives and fiscal constraints [2]. For oil exporters, volatility destabilizes fiscal revenues and national budgets, potentially hindering the state's ability to fund green infrastructure. For oil importers, volatility is primarily an energy security and trade balance concern, which may accelerate political resolve toward energy independence. Despite its theoretical importance, empirical research has often treated countries as homogeneous units or focused on single-country case studies.

The following research questions are pursued in this study to address these gaps:

- To what extent does oil price volatility accelerate or decelerate the renewable energy transition?
- How do oil price volatility effects vary between oil-exporting and oil-importing countries?
- What are the various dynamic patterns in each of these relationships in the short and long run?

In order to address these questions, we use a Panel Autoregressive Distributed Lag (P-ARDL) model. Different from other panel models, the P-ARDL model can handle variables of differing orders of integration, allowing us to incorporate an error correction term, which reflects both short-run and long-run dynamics of the relationship between the variables. In our analysis, we have a balanced panel of 30 countries, 15 of which are oil-exporters, and 15 of which are oil-importers, and we analyze the data between the years 2002 and 2023. The chosen time period includes significant disruptions in the market, such as the financial crisis of 2008, the price slump of 2014–2016, and the COVID-19 crisis of 2020, which provides enough variability to properly capture the effect of volatility.

This paper has the following structure: Section 2 presents a literature review. Section 3 describes econometric methods and sources of the data. Section 4 presents the empirical analysis. Section 5 interprets the outcomes in the context of the existing literature, and Section 6 draws conclusions with suggestions for policies.

2. Literature Review

2.1. Theoretical Framework: Oil Prices and Renewable Energy

The theoretical relationship between the adoption of renewable energy and prices of oil operates through several channels in the economy. The most direct channel is the substitution mechanism, by which higher oil prices make relatively more appealing alternative renewable resources [6]. The mechanism relies on traditional microeconomic

theory, where consumers and firms substitute towards relatively lower inputs when one of the inputs rises in price.

However, the income effect can also be in the opposite direction. Higher oil prices can slow down aggregate economic activity, particularly among importers of oil, by increasing production costs and lowering disposable incomes [7]. This contraction of the economy can reduce available capital for mass-scale renewable energy investments, perhaps stalling the energy transition in spite of the higher relative competitiveness of renewables.

The inclusion of volatility adds another degree of complexity. Investment theory suggests uncertainty has the effect of decreasing investment in irreversible projects [8]. Since renewable energy projects normally have high up-front capital expenditure with long payback periods, increased volatility in oil prices may deter such investment by increasing the option value of waiting for more information.

Conversely, volatility may promote the use of renewable energy through a channel of diversification of portfolios. Oil-dependent countries may view investment in renewable energy as insurance against volatility in oil prices, similar to how financial investors diversify portfolios to reduce risk [9].

2.2. Empirical Evidence on Oil Prices and Renewable Energy

Empirical evidence is inconsistent regarding the substitutability between renewable energy and oil prices. Some evidence supports the substitution hypothesis. Mukhtarov [3], using Canonical Cointegrating Regression for China, 1990–2020, indicated that rising oil prices by 1% led to renewable energy consumption by 0.16%. Murshed and Tanha [7] indicated positive and significant influences of oil prices on renewable energy shares in South Asian economies.

However, there exist more complex relationships in other research. Tambari et al. [4] employed ARDL and NARDL models to examine six African countries and identified symmetric and asymmetric relationships. Curiously, in countries with asymmetric relationships (Angola, Ethiopia, South Africa), positive oil price changes had negative long-run impacts on investment in renewable energy, which goes against the simple substitution hypothesis.

The volatility role has received increased focus. Chen et al. [5] researched 4017 energy companies worldwide between 1996 and 2022 and established that oil price volatility has a marked effect on clean energy investment, where the influence differs based on the nature of the company and market situations. Jin and Kim [9] particularly examined renewable energy as an oil price volatility hedge and found corroborative evidence that renewable energy stock can act as an effective hedging instrument.

Esmaeili et al. [10] examined the implications of different categories of oil price shocks for renewable energy and determined that oil supply shocks, aggregate demand shocks, and oil-specific demand shocks all have differential effects on renewable energy adoption. This emphasizes the importance of decomposing oil price movements based on their root causes.

2.3. Oil-Exporting and Oil-Importing Countries

The distinction between oil-importing and oil-exporting countries is critical to asymmetric responses to oil price shocks. For oil-exporting countries, oil exports are a key source of government income and foreign exchange receipts. Price volatility has immediate consequences for fiscal stability and can create strong incentives for economic diversification [2].

Nchofoung [2] examined 53 African countries and determined that oil price shocks negatively affected the energy transition, but the effect was concentrated among net crude oil-exporting countries. This suggests that the revenue dependence of oil exporters presents unique challenges to the energy transition that are not shared by oil-importing economies.

In oil-importing countries, the situation is turned on its head. An increase in oil prices translates into direct economic costs and energy security threats, and an incentive is thereby established to reduce dependence on imports by opting for renewable energy domestically [7]. Samour et al. [11] found the mechanism at play in Turkey, with oil price rises correlating with increased consumption of renewable energies.

The heterogeneous effects extend beyond simple distinctions of exporter–importers. Islam and Sohag [12] examined transmission channels of mineral and oil price shocks to renewable energy production, and the effects differed based on the nature of economies and their natural endowments.

2.4. Panel ARDL Methodology in Energy Economics

The Panel ARDL (P-ARDL) model has emerged as a popular alternative in energy economics, owing to its capacity to address variable orders of integration, as well as make short-run and long-run predictions [13]. Several advantages exist in using the Panel ARDL model in place of the conventional panel estimation models:

1. It supports variables of different orders of integration ($I(0)$ or $I(1)$).
2. It offers two different estimates concerning short-term and long-term relationships.
3. It provides an error correction process that incorporates adjustment dynamics.
4. It allows for country-specific heterogeneity in adjustment speeds.

Abumunshar et al. [14] used bootstrap ARDL techniques to investigate the impact of oil prices on energy consumption and CO₂ emissions in the Turkish economy, proving the usefulness of the technique in describing dynamic links. The technique has managed to address different issues in the field of energy economics, for instance, the relationship between the price of oil and the consumption of renewable sources of energy.

2.5. Recent Developments and Synthesis of Research Gaps

Recently, studies have started to look into other complexities involved in the relationship between oil prices and renewable energy sources. Recent scholarly debates have moved beyond the simple substitution hypothesis to explore more nuanced dimensions of the oil–renewable nexus. A study by Parziale and Gatto [14] focused on economic challenges in reducing carbon intensity, exploring the complexities of oil shock transitions influenced by CO₂ emissions and market structures. This complexity is further amplified by financial market interactions, as shown by Yaya et al. [15], who analyzed oil shocks, volatility, and green investments using GARCH-MIDAS models. They concluded that there is a high susceptibility to oil shocks along with their volatilities in the case of green investments.

Despite this growing body of work, a critical synthesis of the literature reveals several major gaps that guide this research:

The Volatility vs. Level Dichotomy: Most of the existing research focuses on price levels rather than the volatility in oil prices. While price levels represent a direct cost factor, volatility serves as a proxy for market uncertainty. According to Real Options Theory, such uncertainty can substantially delay investment in capital-intensive renewable energy projects due to higher risk premiums.

Lack of Comparative Asymmetry: The literature appears to lack studies comparing oil-exporting and oil-importing countries with a comparable analytical framework utilizing advanced econometric analysis. These two groups face fundamentally different economic incentives: for exporters, volatility destabilizes fiscal revenues, while for importers, it is primarily an energy security concern.

Methodological and Temporal Scope: A number of papers consider single countries or utilize traditional panel methods, which may not fully address dynamic patterns and

heterogeneity. Furthermore, there is limited coverage of recent periods that include major oil price volatility episodes, such as the COVID-19 crisis, and the rapid development of the market for renewable energy sources.

This study fills these gaps by presenting the first extensive analysis of the impact of oil price volatility on the renewable energy transition in oil-exporting and oil-importing countries through the P-ARDL approach for an extended period that encompasses several cycles of volatility.

3. Data and Methodology

3.1. Data and Sample

This analysis employs a balanced panel dataset of 30 countries between 2002 and 2023, providing 660 country–year observations. The sample is categorized into two groups of 15 countries based on their net oil trade positions and economic structural dependence. The 15 oil-exporting countries include Algeria, Angola, Canada, Iran, Iraq, Kazakhstan, Kuwait, Libya, Nigeria, Norway, Qatar, Russia, Saudi Arabia, the United Arab Emirates, and Venezuela. The 15 oil-importing countries comprise Belgium, China, France, Germany, India, Italy, Japan, the Netherlands, Singapore, South Korea, Spain, Thailand, Turkey, the United Kingdom, and the United States.

The selection of these 30 countries is based on objective economic criteria to ensure global representativeness and statistical validity. First, the classification of countries as net oil exporters or importers follows the standards set by the International Energy Agency (IEA) [16] and the World Bank [17]. Specifically, exporting countries were selected based on the high share of oil rents in their Gross Domestic Product (GDP) and their total crude oil export volumes, as documented in the World Bank's World Development Indicators [17]. Conversely, the importing group includes nations with the highest global oil consumption and a strategic structural dependence on energy imports to sustain industrial growth, such as China, India, and G7 economies, according to the Energy Institute's Statistical Review of World Energy [18].

The choice of 15 countries per group (totaling 30) was determined to achieve a balanced panel, which is essential for the consistency of the Panel ARDL estimator [19]. This sample size captures approximately 80% of global oil supply and demand while ensuring the continuous availability of harmonized data for all variables (GDP, oil volatility, and renewable energy indicators) across the entire 2002–2023 period. Expanding the sample further would have introduced significant missing data issues for certain emerging economies, potentially biasing the long-run equilibrium results.

The chosen time span (2002–2023) is particularly significant as it encompasses several distinct market regimes and periods of intense structural volatility. This period includes the rapid industrialization of emerging economies in the early 2000s, the global financial crisis of 2008, and the subsequent era of price recovery and stabilization between 2010 and 2014. Furthermore, it captures the 2014–2016 oil price collapse, the unprecedented market disruptions caused by the COVID-19 pandemic, and the geopolitical tensions of 2022. By covering these diverse market episodes, this study ensures that the P-ARDL model captures long-term equilibrium shifts across varying degrees of market stress.

3.2. Variables and Data Sources

To ensure clarity and provide a theoretical basis for our model, the variables selected for this study are defined and justified in Table 1. These variables were chosen based on their relevance to the energy transition literature and their ability to capture the dynamics between market uncertainty and renewable energy adoption.

Table 1. Data sources and variable definitions.

	Variable	Definition	Source
Dependent Variable	REC	Renewable energy consumption (% of total final energy consumption)	World Bank WDI
Key Explanatory Variables	OPV	Oil price volatility (annualized standard deviation of log returns)	Authors' calculation from U.S. Energy Information Administration (EIA)
	OPL	Crude oil prices, WTI spot price FOB (USD per barrel)	U.S. EIA
Control Variables	CO ₂	CO ₂ emissions per capita (metric tons)	World Bank WDI
	GDP	GDP per capita, constant 2015 US\$ (log-transformed)	World Bank WDI

3.3. Descriptive Statistics

Table 2 presents the descriptive statistics for the variables used in this study, including renewable energy consumption (REC), oil price volatility (OPV), Log (GDP), and CO₂ emissions. The data is partitioned into three columns: the Full Sample (N = 660) and two sub-groups consisting of oil exporters (N = 330) and oil importers (N = 330). For each variable, the mean, standard deviation (Std. Dev.), minimum (Min), and maximum (Max) values are reported.

Table 2. Descriptive statistics by country group (2002–2023).

Variable	Full Sample (N = 660)	Oil Exporters (N = 330)	Oil Importers (N = 330)
Renewable Energy Consumption (%)			
Mean	21.01	19.45	22.57
Std. Dev.	7.11	6.89	7.23
Min	4.42	4.42	6.78
Max	38.73	35.21	38.73
Oil Price Volatility			
Mean	13.89	13.89	13.89
Std. Dev.	13.31	13.31	13.31
Min	2.26	2.26	2.26
Max	39.65	39.65	39.65
Log(GDP per capita)			
Mean	10.42	10.18	10.66
Std. Dev.	0.91	0.87	0.89
Min	8.12	8.12	8.95
Max	11.89	11.67	11.89
CO ₂ Emissions per capita			
Mean	8.49	9.12	7.86
Std. Dev.	3.86	4.21	3.42
Min	1.91	2.34	1.91
Max	18.31	18.31	16.45

Source: Authors' calculations based on World Bank and EIA data.

The statistics reveal that the mean REC is higher for oil importers (22.57%) than for exporters (19.45%). Similarly, CO₂ emissions are more intense in oil-exporting nations, with a mean of 9.12 per capita compared to 7.86 for importers. The OPV variable remains identical across groups as it reflects global market fluctuations, showing a high standard deviation (13.31) relative to its mean (13.89), which indicates significant dispersion in the data.

These patterns suggest that oil-importing countries have made further progress in the energy transition, possibly as a strategy to reduce dependency on volatile fossil fuel prices. The enormous range of OPV (2.26 to 39.65) is particularly noteworthy, as it captures the extreme market shifts during the study period. The higher GDP per capita in the importing group (10.66) vs. exporters (10.18) also suggests a potential decoupling of economic growth from oil production in those regions.

3.4. Panel ARDL Methodology

The choice of the Panel Autoregressive Distributed Lag (P-ARDL) model is justified by several econometric advantages over traditional methods. Compared to the Generalized Method of Moments (GMM) or standard Fixed Effects (FEs), the P-ARDL is particularly suited for datasets where the time dimension (T) is relatively large (T = 22). As noted by Pesaran et al. (1999) [19], GMM estimators are primarily designed for ‘small T, large N’ contexts and may suffer from inconsistent estimates due to instrument proliferation when T increases. Furthermore, the P-ARDL framework allows for mixed orders of integration, accommodating variables that are I(0), I(1), or a combination of both, thereby relaxing the rigid requirements of traditional cointegration tests [20,21].

A fundamental advantage of this model, specifically the Pooled Mean Group (PMG) estimator, is its capacity to distinguish between short-run dynamics and long-run equilibrium relationships through an error correction mechanism [19]. This approach accounts for cross-country heterogeneity by allowing short-run coefficients and error variances to differ across groups while assuming long-run homogeneity, a balance that provides more robust results in energy-economic studies [22]. Finally, the P-ARDL effectively addresses potential endogeneity and serial correlation by including appropriate lag structures, ensuring consistent estimates even in the presence of heterogeneity [20].

To operationalize this approach, we reparametrize the P-ARDL model into the following Error Correction Model (ECM) form, which allows for the simultaneous estimation of short-run and long-run effects:

$$\Delta REC_{it} = \phi_i (REC_{i,t-1} - \theta_0 - \theta_1 OPV_{i,t} - \theta_2 GDP_{i,t} - \theta_3 CO_{2i,t}) + \sum_{j=1}^{p-1} \lambda_{ij}^* \Delta REC_{i,t-j} + \sum_{j=0}^{q-1} \delta_{ij}^* \Delta OPV_{i,t-j} + \sum_{j=0}^{r-1} \beta_{ij}^* \Delta GDP_{i,t-j} + \sum_{j=0}^{s-1} \gamma_{ij}^* \Delta CO_{2i,t-j} + \mu_i + \varepsilon_{it}$$

In this specification, the dependent variable ΔREC_{it} represents the short-term changes in renewable energy consumption for country *i* at time *t*. The term in parentheses reflects the long-run equilibrium relationship, where the coefficients θ_1 , θ_2 , and θ_3 capture the permanent impacts of oil price volatility (OPV), economic growth (GDP), and CO₂ emissions (CO₂), respectively.

A central feature of this model is the error correction coefficient ϕ_i (ECT). This parameter measures the speed of adjustment, indicating how quickly the system returns to its long-run equilibrium state following a shock in the oil market. For the model to be stable and to confirm cointegration, ϕ_i must be negative and statistically significant. The summation terms associated with the first differences, specifically the coefficients λ_{ij}^* , δ_{ij}^* , β_{ij}^* and γ_{ij}^* , represent the short-run dynamic effects. These parameters capture the immediate response of renewable energy consumption to changes in the independent

variables before the system begins to adjust back to its long-term trend. Finally, μ_i accounts for country-specific fixed effects, while ε_{it} represents the idiosyncratic error term.

4. Empirical Results

4.1. Panel Unit Root Tests

To ensure the robustness of the unit root results, three different tests were employed: Levin–Lin–Chu (LLC), Im–Pesaran–Shin (IPS), and ADF–Fisher. The detailed results of these tests are presented in Table 3. The findings show that CO₂ emissions and renewable energy consumption are evidently non-stationary at levels across all tests, whereas oil price volatility and log GDP show borderline results. Nevertheless, all three tests consistently show that all variables are stationary after first differencing, affirming they are integrated of order one, I(1). This fulfills the fundamental assumption of the P-ARDL approach, which requires that all variables be either I(0) or I(1), and strictly rules out I(2) processes.

Table 3. Panel unit root test results.

Variable	LLC Test	IPS Test	ADF–Fisher	Conclusion
Level				
REC	−1.442 (0.150)	−1.523 (0.164)	15.21 (0.160)	Non-stationary
OPV	−2.177 (0.030)	−1.891 (0.059)	22.45 (0.062)	Borderline
LOG(GDP)	−2.342 (0.030)	−1.967 (0.049)	24.11 (0.045)	Borderline
CO ₂	−1.789 (0.087)	−1.654 (0.098)	17.89 (0.110)	Non-stationary
FIRST DIFFERENCE				
Δ(REC)	−3.764 *** (0.000)	−4.123 *** (0.000)	48.33 * (0.000)	Stationary
Δ(OPV)	−4.086 *** (0.000)	−4.567 *** (0.000)	52.11 * (0.000)	Stationary
Δ(LOG(GDP))	−3.194 *** (0.000)	−3.421 *** (0.000)	41.09 * (0.000)	Stationary
Δ(CO ₂)	−3.889 *** (0.000)	−4.234 *** (0.000)	46.77 * (0.000)	Stationary

Note: *p*-values are reported in parentheses. *** and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

To determine the optimal lag structure for the P-ARDL model, we employed the Akaike Information Criterion (AIC). Following Lütkepohl [23] and Pesaran et al. [19], the AIC is preferred in panel data analysis as it provides a superior balance between model parsimony and goodness of fit, effectively minimizing the risk of over-parameterization. Due to the annual nature of the data and the relatively moderate time dimension ($T = 22$), lower-order lags are statistically preferred to preserve degrees of freedom. Tests conducted across multiple specifications confirmed that increasing the lag length (e.g., to 2 or 3) led to an increase in the AIC values, indicating a loss of model efficiency. Thus, the P-ARDL (1, 1, 1, 1) configuration was selected as it minimizes the information loss while ensuring that the error correction term (ECT) remains within the stable theoretical range of (−1 to 0), confirming a robust return to long-run equilibrium.

4.2. Panel Cointegration Tests

Having established that the variables are integrated of order I(1), we proceed to test for cointegration using the Pedroni [24] panel cointegration framework. Table 4 presents the results of these tests, which evaluate the long-run relationship between CO₂ emissions, oil price volatility, renewable energy, and GDP. The analysis is categorized into two dimensions: within-dimension (Panel statistics) and between-dimension (group statistics). To ensure a comprehensive analysis, the results are reported for the Full Sample as well as the specific sub-groups of oil exporters and oil importers.

Table 4. Pedroni panel cointegration test results.

Test Statistic	Oil Exporters	Oil Importers	Full Sample
PANEL STATISTICS (Within-dimension)			
Panel V-Statistic	2.617 ** (0.030)	1.892 * (0.058)	2.234 ** (0.041)
Panel Rho-Statistic	−1.098 ** (0.048)	−0.876 * (0.067)	−1.234 ** (0.035)
Panel PP-Statistic	−2.872 *** (0.043)	−2.145 ** (0.049)	−2.987 *** (0.021)
Panel ADF-Statistic	−2.213 ** (0.022)	−1.987 ** (0.047)	−2.456 ** (0.018)
Group Statistics (Between-dimension)			
Group Rho-Statistic	−0.627 ** (0.046)	−0.534 * (0.078)	−0.789 ** (0.039)
Group PP-Statistic	−3.499 *** (0.018)	−2.876 *** (0.025)	−3.234 *** (0.015)
Group ADF-Statistic	−2.134 ** (0.018)	−1.876 ** (0.041)	−2.187 ** (0.022)

Note: *p*-values are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

The test results for cointegration are in support of the existence of strong evidence against the null hypothesis of no cointegration. Most of the test statistics are significant at 5% or higher for the two country groups, and this confirms the presence of long-run stable relationships between renewable energy consumption, oil price volatility, GDP, and CO₂ emissions. This supports the use of the P-ARDL method with error correction modeling.

4.3. P-ARDL Model Estimation Results

Based on the Akaike Information Criterion (AIC), which was used to evaluate various lag combinations to ensure model parsimony, we identified the P-ARDL(1, 1, 1, 1) specification as the optimal model for both country groups. This choice ensures a balance between statistical fit and the preservation of degrees of freedom, effectively capturing the dynamic relationships without over-parameterization. Following the empirical framework of Mongo et al. [25], Table 5 presents the estimation results partitioned into long-run elasticities and short-run dynamics, complemented by the error correction mechanism (ECM). This dual presentation allows for a comprehensive understanding of how CO₂ emissions adjust to shocks in oil price volatility, renewable energy consumption, and economic growth over different time horizons, ensuring that short-run deviations are reconciled with the long-run equilibrium.

Table 5. P-ARDL estimation results—renewable energy consumption.

Variable	Oil-Exporting Countries	Oil-Importing Countries
SHORT-RUN COEFFICIENTS		
Δ(OIL PRICE VOLATILITY)	−0.029 (0.034) [−0.86]	0.008 (0.037) [0.23]
Δ(LOG GDP)	0.017 (0.282) [0.06]	0.718 ** (0.341) [2.11]
Δ(CO ₂ EMISSIONS)	0.145 (0.089) [1.63]	−0.087 (0.076) [−1.14]
LONG-RUN COEFFICIENTS		
OIL PRICE VOLATILITY	0.073 ** (0.033) [2.24]	−0.012 (0.036) [−0.33]
LOG(GDP)	0.084 (0.055) [1.52]	0.127 ** (0.056) [2.26]
CO₂ EMISSIONS	0.234 * (0.124) [1.89]	−0.165 * (0.098) [−1.68]
ERROR CORRECTION TERM		
ECM(−1)	−0.359 *** (0.067) [−5.36]	−0.215 *** (0.058) [−3.71]

Table 5. Cont.

Variable	Oil-Exporting Countries	Oil-Importing Countries
DIAGNOSTIC STATISTICS		
R-SQUARED	0.110	0.094
ADJUSTED R-SQUARED	0.095	0.079
OBSERVATIONS	330	330
COUNTRIES	15	15
DIAGNOSTIC TESTS		
BREUSCH–GODFREY LM	2.45 (0.294)	3.12 (0.210)
BREUSCH–PAGAN	12.61 (0.122)	15.33 (0.053)
JARQUE–BERA	11.08 (0.070)	13.27 (0.029)

Note: Standard errors are reported in parentheses () and t-statistics in brackets []. *p*-values are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

4.4. Interpretation of Results

The estimates of P-ARDL reveal a striking contrast between oil-exporting and oil-importing countries in their response to volatility in oil prices.

- Oil-Exporting Countries:

The most significant finding is the positive and statistically significant long-run coefficient for oil price volatility (0.073, $p < 0.05$). This indicates that an increase in oil price volatility by one unit increases renewable energy consumption by 0.073 percentage points in the long run. This finding confirms the economic diversification hypothesis, suggesting that oil-exporting nations mitigate the risks of income volatility by strategically increasing investments in renewable energy sources.

This finding is in agreement with the work of Nchofoung [2], which determined that oil price shocks have differential effects on the energy transition among African countries, with net exporters experiencing different patterns. Our work builds on this by demonstrating that it is not merely the volatility component and indeed price levels that are accountable for this response, according to the work of Tambari et al. [4], which determined complex relationships among oil price dynamics and renewable energy investments in African oil-exporting nations.

The negative and large error correction coefficient (−0.359) shows that approximately 35.9% of whatever is the discrepancy from the long-run equilibrium is adjusted in a one-year horizon. The adjustment speed is quite rapid, which means that oil-exporting countries are highly sensitive to disequilibrium conditions.

- Oil-Importing Countries:

Conversely, oil-importing countries react neither in the short nor long term to uncertainty about the price of oil. The long-run coefficient is not statistically significant but close to zero (−0.012, $p > 0.10$). Instead, economic growth is the most critical factor determining the adoption of renewable energy, with both the short-run (0.718, $p < 0.05$) and long-run (0.127, $p < 0.05$) coefficients being positive and statistically significant.

This result is in line with that of Mukhtarov [3] for China, where GDP was a significant factor in the use of renewable energy, validating the results of Murshed and Tanha [7] that economic capacity has the highest determinability of renewable energy consumption in oil-importing South Asian economies.

The error correction coefficient (−0.215) implies a 21.5% slowdown in adjustment annually, such that oil-importing countries adjust later toward long-run equilibrium levels.

- Control Variables:

CO₂ emissions have varying effects of concern. For oil-exporting countries, greater CO₂ emissions are associated with increased consumption of renewable energy

(0.234, $p < 0.10$), which can be a reflection of environmental policy measures. The results for oil-importing countries (negative -0.165 , $p < 0.10$) could imply that countries with greater CO₂ emissions have greater limitations in using renewable energy.

4.5. Robustness Checks

To ensure the reliability of our findings, several robustness checks were conducted. First, alternative volatility specifications were tested using various GARCH-family models (including EGARCH and TGARCH). The results remained consistent across models, with the conditional volatility of oil prices showing a persistent and significant impact on renewable energy consumption, regardless of the error distribution assumption.

Second, we performed subsample analyses to account for the potential structural break of the 2014–2016 oil price collapse. The results for both the pre-crisis (2002–2014) and post-crisis (2015–2023) periods confirm the stability of our long-run coefficients, although the speed of adjustment (ECT) was found to be slightly faster in the post-crisis era for oil importers.

Finally, alternative lag specifications, specifically P-ARDL(2, 1, 1, 1) and P-ARDL(1, 2, 1, 1), were estimated. As shown in the summary discussion, these alternative models yielded coefficients for GDP and oil volatility that are identical in sign and significance to our primary (1, 1, 1, 1) model, with variations in magnitude of less than 5%. This consistency reaffirms that our baseline results are not sensitive to lag selection or specific sub-periods.

5. Discussion

5.1. Economic Interpretation

Empirical findings largely confirm the hypothesis that oil price volatility affects the renewable energy transition in a different manner in oil-exporting and oil-importing countries. The positive long-term association found for oil-exporting countries conforms to the economic diversification theory proposed by several academics [2].

For oil-exporting countries, volatility is an awakening call highlighting the risks of excessive dependence on oil income. This concurs with Nchofoung [2], who found that shocks in the price of oil have differential effects on the energy transition in African countries, whose net exporters exhibit different patterns. The current findings contribute to this effect by showing that it is the volatility dimension, rather than price levels per se, that causes this reaction.

This interpretation is supported by real policy development. Saudi Arabia (Vision 2030), the UAE (Energy Strategy 2050), and Norway (divestment of Government Pension Fund Global from oil shares) all embarked on substantial renewable energy initiatives following enhanced oil price volatility [3].

For oil-importing countries, the absence of a significant volatility effect means that oil-importing countries consider oil price shocks as outside shocks to be managed, rather than as fundamental in terms of energy system change. Instead, their investments in renewables are determined on the basis of economic capacity (GDP growth) and long-term strategic requirements, and not short-term market volatility.

5.2. Comparison with the Previous Literature

Our findings not only contribute to but also extend and refine existing works. First, in terms of the positive influence on renewable energy adoption in oil-exporting countries, our results are in agreement with those in a recent study by Tambari et al. [4], where complex and non-linear relationships were established in terms of oil price and investment

in renewable energy in African countries. However, in terms of systematization, our work differs.

However, unlike what is expected, there is little evidence that oil volatility influences oil-importing countries. This is unlike earlier studies that found that oil prices have a significant impact on renewable energy uptake [7]. This might have arisen due to our emphasis on oil price volatility and our recent dataset that reflects international experience with the increasing maturity of renewable energies.

Therefore, it was no surprise when our findings indicated that renewable energy adoption in oil-importing countries was mainly driven by GDP growth. This agrees with the strong GDP effects reported in renewable energy consumption in China by Mukhtarov [3]. Such would, therefore, indicate that in the case of oil-importing countries, the energy transition is an income-driven phenomenon rather than a response to the dramatic changes that this oil market has experienced of late. This contrasts with Chen et al. [5], who documented significant volatility effects in financial markets that do not necessarily translate into real energy investments.

5.3. Policy Implications

The differential responses to oil price volatility have distinct and paramount policy implications for each of the two country groups. Policymakers for oil-exporting countries would best utilize high-volatility periods to build political support for renewable investment by taking advantage of economic uncertainty as a compelling justification for diversification. These nations ought to have stabilization instruments, such as renewable energy investment funds that are invested at peak prices and redeemed during low-price periods, thereby establishing a counter-cyclical course of investment. These renewable energy investments should also be fully coordinated with overall fiscal diversification strategies, possibly through sovereign wealth funds or dedicated energy transition funds. Conversely, in oil-importing countries, where adopting renewable energy is finally a matter of economic resources, environmental protection policies favoring sustainable economic development should have precedence because they indirectly help facilitate the energy transition. Since these nations are less sensitive to short-term oil price shocks, they can implement decisive long-term policies toward renewables, making R&D and technology deployment investments on the basis of rising economic growth and not merely as an oil price risk hedge.

5.4. Limitations and Future Research

There are also limitations to this study. To begin with, this study employs data for renewable energy consumption as a composite variable. This might overlook the fact that oil prices might affect different kinds of renewable energy differently. Subsequent studies might attempt to cover this by including a variety of renewable energy types.

Secondly, there was a lack of explicit modeling of policy interventions in terms of subsidies on renewables, carbon pricing, and tariffs. Such policies may play a mediating role in shaping the relationship between oil price volatility and renewables.

Thirdly, this study is based on national-level data. Regional-level analysis could provide further insights. Moreover, the analysis excludes the case where the government directly invests financially in the adoption pattern.

Future research directions include:

- Examining the role of financial market development in mediating oil price volatility effects.
- Investigating the impact of renewable energy technology costs on the volatility–adoption relationship.

- Analyzing the interaction between oil price volatility and climate change policy stringency.
- Extending the analysis to include other fossil fuel price volatilities (natural gas, coal).

6. Conclusions

This study provides the first comprehensive comparative analysis of oil price volatility effects on renewable energy shifts with the Panel ARDL method for oil exporters and importers. The evidence reveals a fundamental asymmetry between the two groups of countries in their response to uncertainty in oil prices.

For oil-exporting countries, volatility in oil prices is a motivation for the utilization of renewable energy, and there is a statistically and positively significant long-run relation. This supports the economic diversification hypothesis in which the volatility in the primary source of revenue stimulates the utilization of alternative energy sources as a risk-reduction measure. The speed of adjustment, at 35.9% per year, is fairly rapid and indicates that oil-exporting countries respond very sensitively to disequilibrium conditions.

Conversely, oil-importing economies react to the volatility in oil prices in a neutral way, and their economic growth is primarily responsible for leading them towards a shift to renewable energy. This suggests that for such countries, the energy transition is a more income-based phenomenon rather than a response to compensate for oil market behavior. The lower adjustment rate of 21.5% per year indicates adjustment at a slower rate towards a long-run equilibrium.

These findings have important policy implications for international climate policy and energy security agendas. They suggest that the path to a sustainable energy future is not a single-size-fits-all solution for countries but depends on their position in international oil markets. For oil exporters, volatility is a chance to mobilize consensus for diversification. For oil importers, long-run economic growth is the foundation for investments in renewable energy.

This study contributes to the literature by demonstrating that volatility, rather than just price levels, matters for energy transition decisions and that this significance varies systematically between oil producers and consumers. As the global energy system continues to evolve, understanding these differential reactions will be crucial for the development of successful policies to accelerate the transition to sustainable energy systems.

This paper also highlights the necessity to control for country heterogeneity in energy economics research. Treating all countries as homogeneous units may lead to misleading inferences about the drivers of the energy transition. Future research should continue to explore these heterogeneous responses with respect to different country characteristics and institutional settings.

In short, oil price volatility can indeed drive the energy transition, but its effect is concentrated in oil-supplier countries where volatility is a strong catalyst for diversifying the economy. In oil-purchasing countries, the transition runs on a different track, driven first and foremost by economic growth rather than oil market dynamics. This more nuanced understanding of volatility effects provides valuable insights for policymakers who have to manage the complex demands of the energy transition in a volatile world.

Author Contributions: Conceptualization, A.B. (Achouak Barguelli) and A.B. (Adel Benhamed); methodology, A.B. (Achouak Barguelli) and A.B. (Adel Benhamed); software, A.B. (Achouak Barguelli) and A.B. (Adel Benhamed); validation, A.B. (Achouak Barguelli) and A.B. (Adel Benhamed); formal analysis, A.B. (Achouak Barguelli) and A.B. (Adel Benhamed); investigation, A.B. (Achouak Barguelli) and A.B. (Adel Benhamed); resources, A.B. (Achouak Barguelli) and A.B. (Adel Benhamed); data curation, A.B. (Achouak Barguelli) and A.B. (Adel Benhamed); writing—original draft preparation, A.B. (Achouak Barguelli) and A.B. (Adel Benhamed); writing—review and editing, A.B. (Achouak Barguelli) and A.B. (Adel Benhamed); visualization, A.B. (Achouak Barguelli) and

A.B. (Adel Benhamed); supervision, A.B. (Achouak Barguelli) and A.B. (Adel Benhamed); project administration, A.B. (Achouak Barguelli) and A.B. (Adel Benhamed); funding acquisition, A.B. (Achouak Barguelli) and A.B. (Adel Benhamed). All authors have read and agreed to the published version of the manuscript.

Funding: The authors acknowledge the Deanship of Scientific Research at King Faisal University for the financial support under Grant N: KFU260691.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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

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