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Malaysia's Renewable Energy and CO_2 Emissions: ARDL–ECM Evidence with Policy and Managerial Implications

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ABSTRACT

This study investigates whether renewable energy (RE) adoption reduces carbon dioxide (CO_2) emissions in Malaysia and under what conditions the effect is durable. We focus on translating empirical results into decisions for Malaysian firms and policymakers, given continuing reliance on coal-fired power and accelerating—but uneven—RE deployment. A quantitative, time-series design is employed using annual national data. An autoregressive distributed lag (ARDL) model and its error-correction representation (ECM) are used to separate short-run dynamics from long-run equilibrium relationships. The dependent variable is CO_2 emissions, with RE, GDP growth (economic scale/EKC context), foreign direct investment (FDI), and forest cover as regressors. Model diagnostics address integration properties, lag selection, and stability. Results show that RE has a negative and statistically significant short-run effect on CO_2—consistent with dispatch substitution in which incremental RE output crowds out marginal coal/gas generation. Long-run elasticities for RE and forest cover are directionally negative but statistically imprecise in the baseline specification, while GDP remains emissions-increasing. The ECM coefficient is negative and significant, indicating relatively fast adjustment toward long-run equilibrium. These findings imply that Malaysia can realise near-term abatement via RE procurement and efficiency measures, but durable decarbonisation requires policy sequences that convert substitution into structural displacement—specifically, competitive RE auctions paired with storage and scheduled coal retirements, complemented by green-halo FDI and credible forest governance. The study contributes Malaysia-specific, horizon-separated evidence that informs both managerial energy procurement choices and the state's transition planning.

Keywords: Malaysia, Renewable Energy, ARDL, ECM, CO_2 Emissions, EKC, FDI, Forest Cover, Energy Transition.

INTRODUCTION

Global climate change has become one of the most urgent challenges of our time, with carbon dioxide (CO_2) emissions recognized as the primary driver of global warming and environmental degradation. As countries strive to balance economic development with environmental sustainability, the role of renewable energy has gained increasing attention. Renewable energy sources such as solar, hydro, biomass, and wind offer cleaner alternatives to fossil fuels and represent a crucial pathway for reducing carbon intensity in national economies.

Malaysia, as an upper-middle-income nation, is highly dependent on fossil fuels, particularly coal and natural gas, to meet its energy demand. This reliance has contributed to a consistent rise in CO_2 emissions over the past decades. Projections indicate that emissions are likely to continue increasing beyond 2023, largely due to the dominance of coal-fired power generation, unless significant changes are made. The high emission intensity of Malaysia's energy sector reflects the structural challenges of transitioning to a low-carbon economy.

In recognition of this challenge, Malaysia has pledged under its Nationally Determined Contribution (NDC) to reduce greenhouse gas (GHG) intensity of GDP by 45% by 2030 compared to 2005 levels (Vaicondam et al., 2024), and to achieve net-zero emissions by 2050 (Aminuddin et al., 2025). In order to operationalize this commitment, the government launched the Malaysia Renewable Energy Roadmap (MyRER 2022–2040) and the National Energy Transition Roadmap (NETR 2023). These policies aim to increase renewable energy capacity from only 4% in 2023 to 31% by 2025 and 40% by 2035, alongside a gradual phase-out of coal.

Concrete measures have already been undertaken to support this transition. For example, the government has targeted the transportation sector, one of the largest contributors to national emissions, by promoting electric vehicles (EVs), introducing incentives for EV adoption, and investing in charging infrastructure (Songkin et al., 2023). Public transportation systems have also been expanded and modernized to reduce dependence on private vehicles (Shahid et al., 2014).

Beyond energy and transport, the government has also acted on the agriculture and plantation sector, particularly palm oil, which is both vital to Malaysia's economy and a source of significant environmental impact. The government has implemented policies to promote sustainable palm oil production and to reduce emissions from this sector, including the adoption of the Malaysian Sustainable Palm Oil (MSPO) certification scheme (Jamaludin et al., 2024). These initiatives aim to balance economic reliance on palm oil exports with Malaysia's environmental commitments, ensuring that growth in this sector aligns with the broader national strategy for carbon reduction.

Given these developments, the relationship between renewable energy adoption and CO_2 emissions in Malaysia warrants careful examination. While renewable energy is theoretically linked to lower emissions, the pace, scale, and effectiveness of its adoption in Malaysia remain critical questions. Assessing whether renewable energy expansion is sufficient to curb the rising trend of CO_2 emissions is central to understanding Malaysia's ability to meet its climate commitments and transition to a sustainable energy future.

Problem Statement

Although Malaysia has acknowledged the urgency of reducing CO_2 emissions and introduced ambitious roadmaps, emissions are still on an upward trend albeit with a gradual decline, surged from 28 million tonnes (Mt) in 1980 to 262.2 Mt in 2020 (Segar et al., 2024), indicating a ninefold increase. The energy sector remains heavily reliant on coal, which is the most carbon-intensive fuel source, and renewable energy adoption, while expanding, still represents a relatively small share of the overall energy mix.

Existing research on Malaysia's energy transition often highlights the technical potential of renewable energy but provides limited empirical evidence on its actual effect in reducing CO_2 emissions. Moreover, projections suggest (Segar et al., 2024) that unless renewable energy adoption accelerates significantly, Malaysia's emissions will continue to rise in the coming decade despite policy targets.

This creates a pressing research gap: it is still unclear to what extent renewable energy adoption in Malaysia can effectively mitigate CO_2 emissions in line with national and international climate goals. Therefore, this study seeks to address the following core question:

Does renewable energy (RE) adoption significantly reduce CO_2 emissions in Malaysia?

Answering this question is vital for policymakers and stakeholders to evaluate the effectiveness of existing strategies and to design stronger interventions that align Malaysia's energy transition with its emission reduction targets.

LITERATURE REVIEW

Malaysia's energy–emissions context and conceptual lenses

Malaysia's carbon outcomes reflect the interaction of its electricity fuel mix, macroeconomic expansion, inward capital, and land-use governance. Coal's rising share has historically locked in emissions intensity, while renewable uptake—dominated by hydro with growing but still modest non-hydro contributions—remains insufficient to reliably baseload fossil generation at scale (Lau, Tan, & Tang, 2016; Lau et al., 2018). Within standard production–energy frameworks, renewable energy can reduce emissions when it displaces fossil inputs rather than simply meeting incremental demand; foreign direct investment may raise emissions via a pollution-haven channel or reduce them through a green-halo mechanism that transfers cleaner technologies and managerial practices (Naz et al., 2019; Pham, Nguyen, Nguyen, & Tran, 2025; Zhao, 2025). Economic growth typically raises emissions at early development stages (scale effect), with any Environmental Kuznets Curve flattening contingent on structural efficiency and energy-mix change (Saboori, Sulaiman, & Mohd, 2016; Sarkar, Al-Amin, Mustapa, & Ahsan, 2019). Forested area acts as a carbon sink with effects that emerge primarily over longer horizons (Begum, Raihan, & Said, 2020; Ponce, Del Río-Rama, Álvarez-García, & Oliveira, 2021; Suman et al., 2025). Malaysia-focused and regional/cross-country studies in the evidence base also provide design cues (ARDL/NARDL; threshold VAR) for interpreting short-run versus long-run dynamics (Akhtar, Masud, Al-Mamun, & Saif, 2023; Zhao, 2025).

Renewable energy → CO_2: what differs in the short run versus the long run

Short run. For Malaysia, the most immediate carbon relief from renewable energy arises via dispatch substitution—incremental hydro or other RE output crowding out marginal coal or gas generation within the year. Malaysia-specific evidence documents dynamic linkages among hydro use, growth, and emissions that are indicative of near-term substitution rather than structural retirement (Lau, Tan, & Tang, 2016). Complementarily, Malaysian studies show that RE consumption is shaped by macro drivers, implying that short-horizon RE shocks chiefly operate through substitution channels (Lau et al., 2018). Regional and multi-country designs reinforce the short-run mitigation result but flag sensitivity to measurement (RE electricity share vs. total final energy) and to displacement (whether RE truly replaces fossil generation): threshold-VAR evidence shows robust mitigation from RE while highlighting regime dependence that can shape the net carbon effect when macro conditions vary (Zhao, 2025).

Long run. Over longer horizons, studies generally find that higher RE penetration reduces CO_2, but statistical precision hinges on (i) whether additions displace coal rather than merely accommodate demand growth, (ii) the metric used for RE, and (iii) broader innovation capacity. Cross-national evidence associates higher RE and R&D human capital with lower emissions, and shows that RE's long-run mitigation persists across macro regimes, although magnitudes vary with thresholds (Mentel et al., 2022; Zhao, 2025). For Malaysia, prior work suggests that deeper and more diversified RE penetration is needed to translate short-run substitution into precise long-run displacement effects, a view consistent with the country's still-modest non-hydro scale (Lau et al., 2018).

Economic growth and the Environmental Kuznets Curve (EKC) debate in Malaysia

On average, Malaysian studies report that economic growth raises CO_2 in the short run, reflecting scale effects that dominate before efficiency or energy-mix changes materialize. Saboori, Sulaiman, & Mohd (2016) and Sarkar, Al-Amin, Mustapa, & Ahsan (2019) both find cointegrated GDP–CO_2 relationships consistent with positive elasticities, with any EKC-type turning point dependent on policy-driven structural shifts rather than automatic with income growth. Regional comparators (e.g., Brunei) report similar growth–emissions links where decoupling follows explicit energy-system reforms. (e.g., Xuan, 2025).

FDI → CO_2: pollution haven, green halo, and thresholds

Malaysia's FDI–emissions nexus is conditional on sectoral composition, absorptive capacity, and macro regimes. Using a NARDL design, Akhtar, Masud, Al-Mamun, & Saif (2023) document emissions linkages to

FDI alongside energy and growth, consistent with exposure to pollution-haven dynamics when inflows favor energy-intensive manufacturing. A Malaysia-focused study on ecological pressures by Chuah, Cheam, Chua, & Arshad (2025) likewise shows sensitivity to composition and regime, indicating that the sign of FDI's impact cannot be assumed ex ante. In a 27-country panel threshold-VAR, Zhao (2025) finds that FDI's net effect can flip under higher growth thresholds, while renewable energy retains a mitigating role—evidence that macro conditions shape both the size and direction of FDI's carbon impact. Robust least squares estimate in Naz et al. (2019) further corroborate the importance of renewable penetration and growth regimes when assessing the FDI–emissions channel. At the same time, cross-country work detects a green-halo under stronger absorptive capacity and innovation linkages: Pham, Nguyen, Nguyen, & Tran (2025) show that FDI can co-move with lower emissions when complementary conditions are present, consistent with the view that sectoral screening and targeting condition FDI's environmental effects.

Forested area → CO_2: sequestration over time

Forested area increases generally reduce CO_2 via carbon sequestration, but effects materialize over longer horizons. For Malaysia, Begum, Raihan, & Said (2020) report dynamic impacts of growth and forested area on emissions consistent with a carbon-reducing role of forests. In broader contexts, ARDL evidence links forest conservation and renewable energy to lower emissions (Ponce, Del Río-Rama, Álvarez-García, & Oliveira, 2021). In G20 settings, improvements in clean energy access and forest cover are likewise associated with lower emissions, underscoring the importance of sustained land-use policy alongside energy transitions (Suman et al., 2025).

In the short-run forest effects are often small or imprecise, consistent with slow biophysical sequestration and gradual land-use adjustment; consequently, many studies detect forest impacts primarily in the long run (Begum et al., 2020; Ponce et al., 2021; Suman et al., 2025).

Synthesis and gap addressed by this study

Three robust takeaways emerge from the evidence base. First, renewables mitigate CO_2 in short-run horizons through substitution—particularly where hydro or fast-dispatch RE is available—whereas long-run precision depends on whether additions displace coal and on how renewable energy is measured (Lau, Tan, & Tang, 2016; Lau et al., 2018; Zhao, 2025; Mentel et al., 2022). Second, in Malaysia, economic growth remains emissions-increasing unless accompanied by structural energy changes and efficiency gains; EKC-type turning points are not automatic at Malaysia's current income level (Saboori, Sulaiman, & Mohd, 2016; Sarkar, Al-Amin, Mustapa, & Ahsan, 2019). Third, the environmental effect of FDI is context-dependent: pollution-haven channels tend to dominate when inflows favor energy-intensive sectors, whereas green-halo effects emerge under stronger absorptive capacity and favorable macro regimes (Akhtar, Masud, Al-Mamun, & Saif, 2023; Naz et al., 2019; Pham, Nguyen, Nguyen, & Tran, 2025; Zhao, 2025). In addition, forest coverage reduces emissions over time, while short-run forest coefficients are often small or imprecise, consistent with sequestration dynamics and gradual land-use adjustment (Begum, Raihan, & Said, 2020; Ponce, Del Río-Rama, Álvarez-García, & Oliveira, 2021; Suman et al., 2025).

Bridge to the empirical design (gap statement). Prior work in Malaysia rarely spans a broad period covering major policy shifts while using a composite renewable metric and jointly accounting for GDP growth, FDI, and forested area within an ARDL/ECM that reports both short-run and long-run elasticities. To address this gap, the present study estimates such a specification to test whether Malaysia's current renewable penetration is associated with short-run substitution and long-run displacement effects under local macro and sectoral conditions.

METHODOLOGY

This study employs annual time-series data for Malaysia covering the period 1991–2024. The dataset was obtained from the World Development Indicators (WDI) published by the World Bank. The variables used are as follows:

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Table 1: Variables Used in This Research

No.	Notation	Type	Indicator Name
1	lco2	Dependent variable	Carbon dioxide emissions as a percentage of total emissions
2	lrenew	Independent variable	Renewable energy consumption as a percentage of total final energy consumption
3	lgrowth	Control variable	GDP (annual % growth)
4	lforest	Control variable	Forest area (% of land area)
5	lfdi	Control variable	Foreign direct investment, net inflows (% of GDP)

All variables were transformed into natural logarithmic form to reduce potential heteroskedasticity, improve distributional properties, and allow elasticity-based interpretations of coefficients.

The relationship between renewable energy consumption and carbon dioxide emissions was estimated using the Autoregressive Distributed Lag (ARDL) approach, developed by Pesaran and Shin (1999). The ARDL methodology is particularly suitable for small sample sizes and for data that are integrated of mixed orders, i.e., I(0) or I(1).

The general ARDL model can be specified as:

$$\mathrm{lco2}_t = \propto_0 + \sum_{i=1}^{p} \emptyset_i \, \mathrm{lco2}_{t-1} + \sum_{j=0}^{q_1} \beta_j \, \mathrm{lrenew}_{t-j} + \sum_{k=0}^{q_2} \gamma_k \, \mathrm{lgrowth}_{t-k} + \sum_{m=0}^{q_3} \delta_m \, \mathrm{lforest}_{t-m} + \sum_{n=0}^{q_4} \theta_n \, \mathrm{lfdi}_{t-n} + \varepsilon_t$$

[Equation 1]

Before estimating the ARDL model, it is necessary to determine the order of integration of each series. Conducting unit root tests such as the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) is crucial to avoid spurious regression results. If the variables are found to be I(2), the ARDL approach is no longer valid.

Besides, the correct lag length is essential to capture the underlying dynamics of the model. Using too few lags can lead to omitted variable bias, while too many lags reduce efficiency and may create multicollinearity. Therefore, lag length selection criteria such as the Akaike Information Criterion (AIC), Hannan-Quinn (HQIC), Schwarz Bayesian Criterion (SBIC), and Final Prediction Error (FPE) were employed.

The ARDL model can be re-parameterized into an Error Correction Model (ECM) form that incorporates both short-run dynamics and the long-run equilibrium adjustment mechanism:

$$\Delta \mathrm{lco2}_t = \propto_0 + \sum_{i=1}^{p-1} \emptyset_i \, \Delta \mathrm{lco2}_{t-1} + \sum_{j=0}^{q_1-1} \beta_j \, \Delta \mathrm{lrenew}_{t-j} + \sum_{k=0}^{q_2-1} \gamma_k \, \Delta \mathrm{lgrowth}_{t-k} + \sum_{m=0}^{q_3-1} \delta_m \, \Delta \mathrm{lforest}_{t-m} + \sum_{n=0}^{q_4-1} \theta_n \, \Delta \mathrm{lfdi}_{t-n} + \varphi \mathrm{ECM}_{t-1} + \varepsilon_t$$

[Equation 2]

where:

ECM_{t-1} is the lagged error correction term capturing deviations from long-run equilibrium,

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φ is the speed of adjustment coefficient.

A negative and statistically significant value of φ confirms convergence toward long-run equilibrium. The ECM coefficient is derived from the lagged dependent variable of the ARDL model. Specifically:

$$\varphi = 1 - \sum \emptyset_i$$

[Equation 3]

where $\emptyset_i$ are the coefficients of the lagged dependent variables in levels.

ARDL/ECM accommodates mixed integration orders commonly observed in annual macro–energy series and yields short-run and long-run elasticities. Following best practice, we note that measurement choices for RE (electricity share vs total final energy) and CO_2 (per-capita vs intensity vs total) can shift elasticity magnitudes; therefore, we report diagnostics and interpret estimates with these differences in mind.

FINDINGS

Unit root tests

The stationarity properties of the series were examined using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. The results are illustrated in Table 2 below.

Table 2: Unit Root Test Results

Variable	ADF Statistic	PP Statistic	Integration Order
lco2	-4.666***	-7.860***	I(0)
lrenew	-1.205	-5.857***	I(1)
lgrowth	-1.922	-1.295	I(1)
lforest	-4.289***	-2.259	I(0)
lfdi	-3.361	-5.401***	Mixed (I(0)/I(1))

Notes: Null = unit root. *** $p < 0.01$.

Results indicate that variables are integrated of mixed orders, I(0) and I(1), thereby validating the use of the ARDL methodology.

ARDL estimation results

The optimal lag structure was determined using information criteria. The ARDL (2,0,2,0,1) specification was selected based on the Akaike Information Criterion (AIC) and Final Prediction Error (FPE).

The ARDL (2,0,2,0,1) results are reported below in Table 3, with R^2 and adjusted R^2 values of 0.733 and 0.607, respectively.

Table 3: Results of ARDL (2,0,2,0,1).

Variable	Coefficient	Std. Error	t-Statistic	p-Value
Long-run relationship				
lgrowth	-1.421	3.903	-0.36	0.720
lrenew	-1.883	5.051	-0.37	0.713
lforest	-106.291	208.254	-0.51	0.616
lfdi	-3.252	8.577	-0.38	0.709
Short-run dynamics				
LD.lco2	-0.658***	0.199	-3.31	0.004
D1.lrenew	-0.513**	0.215	-2.39	0.028
LD.lrenew	-0.335	0.200	-1.68	0.110
D1.lfdi	-0.047*	0.025	-1.85	0.080
Constant	-12.582	11.697	-1.08	0.296
ECM(-1)	-0.972***	0.214	-4.54	0.000

Notes: ECM(-1) is the error correction term. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Based on the above results, the long-run coefficients show negative associations between renewable energy, GDP growth, forest area, FDI inflows, and carbon emissions, although not statistically significant.

The directionally negative yet statistically insignificant long-run elasticities for renewables, GDP, forest area, and FDI are plausible in Malaysia's context of coal lock-in and measurement sensitivity. Demand growth and grid constraints can further dilute steady-state mitigation unless renewable penetration scales sufficiently to displace coal rather than merely meet incremental load (Lau et al., 2018; Zhao, 2025). Malaysia's hydro-centric dynamics suggest that renewable additions have not yet reached a scale that displaces baseload fossil generation, which helps explain imprecise steady-state effects (Lau, Tan, & Tang, 2016). The macro-driven nature of renewable consumption further supports the view that recent gains reflect aggregate conditions rather than structural retirement of fossil capacity (Lau et al., 2018). Regarding FDI, panel evidence indicates regime dependence—its net environmental effect can vary across growth thresholds—and green-halo benefits tend to materialize only under stronger absorptive capacity (Naz et al., 2019; Zhao, 2025; Pham, Nguyen, Nguyen, & Tran, 2025). The lack of long-run precision for forest area is consistent with slow biophysical sequestration and land-use adjustment dynamics documented in Malaysia and broader samples (Begum, Raihan, & Said, 2020; Ponce, Del Río-Rama, Álvarez-García, & Oliveira, 2021).

Meanwhile, in the short run, renewable energy consumption significantly reduces carbon emissions, while FDI inflows exert a modest negative effect at the 10% level.

The significant short-run reduction in CO_2 associated with higher renewable consumption is consistent with dispatch substitution, whereby incremental renewables (notably hydro or fast-dispatch resources) crowd out marginal coal or gas generation (Lau, Tan, & Tang, 2016; Lau et al., 2018). The small, negative short-run FDI coefficient aligns with a nascent green-halo under favorable macro regimes, as observed in Malaysia-focused and panel designs (Chuah, Cheam, Chua, & Arshad, 2025; Zhao, 2025).

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Converting short-run substitution into durable long-run decarbonization requires (i) coal-to-RE displacement rather than capacity addition, (ii) grid flexibility investments (storage, interconnections, system services), and (iii) FDI screening/targeting toward low-carbon, technology-transferring sectors, consistent with regime-dependence and absorptive-capacity findings above.

The ECM (-1) value of -0.972 is negative and highly significant. This indicates that 97% of disequilibrium in carbon emissions is corrected within one year, suggesting a very fast adjustment back to the long-run equilibrium following short-term shocks.

Diagnostic Tests

Diagnostic tests were conducted to ensure model validity. The Breusch-Godfrey LM test was used to detect serial correlation, while the Breusch-Pagan/Cook-Weisberg test examined heteroskedasticity.

Table 5: Diagnostic Tests

Test	Statistic	p-Value	Conclusion
Breusch-Godfrey LM (Autocorrelation) H_0 = No serial correlation	χ^2 (1) = 0.256	0.613	No serial correlation
Breusch-Pagan / Cook-Weisberg (Heteroskedasticity) H_0 = No heteroskedasticity	χ^2 (1) = 3.08	0.079	No heteroskedasticity (10% level)

Both tests confirmed the absence of econometric problems, indicating that the estimated ARDL model is robust and reliable.

CONCLUSION

This paper set out to answer a simple but consequential question: does Malaysia's push toward renewable energy actually lower carbon emissions—and on what timeline? The issue matters because Malaysia's power system has long relied on coal and gas while electricity demand keeps rising. Policymakers have announced ambitious transition plans, but if new renewables merely meet incremental load rather than replace fossil baseload, the country could add capacity without cutting emissions. Understanding whether renewable energy delivers short-run relief, long-run displacement, or both is therefore central to credible pathways for meeting national climate goals while safeguarding growth and energy security.

Our results speak in plain terms. In the short run, more renewable energy is associated with lower emissions, consistent with dispatch substitution—renewables crowd out the marginal coal or gas unit when they are available. Foreign direct investment, on balance, shows a small near-term improvement in environmental performance, suggesting that recent inflows may carry cleaner processes or technologies. In the long run, the elasticities for renewables, growth, forests, and FDI are negative in direction but not estimated precisely. This pattern fits a system in transition: renewables are helping at the margin, yet scale, diversification, and grid readiness have not reached the point where fossil baseload is reliably displaced; forest sequestration works, but slowly; and FDI's effect remains contingent on sectoral composition and macro conditions.

Theoretically, the study clarifies when and how the energy–emissions nexus operates in a middle-income, coal-reliant system. First, it distinguishes substitution from displacement: renewable additions can reduce emissions on impact without guaranteeing precise long-run mitigation unless they replace baseload generation. Second, it underscores regime dependence in the capital–environment channel: the sign and strength of FDI's effect vary with growth phases and absorptive capacity, reconciling mixed findings in the literature. Third, it links biophysical lags to empirical detectability: forest cover contributes to mitigation over extended horizons, which explains why short-run coefficients often look weak even when the long-run contribution is real. Together, these insights integrate energy systems thinking with macro-environmental econometrics, offering a framework for interpreting seemingly inconsistent short-run and long-run results.

For practice and policy in Malaysia, the message is to convert short-run substitution into durable long-run displacement. The Energy Commission, the Single Buyer, and the system operator should align capacity procurement and dispatch with explicit coal down-ramp schedules so new renewable megawatts are tied to measurable fossil-generation reductions, not just headline capacity targets. Tenaga Nasional Berhad and planners should accelerate grid-flexibility investments—storage, fast-ramping reserves, enhanced ancillary-services markets, and strategic interconnections—so variable renewables can reliably replace baseload output. The Economic Planning Unit and investment agencies can tilt incentives toward green FDI—grid technologies, storage, efficiency services—using performance-based criteria that favor demonstrable emissions improvements and technology transfer. State forestry departments and federal agencies should pursue long-horizon forest strategies (avoided deforestation, restoration with robust monitoring) recognizing that benefits accumulate over years, not quarters. Central ministries can improve measurement by publishing emissions-based outcome metrics (coal MWh reduced, tonnes of CO_2 avoided) alongside capacity figures, and by reporting renewables both as electricity share and total final energy to keep policy focused on outcomes rather than inputs.

These contributions come with limitations. The analysis relies on national aggregates for emissions and energy, which cannot capture sectoral or plant-level heterogeneity. Variable definitions—such as using a composite renewable share and an aggregate CO_2 metric—shape elasticities and may mask technology-specific dynamics (for example, hydro versus non-hydro renewables). Although the ARDL framework addresses mixed orders of integration and provides a transparent short-run/long-run decomposition, it cannot fully resolve endogeneity concerns or pin down causal mechanisms under all regime changes and structural breaks. Finally, the time-series perspective prioritizes national dynamics; it does not benchmark Malaysia's progress against ASEAN peers facing similar constraints.

These limits point directly to the next research steps. Future work should (i) open the black box of FDI by disaggregating inflows by sector to separate pollution-haven from green-halo channels and to test for threshold effects explicitly; (ii) refine measurement by using technology-specific renewable series (hydro, solar, wind, biomass) and alternative emissions metrics (per-capita, intensity, sectoral) to assess robustness; (iii) probe regime dependence with asymmetric and threshold ARDL designs and structural-break tests aligned with major policy changes, fuel-price shocks, or drought years; (iv) strengthen identification using plausibly exogenous instruments—such as hydrology-driven variation or global fuel-price shocks—to sharpen the interpretation of short-run substitution versus long-run displacement; and (v) benchmark regionally with comparable ASEAN panels to place Malaysia's displacement progress and policy effectiveness in context. Advancing along these lines will move the debate from whether renewables help to how to design markets, grids, and investment policy so near-term gains harden into sustained, economy-wide decarbonization.

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