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# The Dynamic Trade-Off between Trade Openness and Renewable Energy Share in Indonesia

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**Abstract:** This study examines the dynamic trade-off in the relationship between trade openness and the renewable energy share in Indonesia by distinguishing between short-run and long-run dynamics. Using annual data from 1990 to 2021, the study employs the Autoregressive Distributed Lag (ARDL) approach. The results reveal a clear reversal across time horizons: trade openness is negatively and significantly associated with the renewable energy share in the short run, while the relationship becomes positive and significant in the long run. The negative short-run relationship is consistent with the scale-effect mechanism, whereby trade-related economic expansion may increase energy demand that is not immediately matched by renewable energy utilization. In contrast, the positive long-run relationship is consistent with technique-related adjustments associated with access to cleaner technologies, energy-efficient capital goods, and knowledge that require time to be adopted and implemented. These mechanisms provide a theoretical interpretation rather than being directly identified by the empirical model. The findings highlight the importance of coordinating trade and energy policies to address short-run energy pressures while strengthening Indonesia's capacity to benefit from longer-term opportunities associated with international integration.

**Keywords:** trade openness, renewable energy share, dynamic trade-off, ARDL, Indonesia

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## INTRODUCTION

Climate change and the commitments of many countries to achieve Net Zero Emissions have made the transition from fossil fuels to cleaner energy sources one of the key priorities of the global development agenda. However, the continued growth in global energy demand remains a major challenge to this transition. The International Energy Agency (IEA, 2025) reported that global energy demand increased by 2.2% in 2024, while energy-related $CO_2$ emissions reached 37.8 gigatonnes. These developments further reinforce the importance of expanding renewable energy to reduce dependence on fossil fuels and support a more sustainable energy system. (IRENA, 2025) reported that global renewable energy capacity increased by 585 GW in 2024, accounting for approximately 92.5% of total power capacity additions worldwide during that year.

Although renewable energy development has progressed rapidly at the global level, its expansion is closely linked to various economic factors that influence a country's capacity to undertake an energy transition. One factor that has received increasing attention is openness to international trade. In the trade–environment literature, the relationship between trade and environmental outcomes can be explained through three main mechanisms: the scale effect, composition effect, and technique effect (Copeland & Taylor, 2003). The scale effect arises when increased trade activity expands production and economic activity, thereby increasing energy demand. The composition effect occurs when trade changes the structure of economic activity toward sectors with different levels of energy intensity and environmental characteristics. Meanwhile, the technique effect is associated with changes in technology and production efficiency, including access to cleaner technologies, knowledge, and capital goods from other countries. In the context of the energy transition, these three mechanisms suggest that trade openness can influence patterns of energy use through different channels, meaning that its relationship with renewable energy is not necessarily simple or unidirectional.

The relationship between trade openness and renewable energy is particularly relevant in the Indonesian context. As a developing economy that has become increasingly integrated into the global economy, Indonesia exhibits a relatively high degree of economic openness. In 2024, exports of goods and services accounted for approximately 21.75% of gross domestic product (GDP), while imports represented 19.58%, bringing total trade to approximately 41.33% of GDP (World Bank, 2024). At the same time, Indonesia received approximately US$24.21 billion in foreign direct investment (UNCTAD, 2025). These substantial trade and investment flows illustrate Indonesia's increasing integration into the global economy and its exposure to the economic and technological channels associated with international openness.

However, the development of renewable energy in Indonesia presents a more complex picture. Data from the World Development Indicators show that renewable energy consumption as a share of total final energy consumption declined from approximately 59.2% in 1990 to 20.2% in 2021 (World Bank, 2025). Importantly, this indicator includes both modern renewable energy sources and traditional uses of biomass. Therefore, the relatively high share observed in the early part of the sample should not be interpreted solely as evidence of greater modern renewable-energy deployment, while its decline over time does not necessarily imply a decline in renewable energy consumption in absolute terms.

Despite these measurement considerations, Indonesia's broader energy system remains highly dependent on fossil fuels. In 2023, coal, oil, and natural gas accounted for approximately 40.46%, 30.18%, and 16.28% of Indonesia's primary energy mix, respectively (Kementerian Energi dan Sumber Daya Mineral, 2024). Although the primary energy mix is conceptually different from the renewable energy share in total final energy consumption used in this study, these recent figures illustrate the broader energy context in which Indonesia's renewable energy transition continues to take place. Fossil-fuel dependence is also evident in the electricity sector, where coal accounted for approximately 62%, or 217 TWh, of total electricity generation in 2023 (Ember, 2024). Taken together, these recent energy-system conditions highlight the continued importance of fossil fuels in Indonesia and provide relevant context for understanding the trade–renewable energy relationship examined in this study.

Against this background, Indonesia's increasing integration into the global economy has occurred alongside substantial changes in the renewable energy share and continued dependence on fossil energy. This raises an important question regarding how trade openness is associated with the renewable energy share in Indonesia. The relationship may not be uniform over time because the mechanisms operating in the short run may differ from those emerging through longer-term adjustment processes. In the short run, the scale effect may become particularly relevant, as increased trade activity can stimulate the expansion of production, industrial activity, transportation, and logistics, thereby increasing energy demand (Elfaki et al., 2021; Wang & Dong, 2023). When the energy system remains dominated by coal, oil, and natural gas, additional energy demand can be more readily met by sources that are already well established within the existing system. Consequently, increased trade activity may not immediately raise the renewable energy share and may instead reinforce the relative role of fossil energy in meeting additional demand.

In contrast, the potential benefits associated with the technique and composition effects may require a longer adjustment process. Greater trade openness can facilitate access to low-carbon technologies, more efficient capital goods, knowledge, and innovations from abroad. Economic interaction with countries possessing more advanced technological capabilities may also increase opportunities for the transfer and adoption of green technologies that support renewable energy utilization (Dong et al., 2023). However, these benefits may not materialize immediately because imported technologies and knowledge must be absorbed, adapted, and implemented through investment, clean-energy infrastructure development, improvements in domestic technological capabilities, and adequate policy support (Coronado et al., 2026; Moïsé & Tresa, 2025). Trade may also gradually alter the composition of economic activity across sectors with different energy intensities, although the direction of this relationship depends on the structure of the economy. These differences in adjustment processes suggest that the relationship between trade openness and the renewable energy share may evolve over time rather than remain constant across short-run and long-run horizons.

The possibility of such differences is consistent with the mixed findings reported in the existing literature. Hussein & Abdullahi (2024) and Huang & Liu (2022) reported a positive and statistically significant relationship between trade openness and renewable energy consumption in both the short and long run. In contrast, Somoye et al. (2022) reported a negative and statistically significant short-run relationship, while the long-run relationship was statistically insignificant. Alam & Murad (2020), meanwhile, found that the positive relationship between trade and renewable energy was statistically insignificant in the short run but became significant in the long run. A clearer reversal in the direction of the relationship was identified by Akhi et al. (2024), who reported a negative and statistically significant relationship in the short run that became positive and statistically significant in the long run. Furthermore, Qamruzzaman & Jianguo (2020) and Maluleke (2024) demonstrated that the relationship between trade and renewable energy may be asymmetric, implying that increases and decreases in trade openness do not necessarily generate identical responses. Taken together, these studies demonstrate substantial heterogeneity in the trade–renewable energy relationship across countries and time horizons. However, the existing literature has largely focused on identifying the direction and significance of short-run and long-run relationships, with relatively limited attention to why these relationships may change as economic adjustment unfolds over time. In particular, the temporal differences in the trade–renewable energy relationship have not been sufficiently interpreted through the scale, composition, and technique effects established in the trade–environment literature. This leaves an important theoretical gap in understanding whether differences in the adjustment processes associated with these mechanisms can help explain why the relationship observed in the short run may differ from that emerging in the long run.

Based on this gap, this study employs the concept of a dynamic trade-off to explain potential changes in the relationship between trade openness and the renewable energy share over the course of economic adjustment. In this study, the dynamic trade-off refers to a condition in which pressures associated with the expansion of economic activity and energy demand may emerge relatively quickly, whereas potential benefits associated with efficiency improvements, technology adoption, and changes in economic structure may require a longer adjustment process to materialize. Within the trade–environment framework, the scale, composition, and technique effects provide a theoretical basis for interpreting why the observed relationship may differ across time horizons, without assuming that these mechanisms are directly identified by the empirical model or operate exclusively within a particular time horizon. Indonesia provides a relevant setting for examining this dynamic because its increasing integration into the global economy coexists with persistent dependence on fossil fuels and substantial changes in the renewable energy share over the sample period. The Indonesian case therefore offers broader insights into how the potential pressures and benefits associated with trade openness may evolve differently over the course of the energy transition.

In addition to trade openness, this study incorporates Foreign Direct Investment (FDI), Industrial Value Added (IVA), and Electric Power Consumption (EPC) as control variables because each may be associated with changes in the renewable energy share. FDI can serve as a channel for capital and technology inflows that may facilitate renewable energy utilization, although its role can vary depending on the sectors receiving the investment (Doytch & Narayan, 2016). Industrial development is closely associated with energy demand and consumption, implying that changes in Industrial Value Added may be associated with the relative contribution of renewable energy to final energy consumption (Ben Jebli et al., 2020). Electric Power Consumption, measured in kWh per capita and transformed into its natural logarithm (LnEPC) for estimation, is included to account for changes in electricity consumption per capita that may be associated with the renewable energy share.

Based on these considerations, this study examines the short-run and long-run relationship between trade openness and the renewable energy share in Indonesia using the ARDL framework. Rather than treating differences between short-run and long-run estimates merely as an empirical feature of the model, the study interprets these dynamics through the concept of a dynamic trade-off grounded in the scale, composition, and technique effects of the trade–environment framework. In doing so, the study contributes to the broader trade–energy transition literature by examining whether the relationship between trade openness and the renewable energy share differs across time horizons and by providing a theoretical framework for interpreting the observed pattern. The findings may also provide an empirical basis for considering how trade and energy policies can address short-run energy pressures while supporting longer-term technological and structural adjustments toward greater renewable energy utilization.

## METHOD

This study employs a quantitative approach using annual time-series data for Indonesia over the period 1990–2021. The sample period is determined by the availability of consistent observations across all variables included in the empirical model, with 2021 representing the latest year for which complete data were jointly available when the dataset was constructed. The dependent variable is Renewable Energy Share (RES), measured using the World Development Indicators (WDI) indicator “Renewable energy consumption (% of total final energy consumption)” (EG.FEC.RNEW.ZS). This indicator measures the share of renewable energy in total final energy consumption. The numerator includes the direct consumption of renewable energy sources together with the final consumption of electricity and heat estimated to have been generated from renewable sources, while the denominator is total final energy consumption of all energy products. The measure includes both modern renewable energy sources and traditional uses of biomass. Therefore, RES represents the relative contribution of renewable energy to final energy consumption rather than its absolute level of consumption, and relatively high values in the earlier part of the sample should not be interpreted solely as evidence of modern renewable energy deployment.

The main independent variable is trade openness (Trade), measured using "Trade (% of GDP)" (NE.TRD.GNFS.ZS), defined as the sum of exports and imports of goods and services as a percentage of gross domestic product (GDP). This measure captures Indonesia's overall degree of openness to international trade and is used to examine the aggregate relationship between trade openness and the renewable energy share. The study also includes three control variables. Foreign Direct Investment (FDI) is measured using "Foreign direct investment, net inflows (% of GDP)" (BX.KLT.DINV.WD.GD.ZS), which represents net investment inflows from foreign investors as a percentage of GDP. Industrial Value Added (IVA) is measured using "Industry (including construction), value added (annual % growth)" (NV.IND.TOTL.KD.ZG), which represents the annual percentage change in industry value added at constant prices and captures changes in industrial activity. Electric Power Consumption (EPC) is measured using "Electric power consumption (kWh per capita)" (EG.USE.ELEC.KH.PC), which represents electricity consumption from power plants and combined heat and power plants after accounting for transmission, distribution, and transformation losses and own use by heat and power plants. For estimation, EPC is transformed into its natural logarithmic form (LnEPC), allowing changes in electricity consumption per capita to be interpreted in proportional terms. All variables are obtained from the World Development Indicators (World Bank). The baseline empirical model is specified as follows:

$$RES_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i RES_{t-i} + \sum_{j=0}^{q_1} \beta_j Trade_{t-j} + \sum_{j=0}^{q_2} \gamma_j FDI_{t-j} + \sum_{j=0}^{q_3} \delta_j IVA_{t-j} + \sum_{j=0}^{q_4} \theta_j LnEPC_{t-j} + \varepsilon_t$$

The Autoregressive Distributed Lag (ARDL) approach is employed because it allows short-run and long-run relationships to be examined within a unified estimation framework and can accommodate variables integrated of order I(0), I(1), or a combination of both, provided that none of the variables is integrated of order I(2) (Cho et al., 2023; Kripfganz & Schneider, 2023). Accordingly, prior to model estimation, the stationarity properties of each variable are examined using the Augmented Dickey–Fuller (ADF) unit-root test. Given the relatively small annual sample, the lag structure is restricted to maintain model parsimony and avoid excessive parameterization, and the baseline ARDL specification is selected using the Bayesian Information Criterion (BIC). To account for possible structural changes over the 1990–2021 period, the stationarity analysis is complemented by the Zivot–Andrews unit-root test, which allows for an endogenously determined structural break in both the intercept and trend.

The existence of a long-run relationship among the variables is subsequently examined using the ARDL bounds-testing approach. The baseline bounds test is estimated with an unrestricted intercept and no deterministic trend. Given the small effective estimation sample, finite-sample critical values corresponding to the model specification and number of regressors are used for inference. Both the F-bounds statistic and the t-bounds statistic are reported. The F-bounds test evaluates the joint significance of the lagged level variables, whereas the t-bounds test evaluates the significance of the lagged dependent variable in the conditional error-correction representation. For both tests, the test statistics are evaluated against the corresponding I(0) and I(1) critical bounds, with outcomes classified as evidence against the null hypothesis, insufficient evidence to reject the null hypothesis, or inconclusive depending on their position relative to the bounds. When evidence of a long-run relationship is obtained, the long-run coefficients are estimated from the ARDL model, while short-run dynamics are examined through the Error Correction Model (ECM). A negative and statistically significant error correction term, ECT(−1), indicates adjustment toward the long-run equilibrium, with its magnitude representing the proportion of short-run disequilibrium corrected within one period (Kripfganz & Schneider, 2023).

To provide stronger statistical evidence on the short-run relationship, the analysis reports the individual short-run coefficients together with their 95% confidence intervals. The cumulative short-run effect of trade openness is calculated as the sum of its contemporaneous and lagged first-difference coefficients (Chtioui & Boushib, 2026). In addition, a joint Wald test is conducted to assess whether the individual short-run Trade coefficients are jointly statistically significant. Confidence intervals are also reported for the cumulative short-run effect, the key long-run coefficient, and the error-correction term.

The reliability of the estimated model is further assessed through diagnostic tests for serial correlation, heteroskedasticity, and functional-form misspecification, while parameter stability is examined using the CUSUM test. Robustness is assessed in two stages. First, the baseline ARDL model is re-estimated using alternative information criteria and maximum lag lengths to evaluate sensitivity to model-selection settings. Second, substantive robustness checks are conducted by incorporating the principal structural breaks identified by the Zivot–Andrews analysis and by replacing aggregate trade openness with export and import openness separately. These robustness checks assess whether the negative short-run and positive long-run pattern remains consistent across alternative model-selection settings and substantive specifications. The empirical analysis is interpreted in terms of dynamic associations and long-run equilibrium relationships rather than as evidence of causal effects.

## RESULTS AND DISCUSSION

### Research Results

The stationarity test results using the Augmented Dickey–Fuller (ADF) test, presented in Table 1, show that Industrial Value Added (IVA) is stationary at level and is therefore integrated of order I(0). Meanwhile, Renewable Energy Share (RES), Trade Openness (Trade), Foreign Direct Investment (FDI), and Electric Power Consumption (LnEPC) become stationary after first differencing and are thus integrated of order I(1). Accordingly, the ADF results indicate that all variables are integrated either of order I(0) or I(1), with none integrated of order I(2). This integration pattern satisfies the requirements for applying the ARDL approach.

To account for possible structural changes during the study period, the stationarity analysis was further complemented by the Zivot–Andrews unit root test, which allows for an endogenously determined structural break in both the intercept and trend. The results again show that none of the variables is integrated of order I(2). However, a difference emerges for Trade. While the ADF test classifies Trade as I(1), the Zivot–Andrews test indicates that Trade is stationary at level, or I(0), after accounting for a structural break in 1998. This difference may arise because conventional unit root tests can be less effective in the presence of structural breaks, making tests that account for such breaks useful for validating the stationarity properties of the variables (Baidoo et al., 2023). Accordingly, the different results suggest that the integration classification of Trade is sensitive to the structural change around 1998 rather than representing contradictory evidence between the two tests. Since neither the ADF nor the Zivot–Andrews results indicate that any variable is integrated beyond I(1), the ARDL approach remains appropriate.

**Table 1.** Augmented Dickey–Fuller (ADF) Unit Root Test Results

| Variable | ADF Stat. | p-value | ADF Statistic (First Difference) | Prob. | Order of Integration |
|---|---|---|---|---|---|
| RES | -0.443 | 0.9026 | -4.446 | 0.0002 | I(1) |
| Trade | -1.434 | 0.5660 | -5.968 | 0.0000 | I(1) |
| FDI | -2.312 | 0.1682 | -3.916 | 0.0019 | I(1) |
| IVA | -3.888 | 0.0021 | - | - | I(0) |
| LnEPC | -1.952 | 0.3080 | -3.885 | 0.0021 | I(1) |

The identified break dates are concentrated around 1996–1998 for several explanatory variables, while RES exhibits a level break in 2005. Therefore, 1998 and 2005 were selected as the two principal break dates for the structural-break robustness specification. The year 1998 captures the common break period identified for Trade and FDI and is close to the breaks detected for IVA and LnEPC, whereas 2005 corresponds to the level break identified for RES. These break dates are subsequently incorporated into the robustness analysis reported in Table 7.

**Table 2.** Zivot–Andrews Unit Root Test Results with Structural Break

| Variable | ZA Statistic (Level) | Break Year | ZA Statistic (First Difference) | Break Year | Order of Integration |
|---|---|---|---|---|---|
| RES | -3.494 | 2005 | -7.080*** | 2009 | I(1) |
| Trade | -9.184*** | 1998 | - | - | I(0) |
| FDI | -3.547 | 1998 | -6.786*** | 2001 | I(1) |
| IVA | -5.318** | 1997 | - | - | I(0) |
| LnEPC | -4.372 | 1996 | -6.642*** | 1998 | I(1) |

Following the unit root tests, the baseline ARDL specification was selected using the Bayesian Information Criterion (BIC) with a maximum lag length of two to maintain a parsimonious model given the relatively small annual sample. The model selection procedure identified ARDL(1,2,0,0,0) as the optimal baseline specification, with 30 effective observations used in the estimation. The ARDL bounds test was subsequently conducted with an unrestricted constant and no deterministic trend, consistent with the baseline specification, which includes an intercept but does not impose a deterministic time trend. Given the small sample size, inference was based on the finite-sample critical values of (Kripfganz & Schneider, 2023). As reported in Table 3, the F-statistic of 5.827 exceeds the I(1) upper-bound critical value of 4.896 at the 5% significance level, providing evidence from the F-bounds test in favor of a long-run relationship. In contrast, the t-statistic of −3.476 lies between the corresponding I(0) and I(1) critical values of −2.924 and −4.108, respectively, indicating that the t-bounds test yields an inconclusive result. Nevertheless, the F-bounds result provides evidence of a long-run relationship based on the conventional bounds-testing decision rule. This inference is consistent with a substantial body of empirical ARDL research in which the existence of a long-run relationship is assessed primarily by comparing the F-statistic with the corresponding lower- and upper-bound critical values (Baidoo et al., 2023; Foye, 2023; Iritié & Tiémélé, 2023; Nagawa et al., 2020).

**Table 3.** ARDL Bounds Test Results

| Test | Stat. | I(0) Critical Value (5%) | I(1) Critical Value (5%) |
|---|---|---|---|
| F-bound | 5.827 | 3.406 | 4.896 |
| t-bound | −3.476 | −2.924 | −4.108 |

Following the evidence of a long-run relationship from the F-bounds test, the analysis proceeded to examine the long-run relationships and short-run dynamics. As presented in Table 4, Trade Openness has a positive and statistically significant long-run coefficient of 0.212. This indicates that a one-percentage-point increase in trade openness is associated with an approximately 0.212-percentage-point increase in the renewable energy share, holding other variables constant. Foreign Direct Investment (FDI) also exhibits a positive and statistically significant long-run relationship, with a coefficient of 1.069, implying that a one-percentage-point increase in FDI as a share of GDP is associated with an approximately 1.069-percentage-point increase in the renewable energy share. In contrast, Industrial Value Added (IVA) has a negative coefficient of −0.335 but is not statistically significant, providing insufficient empirical evidence of a systematic long-run relationship with the renewable energy share. Meanwhile, Electric Power Consumption (LnEPC) exhibits a negative and statistically significant long-run coefficient of −19.701. Since electric power consumption is expressed in natural logarithmic form while the dependent variable is measured in percentage points, a 1% increase in electric power consumption per capita is associated with an approximately 0.197-percentage-point decrease in the renewable energy share in the long run, ceteris paribus.

**Table 4.** Short-Run and Long-Run Estimation Results

| Horizon | Variable | Coefficient | Std. Error | t-stat | p-value | 95% Confidence Interval |
|---|---|---|---|---|---|---|
| Short Run | ΔTrade | -0.109 | 0.040 | -2.74 | 0.012 | [−0.191, −0.026] |
| Short Run | ΔTrade (-1) | -0.105 | 0.030 | -3.53 | 0.002 | [−0.167, −0.043] |
| Short Run | Cumulative effect of Trade | −0.214 | 0.065 | −3.28 | 0.003 | [−0.349, −0.078] |
| Long Run | Trade | 0.212 | 0.076 | 2.80 | 0.010 | [0.055, 0.369] |
| Long Run | FDI | 1.069 | 0.509 | 2.10 | 0.047 | [0.013, 2.124] |
| Long Run | IVA | -0.335 | 0.212 | -1.58 | 0.128 | [−0.774, 0.105] |
| Long Run | LnEPC | -19.701 | 1.250 | -15.77 | 0.000 | [−22.292, −17.109] |
| Adjustment | ECT(−1) | −0.522 | 0.150 | −3.48 | 0.002 | [−0.834, −0.211] |

***Note:*** *Cumulative short-run effect = ΔTrade + L.ΔTrade. Joint Wald test: F(2,22) = 6.24, p = 0.007.*

In the short run, the contemporaneous change in trade openness has a coefficient of −0.109 and is statistically significant (p = 0.012; 95% CI: −0.191 to −0.026). This result indicates that a one-percentage-point increase in trade openness is associated with an approximately 0.109-percentage-point decrease in the renewable energy share within the same period. At the first lag, the change in trade openness also exhibits a negative and statistically significant coefficient of −0.105 (p = 0.002; 95% CI: −0.167 to −0.043), indicating that a one-percentage-point increase in trade openness in the previous period is associated with an approximately 0.105-percentage-point decrease in the renewable energy share in the current period. The 95%

confidence intervals for both coefficients lie entirely below zero, further supporting the negative short-run association.

**Table 5.** Model Diagnostic Test Results

| Diagnostic Test | Testing Method | p-value | Decision |
|---|---|---|---|
| Serial Correlation | Breusch–Godfrey LM Test | 0.338 | No evidence of serial correlation |
| Heteroskedasticity | Breusch–Pagan/Cook–Weisberg Test | 0.590 | No evidence of heteroskedasticity |
| Model Specification | Ramsey RESET Test | 0.794 | No evidence of model misspecification |

To assess the overall short-run relationship, the cumulative short-run effect was calculated by summing the contemporaneous and lagged coefficients (Chtioui & Boushib, 2026). In addition, a joint Wald test was conducted to assess whether the individual short-run Trade coefficients are jointly statistically significant. The results show that the cumulative short-run effect of trade openness is −0.214 and statistically significant (p = 0.003; 95% CI: −0.349 to −0.078). The Wald test also rejects the null hypothesis that the contemporaneous and lagged short-run Trade coefficients are jointly equal to zero [F(2,22) = 6.24, p = 0.007]. Thus, the negative short-run relationship is supported not only by the individual coefficients but also by their cumulative effect and joint statistical significance. In contrast, the long-run coefficient of trade openness is positive and statistically significant (0.212; p = 0.010; 95% CI: 0.055 to 0.369). Taken together, these results provide stronger statistical evidence of a short-run–long-run sign reversal, which is interpreted in this study as a dynamic trade-off across time horizons.

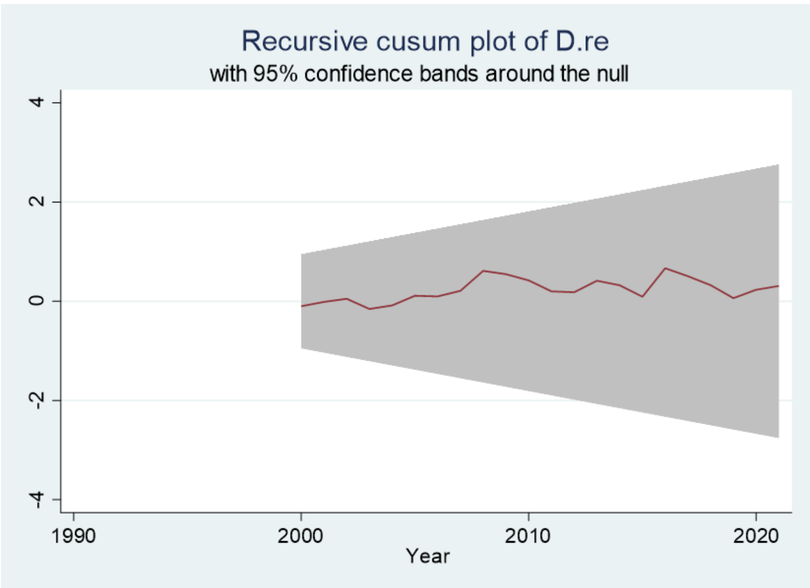


**Figure 1.** CUSUM Stability Test Results

The Error Correction Model (ECM) results further show that the coefficient of ECT(−1) is −0.522 and statistically significant (p = 0.002; 95% CI: −0.834 to −0.211). The negative and statistically significant ECT(−1) coefficient indicates an adjustment mechanism toward the long-run equilibrium, while the confidence interval lying entirely below zero further supports the direction of this adjustment process. The magnitude of the coefficient indicates that approximately 52.2% of the short-run disequilibrium is corrected within one year as the system adjusts toward its long-run equilibrium.

Furthermore, the diagnostic test results presented in Table 5 indicate that the ARDL model does not exhibit evidence of the diagnostic problems examined in this study. The Breusch–Godfrey LM test yields a p-value of 0.338, which exceeds the 5% significance level, indicating no evidence of serial correlation. The heteroskedasticity test produces a p-value of 0.590, likewise indicating no evidence of heteroskedasticity. Similarly, the Ramsey RESET test yields a p-value of 0.794, providing no evidence of functional-form misspecification. Overall, these results support the adequacy of the estimated ARDL model with respect to serial correlation, heteroskedasticity, and functional-form specification.

The stability of the model parameters was further evaluated using the CUSUM test. The results show that the CUSUM line remains within the 95% confidence bounds throughout the observation period, as illustrated in Figure 1. This finding indicates no evidence of parameter instability, suggesting that the estimated ARDL model parameters remain stable over the sample period. However, the parameter stability indicated by the CUSUM test does not preclude the presence or economic relevance of the structural breaks identified by the Zivot–Andrews test. Therefore, the identified break dates are explicitly considered in the structural-break robustness specification reported in Table 7.

**Table 6.** Robustness Checks Using Alternative Lag-Selection Specifications

| Specification | Baseline: BIC, Max Lag 2 | AIC, Max Lag 2 | BIC, Max Lag 3 |
|---|---|---|---|
| Selected ARDL | (1,2,0,0,0) | (1,2,0,0,0) | (1,2,0,0,0) |
| Long-run coefficient | 0.212*** (0.010) | 0.212*** (0.010) | 0.217** (0.016) |
| Cumulative short-run effect | −0.214*** (0.003) | −0.214*** (0.003) | −0.215*** (0.004) |
| Joint Wald F | 6.24 (0.007) | 6.24 (0.007) | 5.98 (0.009) |
| ECT(−1) | −0.522*** (0.002) | −0.522*** (0.002) | −0.519*** (0.003) |
| Bounds F | 5.827 | 5.827 | 5.559 |
| F-bounds (5%) | Cointegration | Cointegration | Cointegration |
| N | 30 | 30 | 29 |

To assess the robustness of the main findings to alternative model-selection settings, the ARDL model was re-estimated using different information criteria and maximum lag lengths. As presented in Table 6, the use of AIC with a maximum lag length of two selected the same ARDL(1,2,0,0,0) specification as the baseline model and produced identical results. When the maximum lag length was extended to three under BIC, the selected specification remained ARDL(1,2,0,0,0), with only minor changes in the estimated coefficients. Under this specification, the long-run coefficient of trade openness remains positive and statistically significant (0.217, $p = 0.016$), whereas the cumulative short-run effect remains negative and statistically significant (−0.215, $p = 0.004$). The short-run Trade coefficients are also jointly significant [$F(2,21) = 5.98$, $p = 0.009$], and the error-correction coefficient remains negative and statistically significant (−0.519, $p = 0.003$). The bounds-test F-statistic of 5.559 also exceeds the corresponding 5% upper-bound critical value of 4.942. Overall, these results indicate that the negative short-run and positive long-run relationship between trade openness and the renewable energy share is robust to the alternative model-selection settings considered.

**Table 7.** Robustness Checks Using Alternative Substantive Specifications

| Specification | Structural Breaks | Export | Import |
|---|---|---|---|
| Selected ARDL | (1,2,0,2,0,1,0) | (1,2,0,0,0) | (1,2,0,0,0) |
| Long-run coefficient | 0.211** (0.014) | 0.317** (0.012) | 0.491** (0.039) |
| Cumulative short-run effect | −0.186** (0.017) | −0.380*** (0.002) | −0.394** (0.022) |
| Joint Wald F | 12.94 (<0.001) | 7.13 (0.004) | 3.85 (0.037) |
| ECT(−1) | −0.774*** (<0.001) | −0.523*** (0.002) | −0.480*** (0.006) |
| Bounds F | 8.425 | 6.299 | 4.491 |
| F-bounds (5%) | Cointegration | Cointegration | Inconclusive |
| N | 30 | 30 | 30 |

To provide a more substantive assessment of robustness, the model was further re-estimated by accounting for the identified structural breaks and by replacing aggregate trade openness with export and import openness separately. As reported in Table 7, the structural-break specification preserves the main pattern, with a negative and statistically significant cumulative short-run Trade effect (−0.186, $p = 0.017$) and a positive and statistically significant long-run coefficient (0.211, $p = 0.014$). The short-run Trade coefficients are also jointly significant [$F(2,17) = 12.94$, $p < 0.001$]. A similar sign-reversal pattern is observed when exports and imports are considered separately. The cumulative short-run effects are negative and statistically significant for both exports (−0.380, $p = 0.002$) and imports (−0.394, $p = 0.022$), whereas their long-run coefficients are positive and statistically significant at 0.317 ($p = 0.012$) and 0.491 ($p = 0.039$), respectively. The Wald tests further indicate that the corresponding short-run coefficients are jointly significant in both specifications. The F-bounds test supports the existence of a long-run relationship in the structural-break and export specifications, whereas the import specification yields an inconclusive F-bounds result at the 5% significance level. Overall, these substantive robustness checks indicate that the negative short-run and positive long-run pattern remains consistent after accounting for structural breaks and when alternative measures of trade openness are used, although evidence of a long-run relationship is less conclusive for the import specification.

**Discussion**

The main finding of this study reveals a dynamic trade-off in the relationship between trade openness and the renewable energy share in Indonesia. In this study, the dynamic trade-off refers to a temporal pattern in which the relationship between trade openness and the renewable energy share differs across time horizons, with a negative relationship observed in the short run and a positive relationship emerging in the long run. The estimation results show that trade openness is negatively and statistically significantly associated with the renewable energy share in the short run, whereas the relationship becomes positive and statistically significant in the long run. This reversal indicates that the estimated trade–renewable energy relationship differs across time horizons rather than representing a time-invariant association, a pattern that also remains broadly consistent across the robustness specifications.

The negative short-run relationship between trade openness and the renewable energy share is consistent with the scale-effect mechanism within the trade–environment nexus. According to Copeland & Taylor (2003) , increased trade can expand the scale of economic and production activities, thereby increasing resource use and energy demand. In the context of Indonesia, greater trade activity may be accompanied by increased production, industrial activity, transportation, and logistics, which can raise energy demand within a relatively short period. Given Indonesia's continued reliance on fossil fuels across its energy system, additional energy demand associated with expanding economic activity may not be immediately matched by a proportional increase in renewable energy utilization. For contextual purposes, fossil fuels still accounted for approximately 86.9% of Indonesia's primary energy mix in 2023 (Kementerian Energi dan Sumber Daya Mineral, 2024). Although this primary-energy indicator is not directly comparable with the renewable energy share used as the dependent variable in this study, it illustrates the continued importance of fossil energy in Indonesia's broader energy system. Consequently, even if renewable energy consumption does not decline in absolute terms, faster growth in non-renewable energy consumption may reduce the relative share of renewable energy in total final energy consumption.

The negative short-run relationship between trade openness and the renewable energy share is consistent with the findings of Akhi et al. (2024) and Somoye et al. (2022), who also reported a negative and statistically significant short-run relationship between trade and renewable energy. This similarity suggests that a more supportive relationship between trade openness and renewable energy may not emerge immediately. In contrast, the findings of this study differ from those of Hussein & Abdullahi (2024) and Huang & Liu (2022), who reported a positive and significant short-run relationship. These differences suggest that the short-run relationship between trade openness and renewable energy may vary across countries depending on their economic characteristics, existing energy structures, and capacity to adjust to expanding trade activity.

In contrast to the short-run results, trade openness exhibits a positive and statistically significant relationship with the renewable energy share in the long run. This finding is consistent with the technique-effect mechanism within the trade–environment nexus, whereby greater trade openness may facilitate access to more efficient and environmentally friendly technologies and production techniques (Copeland & Taylor, 2003). In the Indonesian context, greater international integration may broaden opportunities for access to low-carbon technologies, clean energy equipment, energy-efficient capital goods, knowledge, and innovation from abroad. Trade interactions with countries possessing more advanced technological capabilities may also create opportunities for the transfer and adoption of green technologies that support renewable energy utilization (Dong et al., 2023). However, these potential benefits require time to materialize, as technologies and knowledge accessed through international integration need to be absorbed, adapted, and implemented through investment, infrastructure development, improvements in domestic technological capabilities, and adequate institutional and policy support (Coronado et al., 2026; Moïsé & Tresa, 2025). Therefore, the positive long-run relationship observed in this study is consistent with a gradual adjustment process in which technique-related mechanisms may become more relevant over time and potentially offset the pressures associated with expanding energy demand.

The composition effect may also be relevant, as trade openness can alter the sectoral structure of economic activity toward industries with different energy intensities and renewable energy requirements. However, the present model does not directly examine changes in the sectoral composition of trade or production. Therefore, while composition-related adjustments may form part of the broader trade–energy relationship, their contribution to the observed short-run–long-run reversal cannot be separately identified from the current estimates.

The positive long-run relationship between trade openness and the renewable energy share is consistent with the findings of Alam & Murad (2020), Hussein & Abdullahi (2024), and Huang & Liu (2022). However, the pattern most closely resembling the findings of this study is reported by Akhi et al. (2024), who identified a shift from a negative and significant short-run relationship to a positive and significant long-run relationship. In contrast, Somoye et al. (2022) found that the negative short-run relationship became statistically insignificant in the long run. These differences indicate that the relationship between trade openness and renewable energy may evolve differently across countries and time horizons. In the Indonesian context, the observed reversal from a negative short-run relationship to a positive long-run relationship reflects the dynamic trade-off identified in this study, characterized by a negative short-run association and a positive long-run association.

The persistence of this sign-reversal pattern after accounting for structural breaks and when export and import openness are examined separately further suggests that the observed temporal pattern is not solely driven by the aggregate trade measure or the identified structural changes. However, the inconclusive F-bounds result for the import specification warrants some caution in interpreting the import-based long-run relationship.

In addition to trade openness, the long-run estimation results show that the control variables have different relationships with the renewable energy share. Foreign Direct Investment (FDI) exhibits a positive and statistically significant relationship with the renewable energy share. This positive association may be consistent with potential capital, technology, and knowledge inflows associated with foreign investment, although its magnitude and direction may depend on the sectors receiving the investment (Doytch & Narayan, 2016). Industrial Value Added (IVA) has a negative but statistically insignificant coefficient, providing insufficient empirical evidence of a systematic relationship between industrial activity and the renewable energy share in this model. Meanwhile, Electric Power Consumption (LnEPC) exhibits a negative and statistically significant relationship with the renewable energy share. This result indicates that increases in electricity consumption per capita are associated with a lower renewable energy share in the long run. Given Indonesia's electricity system, in which fossil fuels continue to play a substantial role, growth in electricity consumption may not necessarily be accompanied by a proportional expansion in renewable energy utilization. Importantly, this result provides additional context for the positive long-run relationship between trade openness and the renewable energy share: a more supportive long-run association with trade openness may coexist with pressures arising from increasing electricity demand. Thus, greater trade openness alone may not be sufficient to increase the renewable energy share if rising electricity consumption is not accompanied by a proportional expansion in renewable energy utilization.

The identified dynamic trade-off has important implications for Indonesia's trade and energy policies. In the short run, the negative association suggests the importance of coordinating greater international integration with energy policies aimed at limiting the extent to which additional energy demand is met by fossil fuels. Trade policy should therefore be coordinated with energy policies that accelerate the availability and utilization of renewable energy, particularly in trade-intensive sectors where energy demand may increase alongside expanding economic activity. In the long run, the positive relationship between trade openness and the renewable energy share highlights the importance of strengthening Indonesia's capacity to benefit from opportunities associated with international integration, including access to low-carbon technologies, energy-efficient capital goods, knowledge, and clean-energy investment. Policies that strengthen domestic technological capabilities, renewable energy infrastructure, and the capacity to adopt and utilize cleaner technologies may help accelerate this adjustment process. Thus, from this perspective, the findings do not imply that trade should be restricted in response to the observed short-run negative association. Rather, they point to the importance of managing the energy implications of expanding economic activity while strengthening the conditions under which international integration can support renewable energy utilization over the longer term.

**CONCLUSIONS**

This study examines the short-run and long-run relationship between trade openness and the renewable energy share in Indonesia using the ARDL approach. The findings reveal a dynamic trade-off, whereby the relationship between trade openness and the renewable energy share differs across time horizons. In the short run, trade openness is negatively and statistically significantly associated with the renewable energy share, whereas the relationship becomes positive and statistically significant in the long run. This reversal indicates that greater trade openness is not immediately associated with a higher renewable energy share, while a more supportive relationship emerges over a longer time horizon. The negative and statistically significant error-correction term further indicates an adjustment mechanism through which short-run deviations are corrected toward the estimated long-run equilibrium. The short-run–long-run sign reversal also remains consistent after accounting for the identified structural breaks and when exports and imports are considered separately, although the bounds-test evidence for the import specification is inconclusive at the 5% level. Overall, the observed pattern is consistent with theoretical mechanisms related to the scale and technique effects, while composition-related adjustments may also be relevant. However, these mechanisms provide an interpretive framework for the observed relationships rather than being directly identified by the empirical model.

The identified dynamic trade-off has important implications for the integration of Indonesia's trade and energy policies. In the short run, the negative association highlights the importance of coordinating trade and energy policies so that increasing energy demand is increasingly met by renewable rather than fossil energy sources. In the long run, the positive association highlights the importance of strengthening Indonesia's capacity to benefit from opportunities associated with international integration, particularly through improved access to low-carbon technologies, energy-efficient capital goods, knowledge, and clean-energy investment. Strengthening domestic technological capabilities, renewable energy infrastructure, and the capacity to absorb and adopt cleaner technologies may help support this longer-term adjustment. Accordingly, policy should not focus solely on increasing trade openness but should also address short-run energy pressures while creating conditions that enable international integration to support a greater role for renewable energy over the longer term.

This study is subject to several limitations that also provide directions for future research. First, although the robustness analysis considers exports and imports separately, these measures remain aggregate and do not capture the composition of traded goods and services. Future research could examine more disaggregated dimensions of trade, particularly environmental goods, clean-energy technologies, green capital goods, and sector-specific trade flows. Second, potential channels such as green technology transfer, knowledge diffusion, and changes in the sectoral composition of economic activity are not directly captured in the empirical specification. Future studies could explicitly incorporate these channels to provide a more detailed understanding of the mechanisms underlying the observed short-run and long-run relationships. Third, the ARDL framework employed in this study is designed to examine dynamic associations and long-run equilibrium relationships rather than to identify causal mechanisms directly. Moreover, the ARDL framework does not fully resolve potential endogeneity arising from reverse causality or omitted-variable bias among trade openness, investment, energy demand, and renewable-energy development. Therefore, the estimated coefficients should be interpreted as conditional short-run and long-run associations rather than causal effects. Accordingly, the scale, composition, and technique effects provide a theoretically grounded framework for interpreting the observed relationships, while future research incorporating additional identification strategies and more direct measures of these mechanisms could further examine the underlying causal channels. Finally, because the empirical analysis covers the period 1990–2021, the findings should be interpreted within this sample period. Extending the analysis as more recent observations become available would be valuable for assessing whether the identified dynamic pattern persists amid Indonesia's more recent energy-transition developments.

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