



Renewable Expansion and Fossil Persistence in Southeast Asian Electricity Systems

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Abstract

Southeast Asia has expanded renewable electricity rapidly, yet a rising renewable share does not necessarily indicate an absolute retreat of fossil generation. This study examined 250 country-year observations for ten Southeast Asian economies from 2000 to 2024 using harmonized Ember electricity data and exact accounting decompositions. Regional generation rose from 378.76 to 1,351.60 TWh. Renewable output increased by 276.71 TWh, but fossil output increased by 696.13 TWh, so renewables supplied 28.44% of total generation growth. The regional fossil share fell by 6.56 percentage points; endpoint decomposition attributed a 1.26-point increase to within-country mix changes and a 7.82-point decrease to changing production weights. During 2019–2024, renewables supplied 49.98% of incremental generation, while fossil output still rose in every economy. The results showed that transition monitoring should report renewable additions, absolute fossil volumes, and regional composition together. The evidence supports investment strategies that link renewable deployment with fossil-dispatch, demand, grid, and retirement objectives rather than relying on renewable-share targets alone.

Keywords: Energy Transition, Electricity Generation, Fossil Persistence, Renewable Energy, Southeast Asia



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INTRODUCTION

Electricity demand, industrialization, urban growth, and rising household consumption have expanded the scale of Southeast Asian power systems while governments have simultaneously announced increasingly ambitious renewable-energy targets. The resulting transition is economically important because electricity prices, fuel imports, investment requirements, and the utilization of existing generating assets affect firms and households well beyond the power sector. A renewable share can improve while fossil generation still rises when total demand grows more rapidly than renewable output. This accounting distinction is central to the economic interpretation of transition performance. York (2012) demonstrated that the addition of non-fossil energy does not guarantee one-for-one displacement of fossil energy, and York and Bell (2019) later framed many historical changes as energy additions rather than complete substitutions. For fast-growing Southeast Asian systems, an indicator that records only renewable capacity or share can consequently overstate the degree to which incumbent fossil production has actually retreated.

Recent regional research confirms that Southeast Asia combines large renewable resources with heterogeneous institutions, market structures, and investment conditions. Aleluia et al. (2022) emphasize the role of governments and public policy in accelerating clean-energy investment, while Vakulchuk et al. (2023) identify investment conditions that continue to constrain renewable deployment. Bai et al. (2023) document substantial variation in transition readiness across the region, and Do (2024) reports practitioner perspectives that place implementation capacity and political economy alongside technology costs. These differences matter for economic monitoring because a regional average can move when national generation mixes change, when the relative size of national electricity systems changes, or both. A meaningful regional indicator should preserve those channels instead of attributing every favorable aggregate movement to an improvement inside each national system. The present study

separates these mechanisms by combining national generation accounting with a decomposition of changing regional production weights.

The distinction has direct relevance to Indonesia and Viet Nam, two of the region's largest power systems and two central cases in the literature. Resosudarmo et al. (2023) describe the opportunities and constraints surrounding Indonesia's energy transition, while Wong and Dewayanti (2024) connect the transition to fossil dependence and subsidy structures. Research on Indonesia also identifies adoption barriers for solar and wind investment (Burke et al., 2019) and institutional issues surrounding rooftop solar policy (Setyawati, 2020). Viet Nam provides a different trajectory in which rapid solar and wind growth has occurred alongside questions about system integration and coal withdrawal (Do et al., 2021; Do & Burke, 2023b). A regional comparison that treats these systems as interchangeable would miss both scale and composition. The empirical design used here keeps each country visible while reconciling the regional totals to the same generation boundary.

Cross-border electricity trade further complicates the interpretation of aggregate shares. Do and Burke (2023a) show that multilateral trade in ASEAN depends on institutional sequencing, while Do et al. (2023) examine the role of solar and wind in the Greater Mekong Subregion. Aisbett et al. (2023) broaden the discussion by showing how international green-economy collaboration can create mutual gains when institutional arrangements are credible. Production and consumption can occur in different jurisdictions, so an electricity indicator must specify whether it is allocating generation to producers or final use to consumers. This study follows the generation location recorded in the source data and does not reinterpret trade flows as domestic production. The choice provides a consistent accounting boundary for 2000–2024 and makes changes in each country's share of regional output observable. It also prevents an unreported shift in the geographical basis of the regional series.

Broader empirical work has linked renewable energy to growth, emissions, and sustainable development without implying that a single renewable metric captures every transition outcome. Mu'min et al. (2024) find that the relationship between energy transition and sustainable development in ASEAN is multidimensional, while Tran et al. (2024) analyze the renewable-energy, growth, and emissions nexus in the region. Safrina (2023) situates ASEAN's transition pathway within the 2030 development agenda, and Kuok et al. (2024) synthesize recurring barriers to renewable development. These contributions indicate that renewable expansion can be economically beneficial while leaving unresolved questions about fossil dispatch, asset retirement, affordability, and system reliability. Do and Burke (2024) make the coal phase-out challenge especially explicit for Indonesia and Viet Nam. The analytical contribution of this article is narrower but operational: it asks whether the observed electricity balance shows actual fossil decline, and it quantifies how much of a regional share movement reflects national mixes rather than a redistribution of production weights.

Three research questions structure the analysis. First, how much of the increase in regional electricity generation between 2000 and 2024 was supplied by renewables rather than fossil sources? Second, how can the observed change in fossil generation be separated arithmetically into system-scale growth and a changing fossil share? Third, does the regional decline in fossil share primarily reflect cleaner national mixes or changes in the geographical composition of electricity production? The study also examines annual transitions, overlapping five-year windows, alternative endpoints, and a fixed-generation benchmark for 2019–2024. These checks are descriptive rather than causal. They identify what happened within a fixed statistical boundary and reveal how sensitive the interpretation is to the measurement window. Causal attribution would require policy timing, plant operation, prices, investment decisions, and demand shocks beyond the information contained in annual generation totals.

The novelty lies in joining three measures that are often reported separately: renewable additions, absolute fossil volumes, and the within-country versus between-country sources of regional share change. This integration matters for firms, investors, and policymakers because a renewable procurement target, a coal-retirement target, and a regional decarbonization target impose different information requirements. Installed capacity measures an asset stock; generated electricity measures delivered output; a fuel share measures composition; and an absolute fossil quantity measures the scale of continued fossil operation. The same regional system can improve on one measure while deteriorating on another. By reconciling these quantities exactly and linking them to recent regional policy literature, the study provides a transparent monitoring framework for evaluating whether renewable investment is merely keeping pace with electricity growth or is beginning to reduce fossil dependence in absolute terms.

RESEARCH METHODS

The study used a balanced country-year panel from Ember's yearly electricity data release, retrieved on 11 September 2026 (Ember, n.d.-b). The sample comprised Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Viet Nam from 2000 through 2024, producing 250 country-year observations. Seven generation series measured in terawatt-hours were retained: total generation, fossil generation, renewable generation, coal, gas and other fossil, wind and solar, and hydro together with bioenergy and other renewables. The selected aggregates reconcile numerically as total generation equals fossil plus renewables; fossil equals coal plus gas and other fossil; and renewables equal wind and solar plus the remaining renewable categories. No interpolation, extrapolation, winsorization, or replacement of unavailable values with zero was performed. Ember's methodology notes limitations in harmonized electricity statistics, including incomplete captive-generation coverage in some jurisdictions, so the analysis refers to the recorded statistical boundary rather than an exhaustive plant census (Ember, n.d.-a).

For an interval from year a to year b , the study calculated changes in total generation (ΔG), fossil generation (ΔF), and renewable generation (ΔR). When ΔG was positive, the renewable contribution to generation growth was calculated as $100 \times \Delta R / \Delta G$. Fossil generation was also represented as the product of total generation and the fossil share, $F = G_s$. The exact symmetric decomposition assigned the observed fossil change to a generation-scale component and a fossil-share component, evaluating each factor's change at the average value of the other factor. This complete-decomposition logic follows Sun (1998) and yields no residual apart from display rounding. The method was applied to each economy and the regional aggregate for 2000–2010, 2010–2019, 2019–2024, and 2000–2024. The resulting components are accounting identities rather than estimated behavioral parameters and should not be interpreted as causal policy effects.

Regional composition was evaluated by writing the regional fossil share as a generation-weighted average of national fossil shares. Its endpoint change was separated into a within-country term, reflecting changes in national electricity mixes, and a between-country term, reflecting changes in each economy's share of regional generation. The endpoint calculation was compared with an annually chained version that decomposed every adjacent-year movement and then summed the components. Temporal robustness checks classified 240 annual country changes using a 0.05 TWh tolerance, examined 200 overlapping five-year intervals, changed the endpoint to 2019, 2022, and 2023, used three-year endpoint averages, and removed large systems individually and jointly. A final arithmetic benchmark held observed 2024 generation fixed and calculated the additional renewable output associated with keeping 2024 fossil generation no higher than its 2019 level. No confidence intervals were attached to identities calculated directly from the observed panel.

The empirical interpretation deliberately separates accounting evidence from the investment and policy mechanisms discussed in the literature. Renewable deployment responds to financing, market access, and policy effectiveness (Bourcet, 2020; Bersalli et al., 2020), while fossil withdrawal additionally depends on asset operation, retirement incentives, and stranded-asset risks (van der Ploeg & Rezai, 2020). State-owned utilities can shape decarbonization pathways through governance and capital-allocation decisions (Benoit et al., 2022), while electricity prices and subsidy reform can influence demand (Burke & Kurniawati, 2018; Burke & Do, 2021). The decomposition cannot identify these mechanisms separately. It provides the measured quantities that any mechanism-based explanation must reconcile: how much the system expanded, how the fuel mix changed, where regional production shifted, and whether fossil output actually declined.

RESULTS AND DISCUSSION

Renewable Expansion, System Growth, and Fossil Persistence

The scale of the regional electricity system changed dramatically between the two endpoints. Total domestic generation across the ten economies increased from 378.76 TWh in 2000 to 1,351.60 TWh in 2024, an expansion of 972.84 TWh. Renewable generation increased from 73.23 to 349.94 TWh, while fossil generation rose from 305.53 to 1,001.66 TWh. The arithmetic implication is unambiguous: renewables supplied 276.71 TWh, or 28.44%, of the additional generation, whereas fossil sources supplied the remaining 696.13 TWh. Figure 1 makes the scale contrast visible. The regional renewable share still improved from 19.33% to 25.89%, so relative progress occurred at the same time as a large absolute increase in fossil use. This combination is consistent with the distinction between

energy addition and energy substitution emphasized by York (2012) and York and Bell (2019), and it demonstrates why a percentage share is insufficient as a standalone transition indicator.

The fuel composition inside the fossil aggregate changed even more sharply than the aggregate share suggests. Coal generation rose from 76.03 TWh in 2000 to 603.60 TWh in 2024, increasing coal's share of total generation from 20.07% to 44.66%. Gas and other fossil generation also increased over the full period, from 229.50 to 398.06 TWh, although that category declined slightly after 2019. The regional fossil share can consequently fall while coal becomes more important within the electricity system. This internal shift has financial relevance because coal assets have different retirement profiles, contract structures, and stranded-asset exposure from gas generation. Van der Ploeg and Rezai (2020) show why asset stranding becomes an economic issue during a low-carbon transition, while Do and Burke (2024) identify the particular difficulty of coal phase-out in Indonesia and Viet Nam. Aggregate fossil reporting would conceal part of that investment problem.

Renewable growth accelerated over successive periods, but the acceleration did not yet reverse fossil volumes. Renewables supplied only 12.99% of additional generation during 2000–2010, increased their contribution to 28.01% during 2010–2019, and supplied 49.98% during 2019–2024. The latest interval is materially different from the first decade because roughly half of new generation was renewable. Yet fossil generation still increased by 115.02 TWh from 2019 to 2024, almost exactly matching the 114.91 TWh renewable increase. The result supports a more precise interpretation of recent progress: renewable deployment is increasingly important to meeting new electricity demand, but it has not yet produced a regional decline in annual fossil generation. The pattern aligns with regional assessments that describe rapid renewable expansion alongside continuing structural dependence on fossil assets (Vakulchuk et al., 2023; Wong & Dewayanti, 2024).

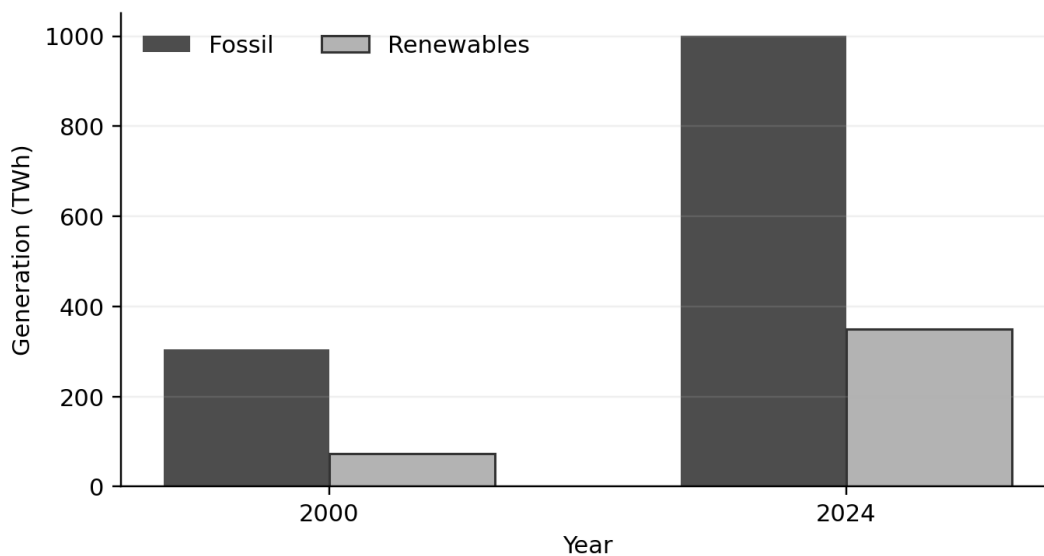


Figure 1. Regional Fossil and Renewable Generation at the Study Endpoints
Source: Authors' calculations from Ember (n.d.-b).

National endpoint data show why the regional result cannot be reduced to a common country trajectory. Cambodia increased its renewable share from 6.25% to 35.66%, Malaysia from 10.82% to 20.37%, Myanmar from 36.67% to 47.86%, Singapore from 1.55% to 4.93%, and Thailand from 6.72% to 14.84%. Indonesia, Lao PDR, the Philippines, and Viet Nam experienced lower renewable shares at the 2024 endpoint despite increases in renewable output in several cases. Table 1 reports generation levels and renewable shares together so that a falling share is not confused with a fall in renewable generation. Viet Nam is the clearest example: renewable output increased strongly, yet the share fell from 54.78% to 42.28% because total generation expanded even faster. Bai et al. (2023) likewise emphasize divergent national transition conditions, while Do (2024) shows that implementation constraints vary substantially across regional systems.

Table 1. National Generation and Renewable Shares at the Study Endpoints

Economy	Generation 2000 (TWh)	Generation 2024 (TWh)	Renewables 2000 (%)	Renewables 2024 (%)
Brunei	2.54	5.56	0.0	0.18
Cambodia	0.48	15.48	6.25	35.66
Indonesia	98.04	371.54	19.99	18.09
Lao PDR	3.65	52.31	89.86	76.72
Malaysia	69.9	198.12	10.82	20.37
Myanmar	5.1	21.71	36.67	47.86
Philippines	45.3	124.17	42.89	20.47
Singapore	31.67	59.61	1.55	4.93
Thailand	95.52	199.52	6.72	14.84
Viet Nam	26.56	303.58	54.78	42.28

Source: Authors' calculations from Ember (n.d.-b).

The scale effect is quantitatively dominant in the full-period fossil decomposition. Regional system growth contributed 752.86 TWh to the calculated increase in fossil generation, while the changing fossil share contributed −56.73 TWh. The negative share term indicates that the regional fossil share improved relative to a counterfactual in which the share remained at its average endpoint level, but the improvement offset only a small portion of the expansion associated with a much larger electricity system. The two components sum to the observed 696.13 TWh increase. This accounting result does not imply that demand growth caused a specific amount of fossil investment, because demand, capacity, dispatch, and trade are jointly determined. It establishes that an analysis of transition progress must control conceptually for system scale. Burke and Kurniawati (2018) show that electricity demand responds to policy and price conditions, reinforcing the relevance of the scale channel for transition planning.

The subperiod decomposition also changes sign in an economically meaningful way. During 2000–2010, both the scale component and the mix component increased fossil generation, producing a 267.97 TWh fossil rise. From 2010–2019 the mix component became negative at −40.39 TWh, and during 2019–2024 it became more negative at −61.06 TWh. National and regional electricity mixes were therefore providing increasing arithmetic resistance to the fossil increase even while the expanding system continued to push absolute output upward. Such a result is compatible with more effective renewable policy without establishing the size of any specific policy effect. Bersalli et al. (2020) demonstrate that renewable policy effectiveness varies with instrument design and institutional conditions, while Bourcet (2020) synthesizes a broad set of determinants of renewable deployment. The decomposition provides an outcome layer that can be combined with those causal explanations in subsequent research.

Table 2. Regional Changes and Exact Fossil Generation Decomposition

Period	ΔG (TWh)	ΔR (TWh)	ΔF (TWh)	R contribution (%)	Scale (TWh)	Mix (TWh)
2000–2010	307.96	39.99	267.97	12.99	252.80	15.17
2010–2019	434.95	121.81	313.14	28.01	353.53	−40.39
2019–2024	229.93	114.91	115.02	49.98	176.08	−61.06
2000–2024	972.84	276.71	696.13	28.44	752.86	−56.73

Source: Authors' calculations from Ember (n.d.-b). Δ = endpoint change; R = renewable generation.

The latest five-year balance highlights the gap between a renewable deployment target and a fossil-reduction target. If an investor or ministry assessed only the additional renewable electricity, the 114.91 TWh increase from 2019 to 2024 would represent considerable progress. If the performance criterion were instead whether fossil generation declined, the same period would not meet that condition because every economy recorded a positive fossil change. These are not contradictory conclusions; they

answer different questions. Aleluia et al. (2022) argue for active public policy in accelerating clean-energy transitions, while Do et al. (2021) show how policy design helped Viet Nam scale solar and wind rapidly. The present evidence indicates that deployment programs require a second operational target if the policy objective includes absolute fossil reduction. That target may concern dispatch, retirement, demand, grid access, or a combination of those mechanisms rather than capacity installation alone.

The economic significance of simultaneous renewable and fossil growth extends to capital allocation. New renewable plants require financing, transmission access, and revenue certainty, but continued fossil expansion also absorbs capital and can extend asset lives. Benoit et al. (2022) show that state-owned power companies occupy a central position in many decarbonization processes, making utility investment plans relevant to the relationship between new renewables and incumbent generation. Burke et al. (2019) identify financing and institutional barriers that can slow solar and wind adoption in Indonesia, while Setyawati (2020) documents policy perceptions surrounding distributed solar. A monitoring framework that reports only renewable investment can consequently miss whether parallel commitments are increasing the future cost of fossil retirement. The regional generation data do not reveal investment decisions directly, yet the observed output pattern supplies a quantitative warning against assuming that renewable growth automatically reduces fossil exposure.

Taken together, the first set of findings supports a three-measure reporting standard: renewable output, renewable share, and absolute fossil output. Each measure provides information that the other two cannot recover. Renewable output records the scale of delivered low-carbon electricity, the share places that output relative to total generation, and the fossil volume indicates whether incumbent fossil production is contracting. Tran et al. (2024) show that the renewable-energy, growth, and emissions nexus is empirically intertwined, while Mu'min et al. (2024) link ASEAN's energy transition to broader sustainable-development outcomes. These wider relationships make accurate electricity accounting more rather than less important. A transition dashboard that preserves all three measures can support investment appraisal, regional benchmarking, and public accountability without claiming causal effects that annual generation statistics cannot identify.

National Heterogeneity and Regional Composition

The national distribution of fossil growth is highly concentrated. Indonesia recorded the largest absolute increase at 225.89 TWh, followed by Viet Nam at 163.21 TWh. Together these two systems accounted for 55.90% of the regional fossil increase. Malaysia added 95.43 TWh, Thailand 80.81 TWh, and the Philippines 72.88 TWh. Smaller increases in Brunei, Cambodia, Lao PDR, Myanmar, and Singapore should not be interpreted as stronger transition performance because their electricity systems are much smaller. Scale-normalized shares and absolute levels serve different analytical purposes. Resosudarmo et al. (2023) emphasize that Indonesia's transition is shaped by the structure of a large and rapidly growing power system, while Do and Burke (2023b) describe the institutional and economic challenges of coal phase-out in Viet Nam. The cross-country decomposition in Table 3 preserves those differences instead of ranking economies by raw fossil increments.

The national decomposition shows that a favorable fuel-share movement is possible even when fossil generation rises. Malaysia's fossil-share component was -12.80 TWh and Thailand's was -11.98 TWh, indicating that changing national mixes offset part of the scale pressure in both systems. Cambodia, Myanmar, Singapore, and Brunei also recorded negative mix components. Indonesia, Lao PDR, the Philippines, and Viet Nam had positive mix components, with the Philippines at $+19.00$ TWh and Viet Nam at $+20.63$ TWh. These terms are not estimated policy effects; they are exact allocations of the observed change in the product of system size and fossil share. The distinction matters because the same policy environment can produce different accounting outcomes depending on demand growth and starting composition. Safrina (2023) similarly argues that ASEAN's transition pathway must be assessed against development and growth objectives rather than through a single decarbonization metric.

Table 3. National Fossil Generation Decomposition, 2000–2024

Economy	ΔF (TWh)	Scale (TWh)	Mix (TWh)	Δ fossil share (pp)
Brunei	3.01	3.02	-0.01	-0.18
Cambodia	9.51	11.86	-2.35	-29.41

Indonesia	225.89	221.42	4.47	1.90
Lao PDR	11.81	8.13	3.68	13.15
Malaysia	95.43	108.23	-12.80	-9.55
Myanmar	8.09	9.59	-1.50	-11.19
Philippines	72.88	53.88	19.00	22.42
Singapore	25.49	27.03	-1.54	-3.38
Thailand	80.81	92.79	-11.98	-8.12
Viet Nam	163.21	142.58	20.63	12.50

Source: Authors' calculations from Ember (n.d.-b). pp = percentage points.

The Philippine and Vietnamese cases illustrate the denominator effect particularly clearly. The Philippines increased renewable output by 5.99 TWh over the full period, yet its renewable share fell from 42.89% to 20.47%. Viet Nam added 113.81 TWh of renewable generation while its renewable share declined from 54.78% to 42.28%. In both cases, total generation expanded sufficiently rapidly to reduce the renewable share despite higher renewable volumes. A share-only comparison would label these endpoints as deterioration without acknowledging substantial additional renewable electricity. An output-only comparison would label them as improvement without showing that fossil generation rose even faster. The paired indicators avoid both errors. Do et al. (2021) document Viet Nam's rapid solar and wind development, and Do et al. (2022) discuss offshore-wind policy options that could extend renewable growth, but the present accounting shows why technology expansion should be evaluated against the whole electricity balance.

The regional fossil share declined by 6.56 percentage points from 2000 to 2024. The endpoint decomposition attributes +1.26 points to changes within national mixes and -7.82 points to changes in country production weights. The between-country term more than accounts for the aggregate decline, while the within-country term moves in the opposite direction. This result does not imply that every national mix worsened; several improved substantially. It means that, after weighting national mix changes by average endpoint production shares, the net within-country contribution was slightly positive. The favorable regional headline is consequently driven mainly by a redistribution of regional generation toward economies whose fossil shares were lower than the regional average. Such composition effects are standard in aggregated economic statistics and deserve explicit reporting whenever regional performance is used for investment or policy evaluation.

Table 4. Regional Fossil-Share Decomposition by Period

Period / convention	Within countries (pp)	Between countries (pp)	Total share change (pp)
2000–2010	4.84	-1.99	2.85
2010–2019	-1.29	-3.18	-4.47
2019–2024	-3.97	-0.96	-4.94
2000–2024	1.26	-7.82	-6.56
2000–2024 chained	0.66	-7.22	-6.56

Source: Authors' calculations from Ember (n.d.-b). Negative contributions lower the regional fossil share.

Changes in production weights make the mechanism concrete. Viet Nam's share of regional generation increased from 7.01% in 2000 to 22.46% in 2024 while its fossil share remained below the regional share at both endpoints. Thailand's regional production weight declined from 25.22% to 14.76%, while its fossil share was above the regional average at both endpoints. Those relative movements lower the regional fossil share mechanically even if no electricity is physically transferred from one country to another. The result should not be interpreted as a national performance score. Aisbett et al. (2023) show that international green-economy collaboration can redistribute benefits across jurisdictions, while Do and Burke (2023a) demonstrate that cross-border power trade requires distinct institutional arrangements. The decomposition isolates production composition only; it does not assign consumption responsibility or trade-adjusted emissions.

Annual chaining provides a useful robustness check on the endpoint allocation. Summing 24 adjacent-year decompositions yields a within-country contribution of +0.66 percentage points and a between-country contribution of −7.22 points. Both conventions reproduce the same −6.56-point total regional change, but the allocation differs because the path of national shares and generation weights matters. The sign of the long-run result is nevertheless stable: the between-country component remains strongly favorable, while the within-country component remains mildly unfavorable. This path sensitivity argues against presenting the endpoint contribution as a causal quantity. It is better interpreted as one transparent accounting convention, accompanied by the chained alternative. Kuok et al. (2024) identify diverse financial, regulatory, and infrastructure barriers across ASEAN; those differences reinforce the value of retaining country trajectories rather than collapsing them into a single regional coefficient.

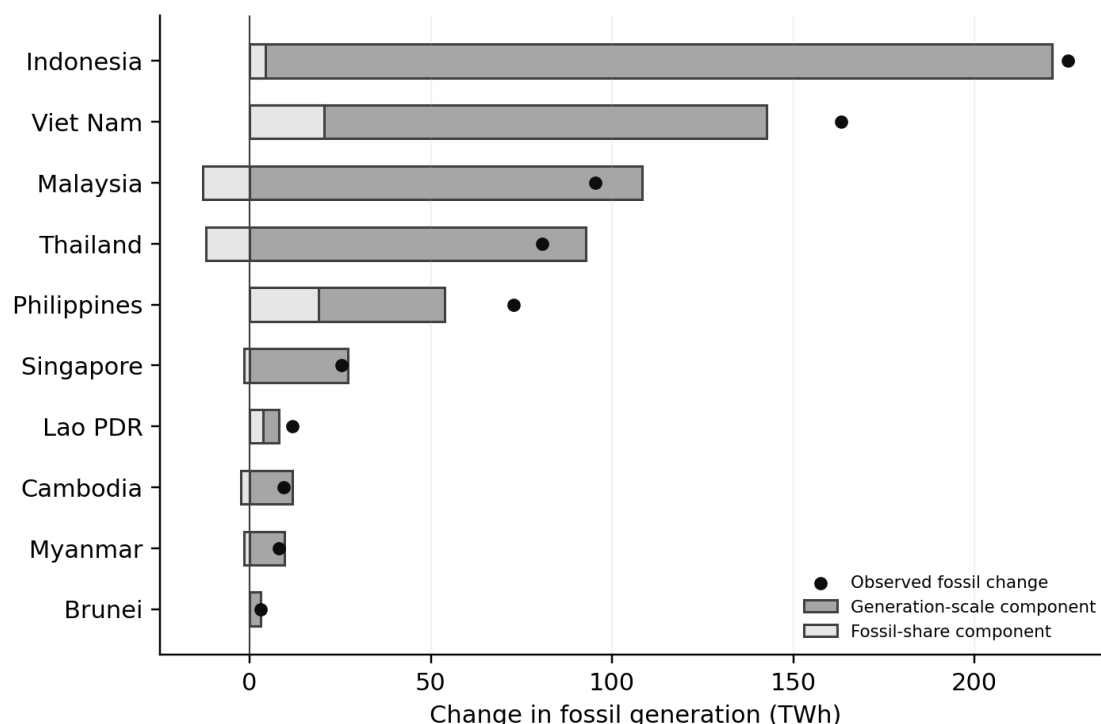


Figure 2. National Fossil Generation Changes and Accounting Components
Source: Authors' calculations from Ember (n.d.-b).

The 2019–2024 decomposition differs from the long-run picture and signals a more favorable recent mix trajectory. National mix changes contributed −3.97 percentage points to the regional fossil-share change, while changing production weights contributed −0.96 points. Most of the recent decline in the regional fossil share therefore came from cleaner national mixes under the chosen decomposition. Viet Nam alone contributed −2.59 points to the within-country term over this interval. This improvement is important because it indicates that the composition of electricity generation changed more decisively after 2019. Yet fossil generation still increased in all ten economies during the same period, so the relative improvement did not cross the threshold into absolute regional fossil decline. The coexistence of these two facts is precisely why transition assessment should distinguish rate-of-progress indicators from level outcomes.

For investors and utilities, the composition findings affect the interpretation of regional transition opportunities. A regional decline in fossil share can create a favorable market narrative even when individual systems face rising fossil volumes and costly future retirement obligations. State-owned utilities, which Benoit et al. (2022) identify as central actors in power-sector decarbonization, may need to finance renewable expansion while managing existing coal and gas portfolios. Renewable policy can also operate unevenly across technologies and ownership structures; Setyawati (2020) shows that perceptions of rooftop solar rules can shape participation in Indonesia. The data here cannot observe balance-sheet exposure, power-purchase agreements, or refinancing risk, but they identify the systems

where large absolute fossil increases coexist with changing renewable shares. That information can guide more detailed financial due diligence without substituting for project-level analysis.

The national and regional evidence also clarifies why transition finance should specify the outcome it intends to purchase. Financing new renewable capacity can expand low-carbon supply, but the aggregate effect on fossil generation depends on demand, dispatch priority, transmission, storage, imports, and retirement schedules. Bourcet (2020) emphasizes that renewable deployment has many determinants, while Burke and Do (2021) show that broader economic instruments are relevant to greener development. A project-level claim of fossil displacement is consequently stronger than a claim of renewable addition and requires evidence on what generation or investment is actually avoided. The decomposition does not estimate that counterfactual. Its contribution is to establish an auditable baseline against which transition-finance claims can be tested: new renewable output should be reported alongside the subsequent path of fossil generation and the scale of electricity demand.

Temporal Sensitivity, Transition Finance, and Policy Implications

Annual transitions show that renewable growth was far more often an addition to expanding fossil generation than a direct coincidence with fossil decline. Using the 0.05 TWh tolerance, renewables increased while fossil generation declined in 31 of 240 annual country changes, or 12.92%. Both generation categories increased in 92 observations, renewable generation declined while fossil increased in 44, both declined in six, and 67 observations fell into the near-zero category. Among the 133 country-years with a renewable increase above the tolerance, only 23.31% also recorded a fossil decline. Figure 3 displays the distribution. The counts are descriptive and cannot establish that renewables caused either the rise or fall in fossil output. They nevertheless provide a direct answer to a practical monitoring question: in most annual episodes with material renewable growth, the observed electricity balance did not show simultaneous fossil contraction.

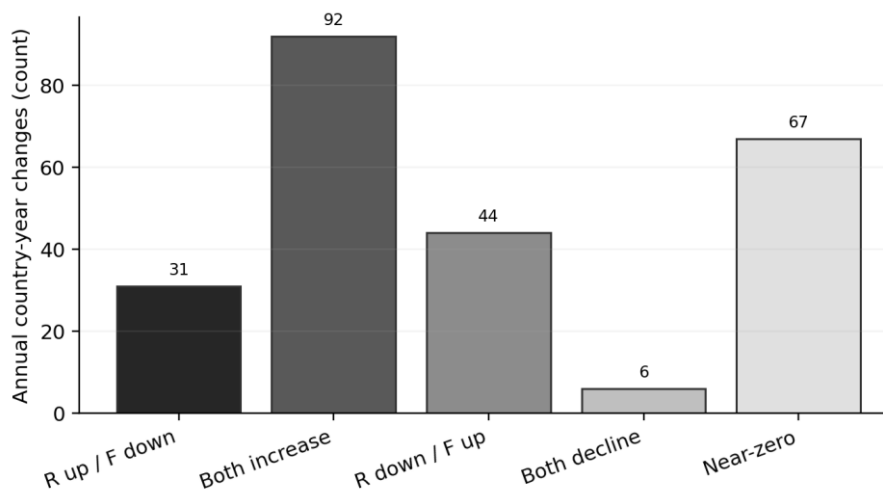


Figure 3. Annual Joint Movements in Renewable and Fossil Generation

Source: Authors' calculations from Ember (n.d.-b), 2001–2024; tolerance = 0.05 TWh.

The pattern remains when the observation window is lengthened. Across 200 overlapping five-year intervals, only 17 cases combined renewable growth with fossil decline, while 132 showed simultaneous increases. Longer windows reduce sensitivity to a single weather year or temporary outage, although overlap means the intervals are not statistically independent. The persistence of simultaneous growth suggests that short-run renewable success and medium-run fossil reduction should not be treated as equivalent performance measures. Urban et al. (2018) document the institutional and distributional complexity of energy transformation in Viet Nam, illustrating why electricity outcomes can reflect multiple social and policy channels. Annual generation statistics cannot isolate those channels, but they can identify whether the desired fossil-volume outcome has actually occurred. This distinction is especially important when public communication frames a renewable expansion as evidence of a completed transition rather than as one input into a longer restructuring process.

Sensitivity to the country sample does not overturn the central volume result. Excluding Indonesia leaves a 470.24 TWh increase in regional fossil generation; excluding Viet Nam leaves 532.92 TWh; excluding both leaves 307.03 TWh; and excluding Lao PDR leaves 684.32 TWh. Every alternative boundary still records higher fossil generation over 2000–2024. Endpoint sensitivity produces the same sign. A three-year average comparing 2000–2002 with 2022–2024 yields a 609.67 TWh fossil increase and a 30.40% renewable contribution to generation growth. The magnitude changes because large systems and endpoint conditions matter, but the substantive conclusion survives. This robustness is useful for economic interpretation because it prevents the regional result from being attributed solely to one dominant country or one anomalous endpoint year.

The fixed-generation benchmark quantifies the scale of the additional renewable output associated with preventing further fossil growth after 2019. Holding observed 2024 total generation fixed, renewable generation would have needed to be 115.02 TWh higher than observed to keep fossil output at its 2019 level of 886.64 TWh. The implied 2024 renewable level is 464.96 TWh rather than the observed 349.94 TWh. Renewable output would consequently have needed to rise by 229.93 TWh from 2019, roughly twice the observed increase of 114.91 TWh. This is not a cost-optimal dispatch solution or a forecast. It is an arithmetic endpoint benchmark that makes the scale gap transparent. The largest country contributions to the benchmark are Indonesia at 56.93 TWh, the Philippines at 14.76 TWh, Thailand at 11.12 TWh, and Viet Nam at 10.34 TWh.

Table 5. Additional Renewable Output Associated with Holding 2024 Fossil Generation at Its 2019 Level

Economy	ΔG 2019–2024 (TWh)	ΔR 2019–2024 (TWh)	Additional R in 2024 (TWh)
Brunei	0.63	0.01	0.62
Indonesia	76.10	19.17	56.93
Cambodia	6.81	1.31	5.50
Lao PDR	21.07	20.30	0.77
Myanmar	2.39	−0.48	2.87
Malaysia	19.62	11.55	8.07
Philippines	18.14	3.38	14.76
Singapore	5.47	1.43	4.04
Thailand	13.01	1.89	11.12
Viet Nam	66.69	56.35	10.34
Regional total	229.93	114.91	115.02

Source: Authors' calculations from Ember (n.d.-b).

The benchmark highlights why electricity-demand policy belongs in transition strategy. If total generation grows quickly, renewable investment must first serve additional demand before it can reduce fossil generation in absolute terms. Burke and Kurniawati (2018) show that Indonesian electricity use responds to subsidy reform, while Burke and Do (2021) discuss economic instruments capable of supporting greener development in Asia. The present study does not advocate suppressing essential electricity consumption or economic growth. It indicates that efficiency, demand management, industrial electrification, and supply expansion should be reconciled within one quantitative planning framework. A renewable target stated only as capacity or percentage share provides no direct information about the fossil volume consistent with the target. Planning documents can improve accountability by publishing expected demand, renewable generation, fossil generation, storage, imports, and retirement trajectories under the same scenario assumptions.

Regional coordination can reduce some transition costs, but it does not remove the need for consistent accounting. More output from a relatively renewable-intensive exporter may lower the regional fossil share, yet welfare, reliability, and emissions consequences depend on transmission, market rules, dispatch, and where fossil generation is avoided. Do and Burke (2023a) emphasize the institutional sequencing required for multilateral ASEAN electricity trade, while Do et al. (2023) identify renewable-trade opportunities in the Greater Mekong Subregion. Aisbett et al. (2023) similarly show that green-economy collaboration can produce shared gains when countries align incentives.

Regional monitoring should accompany national generation with imports and exports and should avoid crediting the same electricity as separate production in both exporting and importing jurisdictions. The generation boundary used here is deliberately conservative: it attributes recorded production to the location where it was generated and leaves trade-adjusted consumption to future analysis.

The findings also alter how renewable success should be described in financial and policy communication. The evidence supports strong recent progress in the contribution of renewables to incremental generation, especially after 2019, but it does not support a claim that the regional fossil fleet has already entered absolute decline. This distinction matters for transition bonds, sustainability-linked finance, and corporate decarbonization plans because performance metrics can create incentives to emphasize favorable relative indicators. Do and Burke (2024) demonstrate that coal phase-out requires explicit attention to retirement in major coal-dependent systems. Van der Ploeg and Rezai (2020) show why delayed adjustment can increase stranded-asset exposure. A credible financing framework can retain renewable deployment metrics while adding absolute fossil generation or verified retirement milestones, thereby reducing the risk that rising demand masks continued fossil expansion behind an improving percentage share.

The analysis has limitations that should remain visible in interpretation. Ember's harmonized series depend on national reporting and may omit parts of captive generation, particularly in settings where industrial self-generation is material (Ember, n.d.-a). Domestic generation is not final consumption and does not allocate emissions embodied in electricity trade. The renewable category combines technologies with different dispatchability, environmental impacts, and financing structures. Annual data cannot distinguish curtailment, transmission constraints, plant outages, fuel-price shocks, hydrological conditions, or contract obligations. The decomposition also has no causal identification and should not be used to assign credit or blame to a specific policy. These limitations favor more detailed follow-up using plant-level production, hourly dispatch, firm financial data, policy implementation dates, and cross-border flows. They do not alter the arithmetic reconciliation of the observed generation categories within the documented source boundary.

For business and public policy, the central implication is a shift from one-dimensional transition reporting toward reconciled operational metrics. Renewable developers need demand and grid information to assess market absorption; utilities need retirement and dispatch plans to manage legacy assets; lenders need exposure metrics for fossil and renewable portfolios; and governments need indicators that distinguish national improvements from regional composition. The ASEAN literature already shows that investment barriers, policy effectiveness, and sustainable-development objectives interact (Aleluia et al., 2022; Kuok et al., 2024; Mu'min et al., 2024). The evidence reported here adds a measurement discipline to that agenda. A regional transition can be described as stronger when renewable additions are large, national mix components improve, and absolute fossil generation begins to fall. Until those conditions coincide, reporting should state explicitly which dimensions are improving and which remain unresolved.

CONCLUSION

The study shows that renewable expansion in Southeast Asia has accelerated substantially without yet producing an absolute regional retreat of fossil electricity. Across ten economies, renewables supplied 28.44% of the 972.84 TWh increase in generation between 2000 and 2024, while fossil output rose by 696.13 TWh. The relative picture is more favorable: the regional fossil share declined by 6.56 percentage points, and renewables supplied nearly half of incremental generation after 2019. Exact decomposition reveals that the long-run regional share improvement is dominated by changing production weights rather than by the weighted sum of national mix improvements, whereas the 2019–2024 interval shows a stronger within-country transition. Reporting renewable additions, absolute fossil volumes, and regional composition together provides a more informative basis for economic and business decisions than any single share indicator.

For transition finance and power-sector planning, the results support explicit linkage between renewable deployment and fossil-operation objectives. Investors and policymakers can separately monitor delivered renewable electricity, total electricity demand, coal and gas generation, verified retirement, cross-border trade, and the financial exposure of incumbent assets. The fixed-generation benchmark indicates that renewable output in 2024 would have needed to be 115.02 TWh higher than observed to keep regional fossil generation at its 2019 level while holding total 2024 generation

unchanged. That quantity is not a feasibility estimate, but it makes the required scale of substitution visible. Future research should combine the accounting framework with plant-level dispatch, transmission constraints, firm-level balance sheets, electricity prices, policy timing, and trade flows so that the mechanisms behind national differences can be estimated rather than inferred from aggregate generation records.

REFERENCES

- Aisbett, E., Raynal, W., Steinhäuser, R., & Jones, B. (2023). International green economy collaborations: Chasing mutual gains in the energy transition. *Energy Research & Social Science*, 104, 103249. <https://doi.org/10.1016/j.erss.2023.103249>
- Aleluia, J., Tharakan, P., Chikkatur, A. P., Shrimali, G., & Chen, X. (2022). Accelerating a clean energy transition in Southeast Asia: Role of governments and public policy. *Renewable and Sustainable Energy Reviews*, 159, 112226. <https://doi.org/10.1016/j.rser.2022.112226>
- Bai, W., Zhang, L., Lu, S., Ren, J., & Zhou, Z. (2023). Sustainable energy transition in Southeast Asia: Energy status analysis, comprehensive evaluation and influential factor identification. *Energy*, 284, 128670. <https://doi.org/10.1016/j.energy.2023.128670>
- Benoit, P., Clark, A., Schwarz, M., & Dibley, A. (2022). Decarbonization in state-owned power companies: Lessons from a comparative analysis. *Journal of Cleaner Production*, 355, 131796. <https://doi.org/10.1016/j.jclepro.2022.131796>
- Bersalli, G., Menanteau, P., & El-Methni, J. (2020). Renewable energy policy effectiveness: A panel data analysis across Europe and Latin America. *Renewable and Sustainable Energy Reviews*, 133, 110351. <https://doi.org/10.1016/j.rser.2020.110351>
- Bourcet, C. (2020). Empirical determinants of renewable energy deployment: A systematic literature review. *Energy Economics*, 85, 104563. <https://doi.org/10.1016/j.eneco.2019.104563>
- Burke, P. J., & Do, T. N. (2021). Greening Asia's economic development. *Asian Economic Policy Review*, 16(1), 22–39. <https://doi.org/10.1111/aepr.12316>
- Burke, P. J., & Kurniawati, S. (2018). Electricity subsidy reform in Indonesia: Demand-side effects on electricity use. *Energy Policy*, 116, 410–421. <https://doi.org/10.1016/j.enpol.2018.02.018>
- Burke, P. J., Widnyana, J., Anjum, Z., Aisbett, E., Resosudarmo, B., & Baldwin, K. G. H. (2019). Overcoming barriers to solar and wind energy adoption in two Asian giants: India and Indonesia. *Energy Policy*, 132, 1216–1228. <https://doi.org/10.1016/j.enpol.2019.05.055>
- Do, T. N. (2024). Insider perspectives on Southeast Asia's clean energy transition. *Asia & the Pacific Policy Studies*, 11(2), e390. <https://doi.org/10.1002/app5.390>
- Do, T. N., & Burke, P. J. (2023a). Is ASEAN ready to move to multilateral cross-border electricity trade? *Asia Pacific Viewpoint*, 64(1), 110–125. <https://doi.org/10.1111/apv.12343>
- Do, T. N., & Burke, P. J. (2023b). Phasing out coal power in a developing country context: Insights from Vietnam. *Energy Policy*, 176, 113512. <https://doi.org/10.1016/j.enpol.2023.113512>
- Do, T. N., & Burke, P. J. (2024). Phasing out coal power in two major Southeast Asian thermal coal economies: Indonesia and Vietnam. *Energy for Sustainable Development*, 80, 101451. <https://doi.org/10.1016/j.esd.2024.101451>
- Do, T. N., Burke, P. J., & Lu, B. (2023). Harnessing solar and wind for sustainable cross-border electricity trade in the Greater Mekong Subregion. *Frontiers in Environmental Science*, 11, 1188335. <https://doi.org/10.3389/fenvs.2023.1188335>
- Do, T. N., Burke, P. J., Hughes, L., & Thi, T. D. (2022). Policy options for offshore wind power in Vietnam. *Marine Policy*, 141, 105080. <https://doi.org/10.1016/j.marpol.2022.105080>
- Do, T. N., Burke, P. J., Nguyen, H. N., Overland, I., Suryadi, B., Swandaru, A., & Yurnaidi, Z. (2021). Vietnam's solar and wind power success: Policy implications for the other ASEAN countries. *Energy for Sustainable Development*, 65, 1–11. <https://doi.org/10.1016/j.esd.2021.09.002>
- Ember. (n.d.-a). Electricity data methodology (Version 1.5). https://files.ember-energy.org/public-downloads/ember_electricity_data_methodology.pdf
- Ember. (n.d.-b). Yearly electricity data [Data set]. Retrieved September 11, 2026, from https://storage.googleapis.com/emb-prod-bkt-publicdata/public-downloads/yearly_full_release_long_format.csv

- Kuok, F., Sdok, S., Ho, S., & Muhamad, I. A. (2024). Barriers to ASEAN renewable energy: A systematic review and bibliometric analysis. *Chemical Engineering Transactions*, 113, 511–516. <https://doi.org/10.3303/CET24113086>
- Mu'min, M. S., Yaqin, M., & Anam, M. S. (2024). Does energy transition matter to sustainable development in ASEAN? *International Journal of Renewable Energy Development*, 13(2), 191–205. <https://doi.org/10.61435/ijred.2024.59544>
- Resosudarmo, B. P., Rezki, J. F., & Effendi, Y. (2023). Prospects of energy transition in Indonesia. *Bulletin of Indonesian Economic Studies*, 59(2), 149–177. <https://doi.org/10.1080/00074918.2023.2238336>
- Safrina, R. (2023). ASEAN energy transition pathway toward the 2030 agenda. *Environmental Progress & Sustainable Energy*, 42(4), e14101. <https://doi.org/10.1002/ep.14101>
- Setyawati, D. (2020). Analysis of perceptions towards the rooftop photovoltaic solar system policy in Indonesia. *Energy Policy*, 144, 111569. <https://doi.org/10.1016/j.enpol.2020.111569>
- Sun, J. W. (1998). Changes in energy consumption and energy intensity: A complete decomposition model. *Energy Economics*, 20(1), 85–100. [https://doi.org/10.1016/S0140-9883\(97\)00012-1](https://doi.org/10.1016/S0140-9883(97)00012-1)
- Tran, T., Bui, H., Vo, A. T., & Vo, D. H. (2024). The role of renewable energy in the energy-growth-emission nexus in the ASEAN region. *Energy, Sustainability and Society*, 14, 17. <https://doi.org/10.1186/s13705-024-00446-3>
- Urban, F., Siciliano, G., Wallbott, L., Lederer, M., & Dang Nguyen, A. (2018). Green transformations in Vietnam's energy sector. *Asia & the Pacific Policy Studies*, 5(3), 558–582. <https://doi.org/10.1002/app5.251>
- Vakulchuk, R., Overland, I., & Suryadi, B. (2023). ASEAN's energy transition: How to attract more investment in renewable energy. *Energy, Ecology and Environment*, 8(1), 1–16. <https://doi.org/10.1007/s40974-022-00261-6>
- van der Ploeg, F., & Rezai, A. (2020). Stranded assets in the transition to a carbon-free economy. *Annual Review of Resource Economics*, 12(1), 281–298. <https://doi.org/10.1146/annurev-resource-110519-040938>
- Wong, R., & Dewayanti, A. (2024). Indonesia's energy transition: Dependency, subsidies and renewables. *Asia & the Pacific Policy Studies*, 11(2), e391. <https://doi.org/10.1002/app5.391>
- York, R. (2012). Do alternative energy sources displace fossil fuels? *Nature Climate Change*, 2(6), 441–443. <https://doi.org/10.1038/nclimate1451>
- York, R., & Bell, S. E. (2019). Energy transitions or additions? *Energy Research & Social Science*, 51, 40–43. <https://doi.org/10.1016/j.erss.2019.01.008>