

Sustainable Green Trade in Asian Trading Nations: Panel Data Evidence on the Environmental Kuznets Curve, Pollution Haven Hypothesis, and Technique Effects

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Abstract

Using two way fixed effect panel regression, we analyze the probable trends of sustainable green trade for the 20 largest Asian trading countries for the period 2000-2022. Using 460 country-year observations, we test three hypotheses related to international trade: the Environmental Kuznets Curve (EKC), the Pollution Haven hypothesis, and the Green Export hypothesis. We generate our models based on the logs of per capita CO₂ emissions for the first four models and a model based on renewable energy. Results showed the income turning point for the EKC hypothesis was found at approximately \$18,604, and a statistically significant relationship was found between income and CO₂ emissions beyond that point. Results showed a statistically significant positive relationship between FDI and CO₂ emissions, therefore providing partial evidence for the Pollution Haven hypothesis. Lastly, the Green Export hypothesis was supported by the results of the sample where a negative relationship between the intensity of green exports and CO₂ emissions was found at the 1% level, as well as the sample where the intensity of renewable energy was negatively related to CO₂ emissions at the 5% level. Overall, the results illustrate that more developed economies in East Asia are more progressed in the Global Green Transition. While advanced economies in East Asia are the first movers in the clean-technology market, labor-

intensive economies in South and Southeast Asia are exposed to two streams: pollution haven and carbon-border regulation.

Keywords: Environmental Kuznets Curve, Pollution Haven hypothesis, Green Export hypothesis, CO2 emissions, Panel regression

1. Introduction

Environmental impact is rapidly becoming a measure of national competitiveness alongside price and volume in global trade. In Asia, currently the strongest contributor to world trade, the shift is best reflected in the region's increasing share of global manufacturing trade (from 30% in 2010 to 50% in 2023). Given the high share of carbon-intensive manufacturing in the region, and the region's potential and growing clean energy industries, understanding how liberalization and growth affect emissions in Asia is of great relevance.

To guide the above mentioned policy concern, the “trade-environment” literature has identified three main hypotheses. The Environmental Kuznets Curve (EKC) posits that after a stage of rising emissions there will be a ‘U’ shaped curve towards reducing emissions at higher and later stages of economic development. Trade liberalization may allow greater scope for the operation of the PHH by facilitating the relocation of more pollution-intensive industries to lesser-developed countries, thus worsening emissions in the host countries. On the other hand, Antweiler, Copeland and Taylor (2001) argue that free trade may allow a country to adopt less pollution-intensive technologies, and thus, in combination with a rise in national income, result in an absolute reduction in national emissions. This involves an empirical study that is multi-country and multi-period, across a wide cross-section of Asian economies, from high-income Singapore and South Korea, to lower income Bangladesh and Nepal, in order to unravel these three mechanisms.

This study makes three major contributions. First, it builds on a previous study by constructing a balanced panel of 20 major Asian-Pacific countries' trade data from 2000 to 2022. It accounts for countries' levels of development, international trade and investments, and energy and value-add mix in their international trade. Instead of assessing each hypothesis in isolation, as done in most of the related literature, the study jointly assesses the three hypotheses using systematic equity. Second, the study employs two-way panel fixed effects, accounts for both entity and time period effects, and assesses the random effects model (Hausman's specification test) to examine the

presence of unobserved country level shocks and common macro-structural shocks. Last, the study accounts for the greenness of exports in addition to income and trade flows to control for the trade-related effects. The study then assesses the impact of the green export share on emissions. This element is largely overlooked in Extended Karma Condition (EKC) studies. The study finds its conclusions pertinent for central banks and trade ministries of the Asian region. This is particularly relevant given the ongoing implementation of the Carbon Border Adjustment Mechanism (CBAM) by the European Union. The empirical results are reported and interpreted in section 6. Policy implications are discussed in Section 7 and concluded in Section 8.

2. Literature Review

2.1 The Environmental Kuznets Curve

The EKC hypothesis stems from Grossman and Krueger's (1991) study on trade and the environment as it pertains to NAFTA. In their study, they document an inverted-U relationship for air pollutants and income for the cross-country sample. The EKC hypothesis has largely been studied using econometrics. Results from the study of various country samples, pollutants, and time periods show that the EKC hypothesis is highly context dependent. The EKC hypothesis for CO₂ has been studied extensively. Some have been able to establish a U-shape relationship for other pollutants. In general, Stern (2004) has called for more research on the EKC hypothesis to measure the effects of different functional forms, integration, and other panel data issues. The body of literature has shown that the EKC hypothesis is more applicable to local pollutants and less applicable to CO₂. As a result, it has been argued that CO₂ should be regulated on an international basis. These EKC-like behaviors are, however, observed for some Asian developing countries. Based on time series analysis, Nasir and Rehman (2011) revealed an EKC in Pakistan. The EKC framework has also been applied to study long-term cointegration for India. For the ASEAN area, Kinisahan and Coning (2010) also conducted a study on their region but were unable to identify EKC in the group of ASEAN countries. Recently, panel studies of the Asia Pacific region have employed a variety of heterogeneous panel estimators—such as mean group, pooled mean group—to show cross-sectional dependence, and advocate for economic results that are broadly EKC-consistent in a smaller number of high-income Asian economies, including those of Rahman, Saidi and Mbarek, 2017. This aspect this study addresses by introducing a larger country set (20

countries comprising various income groups) and examining the EKC in a single regression with the pollution haven and the technique effect channels rather than individually.

2.2 Environmental Resource Poverty and Social Inclusion

The pollution haven hypothesis, which was propounded by Copeland and Taylor (1994), is that pollution would increase in the lower income, low regulation economy and decrease in the higher income, high regulation economy, as trade was liberalized. However, the endogeneity of trade flows and the separation of the impact of FDI from the impact of overall trade openness is difficult to test in an empirical sense for this hypothesis. One empirical question that comes to mind specifically for developing countries in Asia is how the intensity of their emissions would respond to more inflow of FDI assuming that indeed such flow was responding to their developed countries' environmental regulation setting: could the 'beach' country that is less regulated in such regard, attract more of this FDI inflow because of that incentive is contestation on this mechanism in Asia. Eskeland and Harrison (2003) studied FDI inflows to Côte d'Ivoire, Morocco, Venezuela and Mexico and did not find evidence of the effect of pollution standards on the choice of countries for investment by pollution intensive firms. Xing and Kolstad (2002) have found evidence to support presence of pollution haven arguments for U.S. FDI, particularly in sectors like primary metals and chemicals, and that emission intensity is significant for bilateral FDI flows. Studies at the micro level, including Dean, Lovely and Wang (2009)'s study on the determinants of FDI in China, found that FDI in pollution-intensive industries is more sensitive to the variation of the stringency of the pollution environment in the province while FDI in the clean sector. Al-mulali and Sheau-Ting (2014) analyzed six trade and FDI districts in the world and found positive impacts on emissions in the sample districts as well as in Asia. The empirical test is performed in an Asian 20 economy panel using the proxy of FDI net inflows for pollution haven.

2.3 The Technique Effect and Green Trade

Antweiler, Copeland, and Taylor (2001) break the environmental impact of trade liberalization into two components: scale – more output, more pollutants; and composition – changes in the mix of industries, and the techniques – cleaner production methods. Their main empirical result is for a sample of countries based on SO₂ data, and they conclude that the aforementioned income-driven and composition effects dominate the scale effect, which means that free trade is a moderately

good environmental outcome when accounting for income. A dominant technique effect was found by subsequent work by Frankel and Rose (2005) after controlling for income: openness was related to lower levels of air pollution. Cole (2006), however, reported a positive association between trade liberalisation and energy consumption, but noted that the technique effect may not always outweigh.

More specific treatments are available in the literature on the impact of environmental goods and technology on trade. The 2009 trade and climate change report by the WTO/UNEP, highlighted the fast-paced development of the global trade of renewable energy equipment and energy efficient appliances and environmental goods and declared this sector one of the most dynamic of world trade. Later studies such as the one by Jha (2009) and Arce, Lopez, and Bi (2019) have correlated access to cheaper, renewable energy technology brought in via imports to an earlier rate of domestic deployment, which would serve as a trade-mediated mechanism by which green export of technology from exporting countries would lead to emission reductions in importing countries. From this literature, we derive inspiration to include the shares of green exports in the emissions regression, as well as a direct test for the impact of green exports on CO₂ emissions and renewable adoption in addition to the country trade and income volume.

3. Theoretical Framework and Hypotheses

Based on the literature reviewed above, the following formally-stated hypotheses are tested in a single panel framework that includes both fixed effects and random effects: In low income levels, more CO₂ is released per capita, but less in high income levels – hence the positive coefficient to the term for $\ln(\text{GDP per capita})$, and the negative term for $[\ln(\text{GDP per capita})]^2$ in the emissions regression. H2 (Pollution haven hypothesis): Weakening environmental regulations appear to draw in more FDI-net inflows from CO₂-emissions per capita and in Asian economies, carbon intensive sectors appear to attract more foreign capital inflows into countries with relatively loose environmental regulation. The results demonstrate that the effect of participation in green technology supply chain in terms of the relationship with CO₂ emissions per capita is negative, with H3 (Technique Effect) being the strongest, whereas there is a positive link between participation in green technology supply chain and Renewable Energy share, with the strongest being H3 (Technique Effect). As long as the panel specification is the same, all these hypotheses

can be tested. If the current pathway of income growth in the currently middle-income Asian economies are followed (GDP per capita remains lower than the estimated EKC turning-point in most developing Asian economies), the net emission path will also increase in the near future—this is both as a structural consequence of continued growth—making an enhancement of the downward slope of the EKC or a shift down the EKC turning-point an important policy target in making the transition to developing economies in Asia more affordable. In addition, trade openness is controlled for, with its sign theoretically ambiguous, in that it could be associated with either a pollution haven effect (positive) or a technique effect (negative). Likely positive relation between energy intensity and CO₂ emissions (more energy per unit GDP would result in more CO₂ emissions) and negative relation between energy intensity and the share of renewables (fossil-fuel intensive would result in higher CO₂ emissions). The conceptual model is outlined as:

$$\ln(\text{CO}_{2it}) = \alpha + \beta_1 \ln(\text{GDP}_{it}) + \beta_2 [\ln(\text{GDP}_{it})]^2 + \beta_3 \ln(\text{Trade}_{it}) + \beta_4 \text{FDI}_{it} + \beta_5 \ln(\text{Energy}_{it}) + \beta_6 \ln(\text{GreenExp}_{it}) + \mu_i + \lambda_t + \varepsilon_{it}$$

where "i" denotes country and "t" denotes year; μ_i are country fixed effects representing time-invariant unobserved country specific effects (such as quality of institutions, geography, endowment); λ_t are year fixed effects representing the common shocks facing the world in any given year (such as oil price cycles, global financial crises and pandemic disruptions); and ε_{it} is an idiosyncratic error term which is assumed correlated within countries to capture within-country serial correlation.

4. Data And Variables

4.1 Sample

The panel comprises 20 Asian economies over a 23-year time frame (2000-2022), providing a well-balanced panel of 460 country-year observations. The countries are from East Asia (China, Japan, South Korea, Mongolia), Southeast Asia (Indonesia, Malaysia, Thailand, Vietnam, Philippines, Singapore, Myanmar, Cambodia, Lao PDR) and South Asia (India, Bangladesh, Pakistan, Sri Lanka, Nepal, Uzbekistan, Kazakhstan). That shows this coverage is large, both in terms of income (ranging from less than USD 700 in Nepal to over USD 80,000 in Singapore), and can thus be analyzed for the presence of an empirical EKC by leveraging cross-sectional variation alone, rather than variation over time within any single country.

4.2 Variable Definitions

CO₂ emissions per capita/tons comes from the World Bank World Development Indicators (WDI) which are log-transformed in estimation. GDP per capita (PPP) current international dollars is from the World Bank WDI and is log transformed to be readable in terms of income elasticities. The definition of trade openness used is the sum of exports and imports on GDP, and is calculated in the log form for estimation, as detailed in the most widely used operationalization found both in the EKC and pollution haven literature. Net FDI inflows to GDP come from WDI, and are expressed in values except for the cells that are near zero for both country and year due to the use of logs. Energy intensity is calculated as megajoules of energy used per USD of GDP at constant prices (based on 2005 dollars) and is log transformed from the IEA (WDI). The green export share (GES) is a measure of technique-effect exposure, because it shows the composition of export basket. In model 5, the technique-effect pathway is tested by changing the share of renewable energy, the dependent variable. Share of renewable energy is measured as the dependent variable for Model 5 testing the technique-effect pathway, and is measured by a cleaner-energy supply side channel. Our focus is on the primary specific model, two-way fixed effects panel data model. The structure of the TWFE estimator enables to accommodate entity fixed effects (ϕ_i), which represent unobserved country effects (geographic endowments, colonial institutions, structural industrial composition), and year fixed effects (λ_t), which capture unobserved country effects that change over time (global commodity price cycles, multilateral trade liberalization episodes). This is the only reason why TWFE is a natural benchmark estimator in situations where both omitted variable bias are viable. Standard errors are region-specific and could be correlated (serial) within countries over time. A series of 5 models is estimated. Only log GDP per capita and log trade openness are included as regressors in model 1 (FE Baseline). To test H1, a model is also created which includes the square of log GDP per capita (Model 2: FE + EKC). Model 3 (FE Full): All 6 regressors are included – this is the default model and will be used. The Model 4 (RE Full) is an estimation of the same specification as Model 3, but the assumption of setting drift rate for country-level effects is random effects (RE), which are not correlated with the regressors. The specification test proposed by Hausman (1978) is used to determine the choice between FE and RE, which test the null hypothesis that the RE estimator is consistent, that is, that the unobserved country effects are orthogonal to the regressors included. If the null is rejected, then there is FE preference. Model 5

(FE Renewable) estimates the FE Full specification with renewable energy share as the dependent variable to test H3 through a supply-side channel.

Table 1: Descriptive Statistics — Balanced Panel, 20 Asian Economies, 2000–2022

Variable	Obs.	Mean	Std. Dev.	Min	Median	Max
CO ₂ Emissions (per capita, tonnes)	460	4.80	3.37	0.63	3.21	14.10
GDP per capita (PPP, current USD)	460	9675.45	13689.22	586.33	3790.46	80598.11
Trade Openness (% of GDP)	460	83.36	68.71	16.91	62.89	346.59
FDI net inflows (% of GDP)	460	3.41	3.02	0.00	2.55	12.96
Energy Intensity (MJ per USD GDP)	460	5.23	1.48	2.80	4.92	9.76
Green Exports (% of merchandise exports)	460	2.86	3.47	0.05	1.44	20.39
Renewable Energy Share (%)	460	7.86	5.76	5.00	5.00	30.85

Note: N = 460 (20 countries × 23 years). CO₂ per capita in tonnes. GDP per capita in PPP current international USD. Trade openness, FDI, and renewable energy share in percent of GDP or percent of total. Energy intensity in MJ per USD GDP.

5. Econometric Methodology

5.1 Estimation Strategy

This is a panel data model with two-way fixed effects (TWFE). To capture unobservables that are country but not time specific the TWFE estimator has been used, which models both entity fixed effects (μ_i) and year fixed effects (λ_t). This means that if there is omitted variable bias (i.e. bias induced by the omission of variables which may be present but not observed) it is the natural benchmark estimator under the circumstances in which such bias exists and is likely to be present. These standard errors are always country specific and serial correlated within these countries, throughout the book.

We estimate five models: Only log GDP per capita and log trade openness are regressors in Model 1 (FE Baseline). When adding an extra factor, log GDP per capita squared, to test H1 (Model 2 = FE + EKC), the result changes. If it is added to the list of factors being included: log GDP per capita squared, then the result changes when testing H1 (Model 2 = FE + EKC). There are six regressors, and Model 3 (FE Full) is the most comprehensive of the models. It is preferable to use model 3 (FE Full) with all six regressors as this will be the best baseline specification. Model 4 (RE Full) assumes the same specification as that of Model 3, except that it assumes that the country-level effects are uncorrelated with the regressors under the random effects (RE) assumption. The Hausman (1978) specification test that tests the null hypothesis of consistency of the RE estimator, namely that unobserved country effects are orthogonal to the country and the regressors included, is used to determine between FE and RE. When the null is rejected this means that there is FE preference. H3 are tested with a supply-side channel using model 5 (FE Renewable) that uses the percentage of renewable energy on the FE Full specification.

5.2 Diagnostics

To see multicollinearity, Var inflation factor (VIF) is checked. However, unlike most polynomial specifications, the high (and structurally desired) pairing of the linear and quadratic GDP terms is not a data problem, but rather a structural feature of the EKC specification, and does not prevent the fixed effects estimator from being consistent and unbiased but merely makes the estimation of the individual coefficient estimates for these terms less precise. All other regressors have acceptable VIF values, which are below the standard of 10. Breusch-Pagan test is the test for heteroskedasticity and carried out on residual diagnostics.

6. Empirical Results

6.1 Descriptive Overview

Panels are very diverse from country to country, as Asia is very diverse in terms of the developing world. The average of CO₂ per capita is around 4.80 tonnes, with a standard deviation of 3.37 tonnes and a range of 0.63 to 14.10 tonnes, which shows the range of CO₂ consumption between high-emission, high investment countries (Kazakhstan, and Japan) and low-emission, low income countries (Nepal, and Bangladesh). The income heterogeneity needed to find an EKC is confirmed

in the data as mean GDP per capita is around USD 9675 (PPP) and the standard deviation is a very high USD 13689. The variation in terms of Trade Openness is from approximately 17% of GDP in small and trade-dependent economies (such as Singapore) all the way on to 347% of GDP. Clean energy (CE) shares are 7.9% and clean tech exports are 2.9% of the total energy basket, on average, or a small share but rising share of clean-technology exports in the total energy trade basket.

6.2 Hausman Specification Test

The Hausman test very strongly rejects the null hypothesis of consistency of the random effects estimator: Hausman $\chi^2(6) = 30.009$, $p < 0.001$. This indicates that unobserved country effects depend on the regressors and that they are, indeed, correlated with the regressors; this is not surprising as countries' energy-intensive structural industrial composition, institutional quality, and development path are all determined by their income level, trade pattern, and size. It is thus used as the main estimator for Models 1-3 and 5.6.3

6.3 Multicollinearity Diagnostics

Table 2: Variance Inflation Factors — Model 3 Regressors

Variable	VIF
ln(GDP per capita)	243.53
[ln(GDP per capita)] ²	253.14
ln(Trade Openness)	2.47
FDI net inflows (% GDP)	2.45
ln(Energy Intensity)	1.3
ln(Green Exports %)	3.27

Note: VIF > 10 indicates potential multicollinearity concern. High VIF for ln(GDP) and [ln(GDP)]² terms is expected in polynomial EKC specifications and does not bias coefficient estimates. All other regressors show VIF well below 5.

The values of the VIFs are high for the ln(GDP per capita) and [ln(GDP per capita)]² terms as is well known and expected for polynomial specifications – the two terms are by construction highly correlated. This does not affect the consistency of the TWFE estimator. The other regressors (trade

openness, FDI, energy intensity, green exports) are not suffering from the danger of multicollinearity since the VIF values range from 1.3 to 3.3, which is significantly lower than the standard value of 10.

6.4 Main Regression Results

Table 3: Panel Fixed Effects and Random Effects Regression Results — Dependent Variables: $\ln(\text{CO}_2 \text{ per capita})$ (Models 1–4) and Renewable Energy Share (Model 5)

Dependent variable:	$\ln(\text{CO}_2 \text{ pc})$	$\ln(\text{CO}_2 \text{ pc})$	$\ln(\text{CO}_2 \text{ pc})$	$\ln(\text{CO}_2 \text{ pc})$	<i>Renew. Share</i>
Variable	Model 1 FE Baseline	Model 2 FE + EKC	Model 3 FE Full	Model 4 RE Full	Model 5 FE (Renew.)
$\ln(\text{GDP per capita})$	0.2147***	0.8803***	0.8917***	0.915***	-4.9959***
	(0.0666)	(0.1064)	(0.1116)	(0.0983)	(1.7978)
$[\ln(\text{GDP per capita})]^2$	—	-0.0445***	-0.0454***	-0.0375***	0.2635**
		(0.0061)	(0.0061)	(0.0055)	(0.1148)
$\ln(\text{Trade Openness})$	-0.0025	-0.0285	-0.023	0.01	-0.2968
	(0.0288)	(0.0195)	(0.0199)	(0.0391)	(0.3707)
FDI net inflows (% GDP)	—	—	0.0248***	0.0238***	-0.0685
			(0.007)	(0.006)	(0.101)
$\ln(\text{Energy Intensity})$	—	—	0.3169	0.5119***	-0.2497
			(0.1997)	(0.0597)	(1.7622)
$\ln(\text{Green Exports \%})$	—	—	-0.0332**	-0.0291*	0.1537**
			(0.0144)	(0.017)	(0.0767)
Constant	-0.4725	-2.7516***	-3.3877***	-4.6048***	32.7145***
	(0.5573)	(0.4934)	(0.6377)	(0.5589)	(7.0976)
<i>Entity Effects</i>	Yes	Yes	Yes	No	Yes
<i>Time Effects</i>	Yes	Yes	Yes	No	Yes
R^2 (within)	0.1552	0.2257	0.2050	0.2920	0.0484

<i>Observations</i>	460	460	460	460	460
<i>Countries</i>	20	20	20	20	20
<i>Years</i>	23	23	23	23	23

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Heteroskedasticity-robust standard errors clustered by country in parentheses. Models 1–3 and 5: Two-way Fixed Effects (entity and time). Model 4: Random Effects. All models estimated on a balanced panel of 20 Asian economies, 2000–2022 ($N = 460$). Constants are estimated but absorbed into entity fixed effects in FE models.

6.5 Test of H1: Environmental Kuznets Curve

The baseline linear specification in model 1 indicates the presence of a positive and statistically significant relationship between log CO₂ per capita and log GDP per capita ($\beta = 0.215$, $p < 0.01$) which is supported by the results. The results are very different if the quadratic term of GDP is additionally specified in Model 2: the linear term is positive and highly significant ($\beta_1 = 0.880$, $p < 0.01$) and the quadratic term is negative and highly significant ($\beta_2 = -0.044$, $p < 0.01$), directly supporting the prediction of H1. These point estimates imply an EKC turning point at $\ln(\text{GDP per capita}) = -\beta_1 / (2\beta_2) = -0.892 / (2 \times -0.045) \approx 9.83$, corresponding to a GDP per capita of approximately USD 18,604. This result is robust across Model 3, which includes all additional controls ($\beta_1 = 0.892$, $p < 0.01$; $\beta_2 = -0.045$, $p < 0.01$). The H1 is well substantiated. The GDP per capita (USD 18,604) is of direct policy relevance, as it is the estimated turning point. In the 20 economies in this sample only the more advanced economies in East Asia (Japan, South Korea and Singapore) and some of the upper middle income economies in the Association of Southeast Asian Nations (ASEAN) have the criterion. The bulk of South and Southeast Asian economies (including China during the majority of the sample period) are still below the turning point, suggesting that their income growth without green industrial policy would lead to increasing, not decreasing, CO₂ emissions in the short-term. This indicates the importance of the technique-effect channel (H3) for the emissions' reduction speed relative to the natural EKC, which is accessible in a policy.

6.6 Test of H2: Pollution Haven Hypothesis

The coefficient of the FDI net inflows is positive and significant in both the FE Full model (Model 3: $\beta = 0.025$, $p < 0.01$) and the RE Full model (Model 4: $\beta = 0.024$, $p < 0.01$). This is in line with

the pollution haven hypothesis, which suggests that for every 1% increase in FDI net inflows per capita, there is a corresponding increase in CO₂ emissions of 2.5%, given the other factors. The findings are in line with the pollution haven hypothesis that a 1% increase in net FDI inflows per capita is accompanied by a 2.5% increase in CO₂ per capita, while holding all other factors constant, including income, trade openness, energy intensity, and green export composition. This could be because the energy consumption of the products would be greater than that of the source countries, even if the products are exported to other markets with lower emissions, while energy-intensive industries like electronics assembly, metal processing and heavy chemical production are traditionally energy-intensive in Asia. The results of the other variables are not statistically significant in any of the model specifications ($p > 0.10$ throughout). This suggests that the channel – not the volume of trade – per se is the pollution haven channel and it's FDI. There are also policy implications of this separation: in the case of the Asian economies it indicates that the degree of trade liberalization is not systematically linked to higher emissions, while the nature and sectors of inward FDI flows (to clean or dirty sectors) is more pertinent to the pollution haven risk. All of the funding for H2 comes from FDI.

6.7 Test of H3: Technique Effect and Green Exports

This is because green export intensity is negatively related to CO₂ per capita in both the Model 3 ($\text{CO}_2_{\text{per capita}} = -0.033 \cdot \text{GreenEXPORT}$) and Model 4 ($\text{CO}_2_{\text{per capita}} = -0.029 \cdot \text{GreenEXPORT}$). The negative coefficient confirms the positive relationship between green export intensity and CO₂ per capita after controlling for income, trade openness, FDI and energy intensity. The intuitive interpretation of the technique-effect result is the pressure towards technique upgrading within the country, induced by the upgrading pressure from foreign buyers' quality and emissions requirements, the technology spill-overs from foreign technology partners, and the share of lower-emissions production technologies in countries' industrial bases. In the model used with the share of renewable energy as a dependent variable, the sign of the green export coefficient ($\beta = 0.154$, $p < 0.05$) remains and remains statistically significant. This is a complementary piece of evidence, where—in line with the hypothesis that countries can benefit from being part of international processes of clean-technology value chains to promote domestic adoption of clean-technology—this is a positive correlation between green export intensity and the share of renewables in a country's energy mix. The energy intensity is not statistically significant

in the FE model for CO₂, but is statistically significant and positive in the RE model ($\beta = 0.512$, $p < 0.01$), which could be a sign of the absorptive capacity of the entity FE capturing a significant share of variation of energy intensity across countries that is time-invariant in the sample. H3 is confirmed.

7. Policy Implications

The findings have certain policy implications for Asian governments and multilateral institutions. The confirmed EKC with a turning point around USD 18,604 indicates that Asian developing countries are mostly likely on the rising segment of the EKC, and that continued income growth in most of these countries will result in further emissions growth unless conscious actions are taken. Other things being equal, the magnitude of the (H3) technique effect generates an actionable counterfactual: policies that accelerate the speed of green export diversification – the shift toward environmental goods and renewable energy equipment and clean-technology components – are expected to have measurable impacts across income levels on domestic emissions. This therefore has direct policy implications for trade policy instruments like WTO environmental goods negotiations and export subsidies for green product upgrading as well as export subsidies for domestic diffusion of green technology and export subsidies for inward FDI linkages.

The confirmed pollution-haven effect of FDI inflows (H2) confirms the need for FDI quality screening: environmental conditions as part of the investment facilitation agreements, and proactive industrial zoning which channels foreign manufacturing investment to less polluting sectors. The EU Carbon Border Adjustment Mechanism (CBAM), to be implemented in its definitive phase from 1 January 2026, is an exogenous change that could accelerate the adjustment process until this date by increasing the carbon cost of exporting to the EU, thus creating carbon market signals for Asian exporters to reduce the carbon intensity of their FDI-related exports. Eligible countries for domestic carbon pricing implementing EU CBAM crediting provisions are able to keep the benefits of carbon pricing in terms of fiscal revenues rather than passing them on to EU importers. The domestic implementation of CBAM crediting provisions of the EU allows countries to keep the fiscal revenue generated by carbon pricing instead of passing it on to EU importers.

Results also show the need to work on energy intensity as a structural cost driver for South Asian economies like Pakistan and Bangladesh; an energy intensity which, statistically, was not significant in the FE CO₂ model when controlling for income is correlated with lower adoption of renewables (Model 5), and with higher compliance costs in the European supply-chain emissions disclosure regulations getting stricter. Finally, targeted transition finance (through concessional green bonds, blended finance, and credit guarantee instruments) that supports investments for energy efficiency and renewable energy in textile and manufacturing supply chains might be the least-cost alternative for such economies to bridge the gap between development aspiration and carbon-border compliance.

8. Conclusion

This paper provides new evidence on trade-environment linkages in a panel of twenty major countries in Asia between 2000 and 2022. We have given some support to the Environmental Kuznets Curve (H1) by proposing that an increase in GDP per capita of about USD 18,604 would lead to a reduction in CO₂ per capita of about 1%. A statistically significant technique effect is identified with regard to green export intensity (H3) as more green exports are associated with lower CO₂ emissions and higher RE consumption. We also find support for the pollution haven effect with respect to FDI inflows (H2) as an increase in FDI of 1 percentage point is associated with a reduction of about 2.5% in CO₂ per capita.

The results corroborate and augment the qualitative story of the asymmetric situation of Asia in the global green transition of trade. The technique effect channel benefits most the advanced economies of East Asia which are more likely to be on the negative side of the EKC; the low-income South Asian and Southeast Asian economies are more likely to be on the positive side of the EKC and thus more vulnerable to the pollution haven effects of FDI; and policies that shift the export mix toward green products are likely to be more beneficial for low-income economies than allowing the natural EKC pathway to achieve the same emissions reduction in a decade or more of carbon intensive growth. The world's carbon regulations, notably the EU CBAM and increased disclosure requirements under supply-chain carbon accounting, are already having an impact and proactive policy makers can take advantage of compliance costs to drive industrial transition but

not competitive disadvantage by setting up carbon pricing and quality criteria for green FDI and targeted transition finance.

For further research, an extension of this framework is possible: i) Bilateral trade flow data can be used to test the pollution haven hypothesis at the sector level instead of the aggregate country level, ii) Second generation panel unit root and cointegration tests can be used to analyze the cross-sectional dependence in the analysis, and iii) Heterogeneity of EKC turning points across sub-panels of countries can be considered based on income level, trade structure, and institutional quality.

References

- [1] Al-mulali, U., & Sheau-Ting, L. (2014). Econometric analysis of trade, exports, imports, energy consumption and CO₂ emission in six regions. *Renewable and Sustainable Energy Reviews*, 33, 484–498.
- [2] Antweiler, W., Copeland, B. R., & Taylor, M. S. (2001). Is free trade good for the environment? *American Economic Review*, 91(4), 877–908.
- [3] Arce, G., Lopez, L. A., & Bi, H. (2019). CO₂ emissions embodied in international trade: The case of Spain. *Journal of Industrial Ecology*, 23(1), 63–75.
- [4] Asian Development Bank. (2024). *European Union Carbon Border Adjustment Mechanism: Economic impact and implications for Asia* (ADB Briefs No. 276). Asian Development Bank.
- [5] Asian Development Bank. (2025). *Asia capital markets report 2025: Sustainable bonds*. Asian Development Bank.
- [6] Carson, R. T. (2010). The Environmental Kuznets Curve: Seeking empirical regularity and theoretical structure. *Review of Environmental Economics and Policy*, 4(1), 3–23.
- [7] Cole, M. A. (2006). Does trade liberalization increase national energy use? *Economics Letters*, 92(1), 108–112.
- [8] Copeland, B. R., & Taylor, M. S. (1994). North-South trade and the environment. *The Quarterly Journal of Economics*, 109(3), 755–787.
- [9] Dean, J. M., Lovely, M. E., & Wang, H. (2009). Are foreign investors attracted to weak environmental regulations? Evaluating the evidence from China. *Journal of Development Economics*, 90(1), 1–13.
- [10] Dinda, S. (2004). Environmental Kuznets Curve hypothesis: A survey. *Ecological Economics*, 49(4), 431–455.
- [11] Eskeland, G. S., & Harrison, A. E. (2003). Moving to greener pastures? Multinationals and the pollution haven hypothesis. *Journal of Development Economics*, 70(1), 1–23.
- [12] European Commission. (2026). *Carbon Border Adjustment Mechanism: Implementation and definitive regime*. Taxation and Customs Union, European Commission.
- [13] Frankel, J. A., & Rose, A. K. (2005). Is trade good or bad for the environment? Sorting out the causality. *Review of Economics and Statistics*, 87(1), 85–91.

- [14] Ghosh, S. (2010). Examining carbon emissions economic growth nexus for India: A multivariate cointegration approach. *Energy Policy*, 38(6), 3008–3014.
- [15] Grossman, G. M., & Krueger, A. B. (1991). *Environmental impacts of a North American Free Trade Agreement* (NBER Working Paper No. 3914). National Bureau of Economic Research.
- [16] Hausman, J. A. (1978). Specification tests in econometrics. *Econometrica*, 46(6), 1251–1271.
- [17] International Energy Agency. (2025). *Asia-Pacific energy outlook 2025*. IEA.
- [18] Jha, V. (2009). *Trade flows, barriers and market structures in the renewable energy sector: Recent trends* (UNCTAD Discussion Paper No. 195). UNCTAD.
- [19] Lean, H. H., & Smyth, R. (2010). CO₂ emissions, electricity consumption and output in ASEAN. *Applied Energy*, 87(6), 1858–1864.
- [20] McKinsey & Company. (2026). *The great trade realignment: Asia rising*. McKinsey Global Institute.
- [21] Nasir, M., & Rehman, F. U. (2011). Environmental Kuznets Curve for carbon emissions in Pakistan: An empirical investigation. *Energy Policy*, 39(3), 1857–1864.
- [22] Organisation for Economic Co-operation and Development. (2025). *Asia capital markets report 2025*. OECD Publishing.
- [23] Rahman, M. M., Saidi, K., & Mbarek, M. B. (2017). Economic growth in South Asia: The role of CO₂ emissions, population density and trade openness. *Heliyon*, 3(5), e00285.
- [24] Shafik, N., & Bandyopadhyay, S. (1992). *Economic growth and environmental quality: Time-series and cross-country evidence* (World Bank Policy Research Working Paper No. 904). World Bank.
- [25] Stern, D. I. (2004). The rise and fall of the Environmental Kuznets Curve. *World Development*, 32(8), 1419–1439.
- [26] World Bank. (2025). *World development indicators: Trade, environment, and growth*. World Bank Open Data.
- [27] World Economic Forum. (2025). *The impact of the EU's CBAM on business and the carbon-pricing landscape*.
- [28] WTO & UNEP. (2009). *Trade and climate change: A report by the United Nations Environment Programme and the World Trade Organization*. WTO Publications.

- [29] Xing, Y., & Kolstad, C. D. (2002). Do lax environmental regulations attract foreign investment? *Environmental and Resource Economics*, 21(1), 1–22.
- [30] Zero Carbon Analytics. (2025). *The race to invest in Southeast Asia's green economy*. Zero Carbon Analytics.