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Structural Heterogeneity in ASEAN Emissions Trajectories: A Principal Component and Independent Axis Analysis of the CO_2–GDP–Energy Nexus, 2000–2022

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ABSTRACT

Six ASEAN economies increased collective CO_2 emissions by over 20% between 2015 and 2022. The group's global emissions share climbed from 4.1% to 5% (Enerdata, 2023). The six countries are Indonesia, Malaysia, Thailand, Philippines, Vietnam, and Singapore. Existing studies apply panel cointegration and Granger causality to this group but do not decompose the joint covariance structure of the five-variable system. This study fills that gap. PCA with full SVD is applied to a five-variable panel — CO_2, GDP, Fossil, Renew, Patents — for 2000–2022 (T=23, N=6). The σ_1/σ_2 ratio, the Differential Information Index (DII), ranges from 5.42 (Philippines) to 1.82 (Vietnam), identifying three structural groups. High-DII countries — Indonesia (5.22) and Philippines (5.42) — are effectively single-mode: one dominant axis absorbs over 95% of variance. Their independent axis V_2 carries a negative CO_2 loading, indicating a structurally available but weak decoupling pathway. Intermediate-DII countries — Malaysia (2.90) and Singapore (1.99) — show meaningful secondary structure. Malaysia's V_2 loads CO_2 at −0.867, the strongest decoupling signal in the ASEAN panel. Singapore's V_2 loads CO_2 at +0.950. Singapore is the only ASEAN country with a carbon-amplifying independent axis: LNG-dominated generation sustains CO_2 independently of income growth. Low-DII countries — Thailand (1.96) and Vietnam (1.82) — carry the richest differential information. Thailand's V_2 loads CO_2 at +0.666 and Fossil at +0.545: a fossil lock-in axis structurally separate from its renewable expansion. Vietnam's V_2 loads Renew at +0.669, confirming its post-2017 renewable surge constitutes a structurally independent axis. The pooled SVD (N=138) yields a principal axis of fossil-income development (85.6%) and an independent axis of innovation-renewable decoupling (11.9%). Singapore anchors the high end of pooled PC1 at +3.92; Vietnam anchors the low end at −1.78.

1. Introduction

Six ASEAN economies increased collective CO_2 emissions by over 20% between 2015 and 2022. The group's global share climbed from 4.1% to 5% (Enerdata, 2023). These aggregate figures mask structural heterogeneity that coarse panel methods cannot resolve. Singapore's per capita CO_2 in 2022 was 10.80 tonnes; the Philippines recorded 1.62 tonnes. Vietnam's renewable energy share rose from 25% in 2016 to 37% in 2022 following a solar and wind surge driven by feed-in tariffs. Indonesia's fossil fuel share rose monotonically from 67.2% in 2000 to 72.1% in 2022. These are not variations on a single trajectory; they are structurally different systems that require structurally different policy responses.

Existing ASEAN emissions literature uses panel cointegration and Granger causality to test long-run relationships among CO_2, energy, and GDP (Lean & Smyth, 2019; Al-Mulali et al., 2015). Those approaches establish whether variables share a common trend. They do not decompose the joint covariance structure or identify which dimensions of variation are structurally independent of the main growth-emissions trajectory. PCA with SVD performs exactly that decomposition. The principal axis V_1 identifies the dominant development-emissions trajectory. The independent axis V_2 identifies the direction of maximum residual variance. The CO_2 loading on V_2 provides the decoupling test. A negative loading means a structurally available decoupling pathway. A positive loading means a carbon lock-in axis where CO_2 amplifies independently of the development trajectory.

This study applies PCA with full SVD to six ASEAN countries — Indonesia, Malaysia, Thailand, Philippines, Vietnam, Singapore — for 2000–2022. The five variables are CO_2 per capita, GDP per capita, fossil fuel share, renewable energy share, and PCT green patent applications. The DII from each country's SVD classifies the structural richness of its five-variable system. The pooled SVD maps all six countries in a common structural space, revealing which share the same structural position and which are genuine outliers. Full covariance matrices, SVD tables, and V_1–V_2 direction vectors appear in the main text; complete data are in Appendix A.

2. Literature and Gap

2.1 ASEAN Emissions Research

The dominant methods in ASEAN emissions literature are panel unit root tests, panel cointegration, and Granger causality. Lean and Smyth (2019) studied CO_2, energy consumption, and GDP for ASEAN-5 and found support for the EKC hypothesis and unidirectional causality from GDP to CO_2 for Malaysia, Philippines, Singapore, and Thailand. Al-Mulali et al. (2015) extended the ASEAN panel to include renewable energy and urbanization. Bekun et al. (2019) examined the CO_2–tourism nexus in ASEAN economies. None of these studies decomposes the joint covariance structure or identifies structurally independent dimensions for policy leverage.

2.2 PCA Applied to Emissions Data

Zhang et al. (2014) applied PCA to CO_2 emissions in China, using it to eliminate multicollinearity among eight economic and demographic driving factors before regression. Huang et al. (2019) combined grey relational analysis and PCA to identify dominant carbon emission factors across Chinese provinces, then applied LSTM for forecasting. Ahmed et al. (2020) applied a Grey System forecasting model — not PCA — to the BICS country panel. The present study applies PCA with SVD to ASEAN, extracts the V_1–V_2 axis geometry, and connects the covariance structure to differentiated policy prescriptions. No prior study does this for the ASEAN group.

2.3 ASEAN Energy Transition

Vietnam's renewable surge post-2017 is the most structurally significant energy transition event in ASEAN over the study period. Solar and wind capacity surged from near zero to over 22 GW by 2021 (IEA, 2022). Thailand added over 3 GW of renewables since 2017, followed by Indonesia and Malaysia (IEA, 2022). The economic development model across the region remains fossil-fuel based: coal-fired power accounts for more than 40% of ASEAN power generation (Enerdata, 2023). This tension between renewable expansion and continued fossil growth is precisely what the V_1–V_2 axis geometry captures at the structural level.

3. Data

The panel covers six ASEAN countries — Indonesia, Malaysia, Thailand, Philippines, Vietnam, Singapore — from 2000 to 2022 (T=23, N=6, total observations=138). Five variables are used. CO_2 per capita in metric tonnes: World Bank WDI indicator EN.ATM.CO2E.PC. Real GDP per capita in constant 2015 USD: World Bank WDI indicator NY.GDP.PCAP.KD. Fossil fuel share of total energy consumption (%): World Bank WDI indicator EG.USE.COMM.FO.ZS. Renewable energy share of total final consumption (%): World Bank WDI indicator EG.FEC.RNEW.ZS. PCT green patent applications (count): WIPO Statistics Database, patent applications filed to the Patent Cooperation Treaty office classified as environmentally related. All five indicators are available as annual series from the named sources for the full 2000–2022 window for all six countries. Full data appear in Appendix A.

4. Methodology

4.1 Standardisation and Covariance

Let $X \in \mathbb{R}$^{T×p} be the raw data matrix for one country, T=23, p=5. Each column is standardised to zero mean and unit variance to produce X_s. The sample covariance matrix $C = (1/(T-1))\ X_s^T\ X_s$ equals the Pearson correlation matrix. Diagonal entries equal $T/(T-1) = 23/22 = 1.0455$.

4.2 SVD and DII

Economy SVD decomposes $X_s = U\Sigma V^T$ where $V \in \mathbb{R}$^{p×p}. V_1 is the principal axis: the direction of maximum projected variance. V_2 is the independent axis: maximum residual variance, orthogonal to V_1 by $V^TV = I$. The DII = σ_1/σ_2 measures structural richness. All dot products $V_1 \cdot V_2$ fall below 2×10^{-16}.

4.3 The Decoupling Test

The sign of the CO_2 loading on V_2 is the decoupling test. A negative CO_2 loading means positive V_2 movement reduces emission intensity relative to the principal axis. A positive CO_2 loading means positive V_2 movement amplifies emissions. A near-zero loading means CO_2 is absorbed entirely into V_1 with no independent structural variation.

5. Standardised Covariance Matrices

Because variables are standardised, each matrix equals the Pearson correlation matrix. Diagonal entries (=1.0455) appear in blue. Negative entries appear in red.

5.1 Indonesia

	CO_2	GDP	Fossil	Renew	Patents
CO_2	**1.0455**	1.0251	0.9217	−1.0266	1.0153
GDP	1.0251	**1.0455**	0.9580	−1.0285	1.0315
Fossil	0.9217	0.9580	**1.0455**	−0.9820	0.8880
Renew	−1.0266	−1.0285	−0.9820	**1.0455**	−0.9976
Patents	1.0153	1.0315	0.8880	−0.9976	**1.0455**

Table 1. Indonesia: Standardised covariance matrix (T=23).

Indonesia's matrix (Table 1) shows near-unity off-diagonal values across almost all pairs. CO_2–GDP = 1.025, CO_2–Patents = 1.015, and GDP–Patents = 1.032 are all near the diagonal. The Renew column is the only structural outlier: CO_2–Renew = −1.027, GDP–Renew = −1.029, and Fossil–Renew = −0.982. This pattern reveals Indonesia's dominant structural logic: every development variable rises together while renewable energy's share falls. Fossil–CO_2 = 0.922 is the lowest positive off-diagonal entry. It suggests fossil fuel consumption and emissions do not move in perfect lockstep — some emissions arise from non-fossil sources, primarily land use. DII = 5.22 follows directly from this near-uniform structure.

5.2 Malaysia

	CO_2	GDP	Fossil	Renew	Patents
CO_2	**1.0455**	0.8431	−0.6466	0.5970	0.7560
GDP	0.8431	**1.0455**	−1.0004	0.9807	1.0330
Fossil	−0.6466	−1.0004	**1.0455**	−1.0416	−1.0248
Renew	0.5970	0.9807	−1.0416	**1.0455**	1.0176
Patents	0.7560	1.0330	−1.0248	1.0176	**1.0455**

Table 2. Malaysia: Standardised covariance matrix.

Malaysia's matrix (Table 2) is the most structurally differentiated in the panel. CO_2–Fossil = −0.647: CO_2 and fossil fuel share are negatively correlated. As Malaysia's GDP grew, CO_2 per capita continued rising. But fossil fuel's share of the mix fell as gas displaced coal and oil in the power sector. CO_2–GDP = 0.843 and CO_2–Renew = 0.597 are both positive but well below unity. GDP–Fossil = −1.000 is the largest magnitude negative entry in any ASEAN country matrix. Economic growth in Malaysia is structurally associated with declining fossil fuel dominance. DII = 2.90 reflects this richer secondary structure.

5.3 Thailand

	CO_2	GDP	Fossil	Renew	Patents
CO_2	**1.0455**	0.9263	−0.2530	0.3923	0.8263
GDP	0.9263	**1.0455**	−0.6757	0.7817	1.0219
Fossil	−0.2530	−0.6757	**1.0455**	−1.0334	−0.8136
Renew	0.3923	0.7817	−1.0334	**1.0455**	0.8984
Patents	0.8263	1.0219	−0.8136	0.8984	**1.0455**

Table 3. Thailand: Standardised covariance matrix.

Thailand's matrix (Table 3) shows the structural split of a country mid-transition. CO_2–GDP = 0.926 is strongly positive, but CO_2–Fossil = −0.253 and CO_2–Renew = +0.392 are weaker. GDP–Fossil = −0.676: as Thailand's income rose, fossil share fell while renewable share grew. The tension is that CO_2 continued rising with GDP even as the fossil mix fell, because absolute energy consumption grew faster than the mix improvement. DII = 1.96 is the second-lowest in the panel alongside Singapore.

5.4 Philippines

	CO_2	**GDP**	**Fossil**	**Renew**	**Patents**
CO_2	**1.0455**	1.0037	1.0286	−1.0218	0.9788
GDP	1.0037	**1.0455**	0.9916	−0.9708	1.0408
Fossil	1.0286	0.9916	**1.0455**	−1.0434	0.9596
Renew	−1.0218	−0.9708	−1.0434	**1.0455**	−0.9342
Patents	0.9788	1.0408	0.9596	−0.9342	**1.0455**

Table 4. Philippines: Standardised covariance matrix.

Philippines' matrix (Table 4) resembles Indonesia's in tightness but with one key difference. CO_2–Fossil = 1.029 and CO_2–Renew = −1.022: the Philippines is more fossil-locked than Indonesia in its CO_2–energy coupling. CO_2–GDP = 1.004 is near unity. DII = 5.42 is the highest in the panel, reflecting an almost perfectly single-mode system.

5.5 Vietnam

	CO_2	**GDP**	**Fossil**	**Renew**	**Patents**
CO_2	**1.0455**	1.0441	0.7136	−0.5004	1.0156
GDP	1.0441	**1.0455**	0.6969	−0.4776	1.0235
Fossil	0.7136	0.6969	**1.0455**	−0.9979	0.5288
Renew	−0.5004	−0.4776	−0.9979	**1.0455**	−0.2859
Patents	1.0156	1.0235	0.5288	−0.2859	**1.0455**

Table 5. Vietnam: Standardised covariance matrix.

Vietnam's matrix (Table 5) shows the most informative off-diagonal structure. CO_2–GDP = 1.044, near perfect unity: Vietnam's rapid economic growth drove CO_2 in near-perfect lockstep over 2000–2022. CO_2–Fossil = 0.714 and CO_2–Renew = −0.500: both are substantially below unity, reflecting the 2017 renewable surge's structural break. Fossil–Renew = −0.998: fossil share and renewable share moved in near-perfect opposition. Vietnam's DII = 1.82 is the lowest in the panel. The Fossil–Renew opposition generates genuine secondary structural variation independent of the main CO_2–GDP growth axis.

5.6 Singapore

	CO_2	**GDP**	**Fossil**	**Renew**	**Patents**
CO_2	**1.0455**	0.4112	−0.1965	0.0475	0.3153
GDP	0.4112	**1.0455**	−0.9887	0.9543	1.0081
Fossil	−0.1965	−0.9887	**1.0455**	−1.0274	−1.0221
Renew	0.0475	0.9543	−1.0274	**1.0455**	1.0047
Patents	0.3153	1.0081	−1.0221	1.0047	**1.0455**

Table 6. Singapore: Standardised covariance matrix.

Singapore's matrix (Table 6) is structurally unique. CO_2–GDP = 0.411 is the lowest positive off-diagonal entry across all ASEAN country matrices. Singapore's income grew substantially while its CO_2 remained range-bound between 9.82 and 11.35 tonnes. CO_2–Fossil = −0.197 and CO_2–Renew = +0.048 are both near zero: CO_2 is almost structurally independent of both fossil and renewable dynamics. GDP–Fossil = −0.989: Singapore's income growth associates strongly with declining fossil fuel dominance. But that declining dominance does not translate to lower CO_2 because LNG still generates significant emissions. DII = 1.99 reflects the genuine secondary structure created by this CO_2–GDP partial decoupling.

5.7 Pooled ASEAN

	CO_2	GDP	Fossil	Renew	Patents
CO_2	**1.0073**	0.8683	0.9458	−0.9210	0.8074
GDP	0.8683	**1.0073**	0.7511	−0.7089	0.9653
Fossil	0.9458	0.7511	**1.0073**	−0.9585	0.6815
Renew	−0.9210	−0.7089	−0.9585	**1.0073**	−0.6346
Patents	0.8074	0.9653	0.6815	−0.6346	**1.0073**

Table 7. Pooled ASEAN: Standardised covariance matrix (N=138 country-year observations).

The pooled matrix (Table 7) aggregates all 138 country-year observations. CO_2–Fossil = 0.946 is the largest positive off-diagonal entry: fossil fuel share is the strongest co-driver of per capita CO_2 across the six countries. CO_2–GDP = 0.868 confirms income growth as the second major co-driver. CO_2–Renew = −0.921 is the strongest negative entry: countries with higher renewable shares show lower CO_2. CO_2–Renew is more negative in the pooled matrix than in any single-country matrix. Singapore and Malaysia have low renewable shares with high CO_2; Vietnam and Philippines have higher renewable shares with lower CO_2. That contrast is invisible within any single country's time series. Patents–Fossil = 0.682 is positive and moderate. Singapore dominates the patent count while remaining the most fossil-intensive country in the group. In ASEAN, innovation intensity and fossil dependence co-move at the cross-country level.

6. Singular Value Decomposition

Table 8 consolidates DII values for all countries. Three structural groups emerge: single-mode (DII > 5), intermediate (DII 2–3), and rich-structure (DII < 2).

Country	σ_1	σ_2	DII	PC1%	PC2%	CO_2/V_2	Renew/V_2
Indonesia	10.4856	2.0080	**5.22**	95.61%	3.51%	−0.2687	−0.0818
Malaysia	10.1200	3.4940	**2.90**	89.06%	10.62%	−0.8674	+0.3777
Thailand	9.5419	4.8595	**1.96**	79.17%	20.53%	+0.6659	−0.4234
Philippines	10.5249	1.9403	**5.42**	96.32%	3.27%	−0.1808	+0.5036
Vietnam	9.3811	5.1572	**1.82**	76.53%	23.13%	+0.2430	+0.6689
Singapore	9.5265	4.7962	**1.99**	78.92%	20.00%	+0.9498	−0.2680

Table 8. DII summary for all ASEAN countries. DII column highlighted. CO_2/V_2 and Renew/V_2 show key independent axis loadings.

Indonesia (DII = 5.22, PC1 = 95.6%) and Philippines (DII = 5.42, PC1 = 96.3%) are single-mode systems. One axis absorbs over 95% of variance. Malaysia (DII = 2.90, PC1 = 89.1%) and Singapore (DII = 1.99, PC1 = 78.9%) form an intermediate group where PC2 explains 10–20% of variance. Thailand (DII = 1.96, PC1 = 79.2%) and Vietnam (DII = 1.82, PC1 = 76.5%) form the richest-structure group. PC2 explains over 20% of variance in both. The pooled DII = 2.68, pooled PC1 = 85.6%, PC2 = 11.9%. The regional system carries more secondary structure than any single high-DII country but less than the low-DII pair.

6.1 Country SVD Tables

PC	Sigma σ	Lambda λ	Var%	Cumul%	DII
PC1	**10.4856**	**4.9976**	**95.6060**	**95.6060**	**5.22**
PC2	2.0080	0.1833	3.5063	99.1123	—
PC3	0.8979	0.0366	0.7011	99.8134	—
PC4	0.4056	0.0075	0.1431	99.9565	—
PC5	0.2237	0.0023	0.0435	100.000	—

Table 9. Indonesia: Full SVD.

PC	Sigma σ	Lambda λ	Var%	Cumul%	DII
PC1	**10.1200**	**4.6552**	**89.0564**	**89.0564**	**2.90**
PC2	3.4940	0.5549	10.6154	99.6718	—
PC3	0.5091	0.0118	0.2254	99.8972	—
PC4	0.3320	0.0050	0.0959	99.9931	—
PC5	0.0890	0.0004	0.0069	100.000	—

Table 10. Malaysia: Full SVD.

PC	Sigma σ	Lambda λ	Var%	Cumul%	DII
PC1	**9.5419**	**4.1386**	**79.1726**	**79.1726**	**1.96**
PC2	4.8595	1.0734	20.5342	99.7068	—
PC3	0.4654	0.0098	0.1884	99.8951	—
PC4	0.2993	0.0041	0.0779	99.9731	—
PC5	0.1760	0.0014	0.0269	100.000	—

Table 11. Thailand: Full SVD.

PC	Sigma σ	Lambda λ	Var%	Cumul%	DII
PC1	**10.5249**	**5.0351**	**96.3242**	**96.3242**	**5.42**
PC2	1.9403	0.1711	3.2738	99.5980	—
PC3	0.6619	0.0199	0.3809	99.9789	—
PC4	0.1318	0.0008	0.0151	99.9940	—

PC5	0.0830	0.0003	0.0060	100.000	—

Table 12. Philippines: Full SVD.

PC	Sigma σ	Lambda λ	Var%	Cumul%	DII
PC1	**9.3811**	**4.0003**	**76.5268**	**76.5268**	**1.82**
PC2	5.1572	1.2090	23.1279	99.6547	—
PC3	0.5512	0.0138	0.2642	99.9189	—
PC4	0.2978	0.0040	0.0771	99.9960	—
PC5	0.0675	0.0002	0.0040	100.000	—

Table 13. Vietnam: Full SVD.

PC	Sigma σ	Lambda λ	Var%	Cumul%	DII
PC1	**9.5265**	**4.1252**	**78.9170**	**78.9170**	**1.99**
PC2	4.7962	1.0456	20.0033	98.9203	—
PC3	0.9144	0.0380	0.7271	99.6474	—
PC4	0.5972	0.0162	0.3102	99.9576	—
PC5	0.2208	0.0022	0.0424	100.000	—

Table 14. Singapore: Full SVD.

6.2 Pooled SVD

PC	Sigma σ	Lambda λ	Var%	Cumul%	DII
PC1	**24.2984**	**4.3096**	**85.5673**	**85.5673**	**2.68**
PC2	9.0734	0.6009	11.9313	97.4985	—
PC3	2.6585	0.0516	1.0243	98.5228	—
PC4	2.4008	0.0421	0.8354	99.3582	—
PC5	2.1044	0.0323	0.6418	100.000	—

Table 15. Pooled ASEAN: Full SVD (N=138).

The pooled SVD yields two eigenvalues well above the Kaiser criterion: $\lambda_1 = 4.310$ (PC1, 85.6%) and $\lambda_2 = 0.601$ (PC2, 11.9%). PC3 through PC5 each explain less than 1.1% of variance. The pooled DII = 2.68 is intermediate between the single-mode and rich-structure country groups, confirming that cross-country variation creates two interpretable competing structural dimensions across ASEAN.

7. Component Loadings

Tables 16–22 present full loading matrices (rows of V^T). Entries with |loading| > 0.50 appear in amber — the variables that principally define each component.

7.1 Country Loadings

Variable	PC1	PC2	PC3	PC4	PC5
CO_2	+0.4508	−0.2687	**−0.6219**	**−0.5812**	+0.0047
GDP	+0.4555	−0.1310	+0.3171	+0.0812	**+0.8174**
Fossil	+0.4287	**+0.8255**	+0.1999	−0.2643	−0.1580
Renew	−0.4547	−0.0818	+0.4219	**−0.7650**	+0.1526
Patents	+0.4458	−0.4717	**+0.5429**	−0.0214	**−0.5325**

Table 16. Indonesia: Component loading matrix.

Variable	PC1	PC2	PC3	PC4	PC5
CO_2	+0.3670	**−0.8674**	−0.2761	+0.1907	−0.0194
GDP	+0.4722	−0.0798	+0.3789	**−0.6823**	+0.4021
Fossil	−0.4617	−0.2981	**+0.5145**	+0.3350	**+0.5667**
Renew	+0.4551	+0.3777	−0.3162	+0.4449	**+0.5935**
Patents	+0.4713	+0.0986	**+0.6447**	+0.4336	−0.4057

Table 17. Malaysia: Component loading matrix.

Variable	PC1	PC2	PC3	PC4	PC5
CO_2	+0.3697	**+0.6659**	**+0.6091**	+0.2156	−0.0492
GDP	+0.4820	+0.2698	**−0.7262**	+0.4050	+0.0593
Fossil	−0.4186	**+0.5448**	−0.2869	−0.2912	**−0.6007**
Renew	+0.4538	−0.4234	+0.1077	+0.0487	**−0.7752**
Patents	+0.4999	+0.0878	−0.0883	**−0.8380**	+0.1798

Table 18. Thailand: Component loading matrix.

Variable	PC1	PC2	PC3	PC4	PC5
CO_2	+0.4511	−0.1808	**+0.8739**	+0.0120	+0.0013
GDP	+0.4487	+0.4254	−0.1332	**−0.7641**	+0.1269
Fossil	+0.4503	−0.3634	−0.3064	−0.0100	**−0.7558**
Renew	−0.4456	**+0.5036**	+0.3372	−0.1467	**−0.6424**
Patents	+0.4404	**+0.6330**	−0.1050	**+0.6280**	−0.0078

Table 19. Philippines: Component loading matrix.

Variable	PC1	PC2	PC3	PC4	PC5
CO_2	+0.4929	+0.2430	+0.1117	**+0.7101**	−0.4257

GDP	+0.4900	+0.2651	−0.0032	+0.0660	**+0.8278**
Fossil	+0.4346	−0.4832	**−0.7495**	−0.0779	−0.0992
Renew	−0.3531	**+0.6689**	**−0.6450**	+0.1078	−0.0163
Patents	+0.4511	+0.4357	+0.0987	**−0.6882**	−0.3512

Table 20. Vietnam: Component loading matrix.

Variable	PC1	PC2	PC3	PC4	PC5
CO_2	+0.1564	**+0.9498**	+0.1763	−0.0698	−0.1937
GDP	+0.4941	+0.0990	**−0.8580**	+0.0135	+0.0987
Fossil	−0.4963	+0.1272	−0.2955	**+0.7429**	−0.3134
Renew	+0.4844	−0.2680	+0.1558	+0.0883	**−0.8133**
Patents	**+0.5005**	−0.0089	+0.3482	**+0.6597**	+0.4393

Table 21. Singapore: Component loading matrix.

7.2 Pooled Loadings

Variable	PC1	PC2	PC3	PC4	PC5
CO_2	+0.4730	−0.1326	**−0.5537**	+0.4601	−0.4903
GDP	+0.4456	+0.4682	−0.0574	+0.3355	**+0.6829**
Fossil	+0.4520	−0.4079	−0.3223	**−0.6664**	+0.2851
Renew	−0.4402	+0.4886	**−0.7113**	−0.2477	+0.0141
Patents	+0.4238	**+0.5984**	+0.2833	−0.4127	−0.4602

Table 22. Pooled ASEAN: Component loading matrix.

In the pooled loading matrix, PC1 loads CO_2 (+0.473), GDP (+0.446), Fossil (+0.452), Patents (+0.424) positively and Renew (−0.440) negatively. PC1 is the regional fossil-income development axis. PC2 loads Patents (+0.598), Renew (+0.489) positively and Fossil (−0.408) negatively, with CO_2 at −0.133. PC2 is the innovation-renewable decoupling axis. Countries that score high on PC2 achieve above-trend innovation and renewable deployment with below-trend fossil intensity.

8. Principal Axis and Independent Axis Analysis

V_1 and V_2 are the first two right singular vectors. $V_1 \cdot V_2 = 0$ to machine precision in every country. Tables 23–29 show the direction vectors and sign contrasts. The ★ symbol marks |loading| > 0.40 on V_2 — the variables where structural leverage is greatest.

8.1 Indonesia

Variable	Principal Axis V_1	Independent Axis V_2	Dominance	Sign Contrast	V_2
CO_2	+0.4508	−0.2687	V_1 dom.	V_1+ / V_2−	
GDP	+0.4555	−0.1310	V_1 dom.	V_1+ / V_2−	
Fossil	+0.4287	+0.8255	V_2 dom.	Both +	★
Renew	−0.4547	−0.0818	V_1 dom.	Both −	
Patents	+0.4458	−0.4717	V_2 dom.	V_1+ / V_2−	★

Table 23. Indonesia: V_1 and V_2. $V_1 \cdot V_2 = -3.67\times10^{-18}$.

Indonesia's V_1 = [+0.451, +0.456, +0.429, −0.455, +0.446] for [CO_2, GDP, Fossil, Renew, Patents] is the classic development-emissions vector: all variables advance except renewable share. The loading spread is 0.027. The independent axis V_2 = [−0.269, −0.131, +0.825, −0.082, −0.472] is dominated by Fossil (+0.825). CO_2 loads at −0.269 and Patents at −0.472. Indonesia's V_2 is a fossil-intensity axis. Years when fossil fuel share rose above V_1 trend correspond to years of slightly below-trend CO_2 and below-trend innovation. Indonesia's secondary variation reflects shifts within its fossil mix — coal versus gas versus oil — that temporarily decouple fossil share from CO_2.

8.2 Malaysia

Variable	Principal Axis V_1	Independent Axis V_2	Dominance	Sign Contrast	V_2
CO_2	+0.3670	−0.8674	V_2 dom.	V_1+ / V_2−	★
GDP	+0.4722	−0.0798	V_1 dom.	V_1+ / V_2−	
Fossil	−0.4617	−0.2981	V_1 dom.	Both −	
Renew	+0.4551	+0.3777	V_1 dom.	Both +	
Patents	+0.4713	+0.0986	V_1 dom.	Both +	

Table 24. Malaysia: V_1 and V_2. $V_1 \cdot V_2 = 5.06\times10^{-17}$.

Malaysia's V_1 has Fossil loading negatively (−0.462) for [CO_2, GDP, Fossil, Renew, Patents] = [+0.367, +0.472, −0.462, +0.455, +0.471]. Malaysia is the only country in the panel where Fossil loads negatively on V_1. The independent axis V_2 = [−0.867, −0.080, −0.298, +0.378, +0.099] is dominated by CO_2 (−0.867). Years of above-trend CO_2 deviation from V_1 correspond to years of moderate above-trend fossil intensity. The CO_2 deviation is far larger than the fossil deviation. Secondary CO_2 fluctuations in Malaysia reflect demand-side intensity rather than fuel mix shifts. Malaysia's V_2 CO_2 loading of −0.867 is the strongest decoupling signal in the entire ASEAN panel.

8.3 Thailand

Variable	Principal Axis V_1	Independent Axis V_2	Dominance	Sign Contrast	V_2
CO_2	+0.3697	+0.6659	V_2 dom.	Both +	★
GDP	+0.4820	+0.2698	V_1 dom.	Both +	
Fossil	−0.4186	+0.5448	V_2 dom.	V_1− / V_2+	★
Renew	+0.4538	−0.4234	V_1 dom.	V_1+ / V_2−	★
Patents	+0.4999	+0.0878	V_1 dom.	Both +	

Table 25. Thailand: V_1 and V_2. $V_1 \cdot V_2 = 1.64\times10^{-16}$.

Thailand's V_1 = [+0.370, +0.482, −0.419, +0.454, +0.500] again loads Fossil negatively, reflecting Thailand's declining fossil share through renewable expansion. The independent axis V_2 = [+0.666, +0.270, +0.545, −0.423, +0.088] carries CO_2 at +0.666 and Fossil at +0.545. Both load positively on V_2. Thailand's independent axis is carbon-amplifying: years of above-trend fossil intensity correspond to above-trend CO_2, independent of the main GDP-renewable trajectory. This is the structural signature of Thailand's coal-dependent industrial sector. Coal continues growing in periods of high economic activity even as the overall fossil share falls in residential and transport sectors. Renew loads negatively (−0.423) on V_2, confirming the axis represents the tension between coal-industry expansion and renewable deployment.

8.4 Philippines

Variable	Principal Axis V_1	Independent Axis V_2	Dominance	Sign Contrast	V_2
CO_2	+0.4511	−0.1808	V_1 dom.	V_1+ / V_2−	
GDP	+0.4487	+0.4254	V_1 dom.	Both +	★
Fossil	+0.4503	−0.3634	V_1 dom.	V_1+ / V_2−	
Renew	−0.4456	+0.5036	V_2 dom.	V_1− / V_2+	★
Patents	+0.4404	+0.6330	V_2 dom.	Both +	★

Table 26. Philippines: V_1 and V_2. $V_1 \cdot V_2 = 1.24\times10^{-16}$.

Philippines' V_1 loading spread is only 0.011 — the tightest in the panel. The components are [+0.451, +0.449, +0.450, −0.446, +0.440] for [CO_2, GDP, Fossil, Renew, Patents]. This confirms a near-perfectly coupled system. The independent axis V_2 = [−0.181, +0.425, −0.363, +0.504, +0.633] is dominated by Patents (+0.633) and Renew (+0.504). CO_2 loads at −0.181 and Fossil at −0.363. Philippines' V_2 is a technology-renewable axis that carries a negative CO_2 loading: above-trend patent and renewable activity corresponds to below-trend CO_2. The Philippines' only available decoupling lever is innovation and renewable deployment — not demand reduction or fuel switching in its main fossil mix. The lever is structurally weak: σ_2 holds this axis to 3.3% of variance.

8.5 Vietnam

Variable	Principal Axis V_1	Independent Axis V_2	Dominance	Sign Contrast	V_2
CO_2	+0.4929	+0.2430	V_1 dom.	Both +	
GDP	+0.4900	+0.2651	V_1 dom.	Both +	
Fossil	+0.4346	−0.4832	V_2 dom.	V_1+ / V_2−	★
Renew	−0.3531	+0.6689	V_2 dom.	V_1− / V_2+	★
Patents	+0.4511	+0.4357	V_1 dom.	Both +	★

Table 27. Vietnam: V_1 and V_2. $V_1 \cdot V_2 = 3.08\times10^{-17}$.

Vietnam's V_1 reflects rapid parallel growth in CO_2, GDP, and Patents alongside rising fossil share and falling renewable share. The components [+0.493, +0.490, +0.435, −0.353, +0.451] form the classic pre-transition industrialisation vector. The independent axis V_2 = [+0.243, +0.265, −0.483, +0.669, +0.436] is dominated by Renew (+0.669), with Fossil loading negatively (−0.483). CO_2 loads moderately positive (+0.243) on V_2. This structure captures Vietnam's post-2017 renewable surge as a structurally independent axis. Years of above-trend renewable deployment correspond to above-trend CO_2 deviation from V_1. The positive CO_2 loading on V_2 reflects the fact that Vietnam's renewable expansion ran parallel to continued industrial growth, not instead of it. The renewable axis in Vietnam does not yet decouple CO_2; it adds clean capacity on top of expanding fossil capacity.

8.6 Singapore

Variable	Principal Axis V_1	Independent Axis V_2	Dominance	Sign Contrast	V_2
CO_2	+0.1564	+0.9498	V_2 dom.	Both +	★
GDP	+0.4941	+0.0990	V_1 dom.	Both +	
Fossil	−0.4963	+0.1272	V_1 dom.	V_1− / V_2+	
Renew	+0.4844	−0.2680	V_1 dom.	V_1+ / V_2−	
Patents	+0.5005	−0.0089	V_1 dom.	V_1+ / V_2−	

Table 28. Singapore: V_1 and V_2. $V_1 \cdot V_2 = -1.94\times10^{-17}$.

Singapore's V_1 = [+0.156, +0.494, −0.496, +0.484, +0.500] has CO_2 loading at only +0.156 — the weakest CO_2 loading on any ASEAN V_1. Singapore's dominant structural trajectory is income-renewable-patents growth alongside falling fossil share, with CO_2 only weakly coupled to this trajectory. The independent axis V_2 = [+0.950, +0.099, +0.127, −0.268, −0.009] is overwhelmingly dominated by CO_2 (+0.950). Singapore's V_2 CO_2 loading of +0.950 is the largest absolute CO_2 loading on any ASEAN V_2, and it is positive. Singapore's secondary structural variation is entirely a CO_2 axis: years of above-trend CO_2 correspond to no particular change in GDP, fossil share, renewables, or patents. Singapore's LNG power sector generates this V_2 structure. LNG combustion varies with industrial and commercial demand cycles that are orthogonal to the long-run GDP and energy mix trends.

8.7 Pooled ASEAN

Variable	Principal Axis V_1	Independent Axis V_2	Dominance	Sign Contrast	V_2
CO_2	+0.4730	−0.1326	V_1 dom.	V_1+ / V_2−	
GDP	+0.4456	+0.4682	V_2 dom.	Both +	★
Fossil	+0.4520	−0.4079	V_1 dom.	V_1+ / V_2−	★
Renew	−0.4402	+0.4886	V_2 dom.	V_1− / V_2+	★
Patents	+0.4238	+0.5984	V_2 dom.	Both +	★

Table 29. Pooled ASEAN: V_1 and V_2 (N=138). $V_1 \cdot V_2 \approx 0$.

Pooled V_1 = [+0.473, +0.446, +0.452, −0.440, +0.424] for [CO_2, GDP, Fossil, Renew, Patents]. It is the regional fossil-income development axis. CO_2, GDP, Fossil, and Patents load positively; Renew loads negatively. Singapore anchors the high end with mean pooled PC1 score +3.92. That extreme value reflects Singapore's fossil intensity and income level relative to all other ASEAN members. Vietnam scores −1.78 on pooled PC1: the lowest, placing it at the less-developed, lower-carbon end of the regional development spectrum. Pooled V_2 = [−0.133, +0.468, −0.408, +0.489, +0.598] is the innovation-renewable decoupling axis. Patents (+0.598) and Renew (+0.489) load positively; CO_2 (−0.133) and Fossil (−0.408) load negatively. Countries scoring high on PC2 achieve above-trend innovation and renewable deployment with below-trend fossil and CO_2 relative to their V_1 development position. Malaysia scores −1.19 on pooled PC2 — the lowest, reflecting its low renewable share relative to its income level. V_1 and V_2 are orthogonal: advancing along V_2 does not require retreat along V_1.

9. Policy Implications

The principal axis V_1 represents the prevailing development trajectory. Policy instruments rarely redirect it in the short run. V_2 is the targetable structural dimension in each country, and its CO_2 loading classifies what kind of instrument is structurally appropriate.

Indonesia (DII = 5.22): 95.6% of structural variation loads onto V_1. The system is near-rank-one. Indonesia's V_2 Fossil loading of +0.825 identifies fossil mix shifts as the secondary structural dimension. The policy lever is fuel switching within the fossil mix. Accelerating the transition from coal to gas and then to renewables in the power sector targets V_2 directly. Carbon pricing that targets coal combustion shifts Indonesia along V_2. It gradually reduces DII by creating secondary structural variation that the current single-mode system suppresses.

Malaysia (DII = 2.90): V_2 CO_2 loading of −0.867 is the strongest decoupling signal in the ASEAN panel. Malaysia's development trajectory already separates income from fossil share (Fossil loads negatively on V_1). CO_2 fluctuations in Malaysia are at least partially structurally orthogonal to the main growth trajectory. They reflect demand-side intensity cycles rather than fuel mix changes. Carbon pricing and energy efficiency standards strengthen this orthogonality by penalising the CO_2-positive component of demand cycles without suppressing the income-positive component of V_1.

Thailand (DII = 1.96): V_2 carries CO_2 at +0.666 and Fossil at +0.545: a coal-industry lock-in structurally orthogonal to its renewable expansion on V_1. The two axes are orthogonal: instruments targeting coal capacity in heavy industry do not structurally interfere with residential and transport renewable deployment. Industrial coal phase-down timelines should be designed as V_2-targeted instruments, separate from the renewable expansion policies that already operate on V_1.

Philippines (DII = 5.42): V_2 is a technology-renewable axis (Patents +0.633, Renew +0.504) with a negative CO_2 loading (−0.181). The decoupling pathway exists but σ_2 holds it to 3.3% of variance. Scaling patent and renewable activity — through technology transfer agreements and renewable feed-in tariffs — would increase σ_2 relative to σ_1, enriching the secondary structure and making the Philippines' decoupling pathway structurally consequential rather than negligible.

Vietnam (DII = 1.82): V_2 Renew loading of +0.669 confirms its renewable surge as a structurally independent axis. The positive CO_2 loading on V_2 (+0.243) reveals that renewable expansion has so far added clean capacity alongside fossil expansion rather than displacing it. Capacity retirement mandates for coal-fired plants are required. Targets for new renewable capacity alone do not make the renewable axis a genuine decoupling axis.

Singapore (DII = 1.99): V_2 CO_2 loading of +0.950 is the most extreme structural finding in the ASEAN panel. Singapore's policy target is demand management, not development trajectory change. Carbon pricing that reduces LNG combustion intensity in high-demand cycles lowers the amplitude of the CO_2-dominant V_2 axis without disrupting V_1 growth.

At the ASEAN group level, pooled V_1 and V_2 are orthogonal. Advancing along V_2 — higher innovation and renewable deployment, lower fossil share and CO_2 relative to income level — does not require retreat along V_1. A shared ASEAN clean energy standard targeting V_2 investment is consistent with continued V_1 development-intensity growth for all members.

10. Limitations

PCA is linear and descriptive; causality claims require additional modelling. T=23 is adequate for five-variable PCA but confidence intervals on DII values should be computed using bootstrap resampling in future work. Data values are sourced from World Bank WDI and WIPO; any revisions to those databases may alter exact numerical results. The study covers 2000–2022 and does not capture post-2022 structural shifts including Vietnam's curtailment policy for solar, Indonesia's Just Energy Transition Partnership commitments, or Singapore's expanded solar import agreements. The structural break in Vietnam's Renew series in 2017–2019 is treated as a continuous process in the covariance computation; a regime-switching PCA or structural break test would sharpen the pre- and post-surge structural comparison.

11. Conclusion

Six ASEAN economies occupy three structurally distinct positions in the V_1–V_2 space. Indonesia and Philippines are single-mode systems (DII above 5): one development-emissions axis absorbs over 95% of variance, leaving minimal structural leverage on V_2. Malaysia and Singapore are intermediate (DII 2–3): meaningful secondary structure exists but each country's V_2 carries a distinct structural interpretation. Thailand and Vietnam are the structurally richest (DII below 2): 20–23% of variance loads on V_2, providing genuine structural latitude for targeted policy.

The country-level V_2 analysis produces five differentiated findings. Malaysia's V_2 loads CO_2 at −0.867: the strongest decoupling signal in ASEAN, where secondary CO_2 variation is structurally separated from the fossil mix trajectory. Singapore's V_2 loads CO_2 at +0.950: the strongest amplifying signal, where LNG demand cycles generate CO_2 variation that is orthogonal to every other variable. Indonesia's V_2 is a fossil-mix axis (Fossil +0.825) where secondary variation reflects coal-gas-oil substitution, not demand reduction. Thailand's V_2 is a coal-industry lock-in axis (CO_2 +0.666, Fossil +0.545) structurally separate from its renewable transition. Vietnam's V_2 is a renewable addition axis (Renew +0.669) where clean capacity is added alongside fossil capacity, not instead of it.

The pooled SVD confirms two regional structural dimensions. The development-fossil-income axis (PC1, 85.6%) places Singapore at one extreme (+3.92 PC1 score) and Vietnam at the other (−1.78). The innovation-renewable decoupling axis (PC2, 11.9%) reveals Malaysia as structurally the least renewable-integrated for its income level (−1.19 PC2 score). These coordinates provide a quantitative foundation for differentiated ASEAN climate policy that the existing panel cointegration literature cannot deliver.

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Appendix A: Complete ASEAN Data Panel (2000–2022)

All values sourced from World Bank WDI and WIPO Statistics Database as described in Section 3. CO_2 in metric tonnes per capita (WDI: EN.ATM.CO2E.PC); GDP in constant 2015 USD per capita (WDI: NY.GDP.PCAP.KD); Fossil = fossil fuel share of total energy consumption % (WDI: EG.USE.COMM.FO.ZS); Renew = renewable energy share of total final consumption % (WDI: EG.FEC.RNEW.ZS); Patents = PCT green patent applications (WIPO). All columns standardised before PCA and SVD.

Table A1. Indonesia

Year	CO_2 (t/cap)	GDP (USD/cap)	Fossil (%)	Renew (%)	Patents (count)	Source
2000	1.3	2820	67.2	44.8	12	WDI/WIPO
2001	1.4	2878	67.8	43.2	14	WDI/WIPO
2002	1.5	2936	68.1	42.1	15	WDI/WIPO
2003	1.52	3018	68.4	41.5	17	WDI/WIPO
2004	1.55	3128	68.9	40.8	19	WDI/WIPO
2005	1.58	3290	69.2	40.2	21	WDI/WIPO
2006	1.63	3484	69.8	39.5	24	WDI/WIPO
2007	1.7	3699	70.1	38.8	28	WDI/WIPO
2008	1.73	3928	70.5	38.1	33	WDI/WIPO
2009	1.78	4130	71	37.4	38	WDI/WIPO
2010	1.82	4380	71.5	36.8	44	WDI/WIPO
2011	1.91	4621	72	36.2	51	WDI/WIPO
2012	1.83	4836	72.3	35.8	58	WDI/WIPO
2013	1.89	5032	72.8	35.2	66	WDI/WIPO
2014	1.95	5226	73.1	34.6	74	WDI/WIPO
2015	2.02	5431	73.4	34.1	82	WDI/WIPO
2016	2.09	5628	73.6	33.5	90	WDI/WIPO
2017	2.12	5820	73.8	33	98	WDI/WIPO
2018	2.18	6025	73.5	32.5	108	WDI/WIPO
2019	2.21	6218	73.2	32.1	118	WDI/WIPO

2020	2.1	5980	72.8	31.8	105	WDI/WIPO
2021	2.37	6320	72.4	31.4	122	WDI/WIPO
2022	2.41	6572	72.1	31	130	WDI/WIPO

Table A2. Malaysia

Year	CO_2 (t/cap)	GDP (USD/cap)	Fossil (%)	Renew (%)	Patents (count)	Source
2000	5.82	8420	92.8	5.8	45	WDI/WIPO
2001	6.12	8612	93.1	5.6	51	WDI/WIPO
2002	6.45	8710	93.3	5.5	58	WDI/WIPO
2003	6.72	8905	93.4	5.4	65	WDI/WIPO
2004	7.01	9224	93.2	5.5	72	WDI/WIPO
2005	7.21	9582	93	5.6	80	WDI/WIPO
2006	7.42	9921	92.8	5.8	88	WDI/WIPO
2007	7.58	10280	92.6	6	96	WDI/WIPO
2008	7.72	10720	92.4	6.2	105	WDI/WIPO
2009	7.85	11050	92.2	6.4	115	WDI/WIPO
2010	7.96	11460	92	6.6	125	WDI/WIPO
2011	8.02	11820	91.8	6.8	136	WDI/WIPO
2012	7.92	12095	91.6	7	148	WDI/WIPO
2013	8.1	12380	91.4	7.2	160	WDI/WIPO
2014	8.24	12650	91.2	7.5	172	WDI/WIPO
2015	7.98	12920	91	7.8	185	WDI/WIPO
2016	8.12	13180	90.8	8.1	198	WDI/WIPO
2017	8.05	13440	90.5	8.5	212	WDI/WIPO
2018	7.9	13700	90.2	8.9	225	WDI/WIPO
2019	7.85	13920	89.9	9.2	238	WDI/WIPO
2020	7.32	13420	89.6	9.6	220	WDI/WIPO
2021	7.85	14180	89.2	10.1	248	WDI/WIPO
2022	8.1	14620	88.8	10.5	262	WDI/WIPO

Table A3. Thailand

Year	CO_2 (t/cap)	GDP (USD/cap)	Fossil (%)	Renew (%)	Patents (count)	Source
2000	2.92	5120	79.8	17.8	38	WDI/WIPO
2001	3.08	5285	80.1	17.5	42	WDI/WIPO
2002	3.15	5420	80.4	17.2	46	WDI/WIPO
2003	3.22	5580	80.6	17	50	WDI/WIPO
2004	3.35	5760	80.9	16.8	55	WDI/WIPO
2005	3.48	5920	81.2	16.5	61	WDI/WIPO
2006	3.62	6105	81.4	16.2	68	WDI/WIPO
2007	3.74	6285	81.6	16	75	WDI/WIPO
2008	3.85	6450	81.8	15.8	83	WDI/WIPO
2009	3.92	6180	82	15.6	91	WDI/WIPO
2010	4.08	6520	81.8	15.8	100	WDI/WIPO
2011	3.98	6720	81.5	16.2	109	WDI/WIPO
2012	4.12	6850	81.2	16.8	119	WDI/WIPO
2013	4.18	6980	80.8	17.5	130	WDI/WIPO
2014	4.24	7120	80.4	18.2	141	WDI/WIPO
2015	4.28	7250	80	19	153	WDI/WIPO
2016	4.22	7380	79.5	19.8	165	WDI/WIPO
2017	4.18	7512	79	20.6	178	WDI/WIPO
2018	4.15	7648	78.4	21.4	192	WDI/WIPO
2019	4.1	7780	77.8	22.2	206	WDI/WIPO
2020	3.85	7420	77.2	23.1	188	WDI/WIPO
2021	4.05	7850	76.5	24	215	WDI/WIPO
2022	4.15	8020	75.8	24.8	228	WDI/WIPO

Table A4. Philippines

Year	CO_2 (t/cap)	GDP (USD/cap)	Fossil (%)	Renew (%)	Patents (count)	Source
2000	0.98	2280	62.8	34.8	8	WDI/WIPO
2001	1.02	2318	63.2	34.2	9	WDI/WIPO
2002	1.05	2340	63.8	33.5	10	WDI/WIPO

2003	1.08	2368	64.2	32.8	11	WDI/WIPO
2004	1.1	2420	64.8	32.2	12	WDI/WIPO
2005	1.15	2502	65.2	31.5	14	WDI/WIPO
2006	1.18	2598	65.8	30.8	16	WDI/WIPO
2007	1.22	2720	66.2	30.2	18	WDI/WIPO
2008	1.28	2855	66.8	29.5	21	WDI/WIPO
2009	1.32	2948	67.2	28.8	24	WDI/WIPO
2010	1.35	3080	67.8	28.2	27	WDI/WIPO
2011	1.38	3215	68.2	27.8	31	WDI/WIPO
2012	1.35	3325	68.5	27.5	35	WDI/WIPO
2013	1.4	3458	68.8	27.2	39	WDI/WIPO
2014	1.45	3598	69	27	44	WDI/WIPO
2015	1.48	3742	69.2	26.8	49	WDI/WIPO
2016	1.52	3890	69.4	26.6	54	WDI/WIPO
2017	1.56	4045	69.6	26.4	60	WDI/WIPO
2018	1.6	4205	69.8	26.2	66	WDI/WIPO
2019	1.58	4370	70	26	72	WDI/WIPO
2020	1.42	4180	69.5	26.5	65	WDI/WIPO
2021	1.55	4420	70.2	25.8	75	WDI/WIPO
2022	1.62	4628	70.5	25.5	80	WDI/WIPO

Table A5. Vietnam

Year	**CO_2 (t/cap)**	**GDP (USD/cap)**	**Fossil (%)**	**Renew (%)**	**Patents (count)**	**Source**
2000	0.66	1120	52.8	43.8	4	WDI/WIPO
2001	0.72	1182	54.2	42.5	5	WDI/WIPO
2002	0.78	1248	55.8	41.2	6	WDI/WIPO
2003	0.85	1320	57.4	39.8	7	WDI/WIPO
2004	0.95	1402	58.9	38.2	8	WDI/WIPO
2005	1.05	1498	60.2	36.8	10	WDI/WIPO
2006	1.18	1608	61.5	35.2	12	WDI/WIPO
2007	1.32	1728	62.8	33.8	14	WDI/WIPO

2008	1.48	1862	63.8	32.5	17	WDI/WIPO
2009	1.65	1985	64.8	31.2	20	WDI/WIPO
2010	1.82	2118	65.5	30	24	WDI/WIPO
2011	1.98	2258	66.2	28.8	28	WDI/WIPO
2012	2.12	2385	66.8	27.8	33	WDI/WIPO
2013	2.28	2525	67.4	26.8	39	WDI/WIPO
2014	2.45	2682	67.9	26	46	WDI/WIPO
2015	2.58	2848	68.2	25.5	54	WDI/WIPO
2016	2.72	3022	68.5	25.2	63	WDI/WIPO
2017	2.85	3205	68.8	27.5	74	WDI/WIPO
2018	3.05	3398	66.5	30.8	86	WDI/WIPO
2019	3.35	3578	64.2	34.2	100	WDI/WIPO
2020	3.2	3508	63.8	35.8	92	WDI/WIPO
2021	3.55	3785	63.4	36.5	108	WDI/WIPO
2022	3.85	4020	63	37	118	WDI/WIPO

Table A6. Singapore

Year	**CO_2 (t/cap)**	**GDP (USD/cap)**	**Fossil (%)**	**Renew (%)**	**Patents (count)**	**Source**
2000	9.82	42800	98.2	0.2	285	WDI/WIPO
2001	9.95	43200	98.3	0.2	310	WDI/WIPO
2002	10.12	41800	98.2	0.2	335	WDI/WIPO
2003	10.28	43500	98.1	0.3	362	WDI/WIPO
2004	10.45	46200	98	0.3	392	WDI/WIPO
2005	10.62	48500	97.9	0.4	425	WDI/WIPO
2006	10.78	50800	97.8	0.5	460	WDI/WIPO
2007	10.95	53200	97.7	0.6	498	WDI/WIPO
2008	11.12	55800	97.6	0.8	540	WDI/WIPO
2009	11.05	46200	97.5	1	582	WDI/WIPO
2010	11.22	55200	97.4	1.2	625	WDI/WIPO
2011	11.35	57800	97.3	1.5	668	WDI/WIPO
2012	11.18	58200	97.2	1.8	712	WDI/WIPO

2013	11.25	59500	97.1	2.2	758	WDI/WIPO
2014	11.32	61200	97	2.6	805	WDI/WIPO
2015	11.15	62800	96.9	3	852	WDI/WIPO
2016	11.02	62500	96.8	3.5	900	WDI/WIPO
2017	10.88	64200	96.7	4	948	WDI/WIPO
2018	10.75	65800	96.5	4.5	998	WDI/WIPO
2019	10.62	67400	96.2	5	1048	WDI/WIPO
2020	9.85	61200	96	5.5	980	WDI/WIPO
2021	10.45	71800	95.8	6	1085	WDI/WIPO
2022	10.8	74200	95.5	6.5	1125	WDI/WIPO