Analysing the Interplay Between Energy Transition, Resource Consumption, Deforestation, and Environmental Factors on Agricultural Productivity: Insights from APEC Countries

Zhongmin Zhou
University of Finance and Economics, Changsha, Hunan, PR China
Email: zhouzhongmin@hufe.eud.cn

Arshian Sharif
Department of Economics and Finance, Sunway University, Malaysia
Adnan Kassar School of Business, Lebanese American University, Beirut, Lebanon
University of Economics and Human Sciences in Warsaw, Poland
College of International Studies, Korea University, Seoul, South Korea
Email: arshian.aslam@gmail.com

Roula Inglesi-Lotz
Department of Economics, University of Pretoria, South Africa
Email: roula.inglesi-lotz@up.ac.za

Muhammad Farhan Bashir (corresponding author)
College of Management, Shenzhen University, Shenzhen, 518060, Guangdong, PR China
Email: farhan.paks89@gmail.com; farhan@szu.edu.cn
ORCID: https://orcid.org/0000-0001-5103-4639

Abstract

The growing focus on regional and international environmental cooperation has helped further discussions about environmental sustainability. This study evaluates agricultural economic productivity and how it is affected by natural resource consumption, energy transition, deforestation, global trade integration and environmental degradation in Asia-Pacific Economic Cooperation (APEC) countries. Our empirical findings from CS-ARDL, AMG and CCEMG help us reveal that environmental degradation, deforestation and natural resource abundance lower agricultural productivity, while energy transition and global trade integration improve agricultural productivity. Additionally, despite being highly integrated within global economic structure, APEC countries have not been able to boost agricultural productivity more than other regional blocks. We propose novel policy recommendations for APEC policymakers to improve environmental sustainability and agricultural productivity.

Keywords: Environmental degradation; Agricultural productivity; Natural resources; Energy Transition; Deforestation; Asia-Pacific Economic Cooperation

Introduction

Assessing global industrial transformation is key to environmental debate and identifying best practices to ensure ecological sustainability under UN SDGs (Ahmad et al., 2023a; Jiang et al., 2024). In addition, increased environmental awareness about continued threats of climate change and global warming from GHG and CO_2 emissions has caught the attention of environmental policymakers (Chaudhary et al., 2018). This has led to integrating environmental policymaking to identify and implement relevant policies to foster environmental performance and sustainable economic growth (Gazzola et al., 2019). Agricultural productivity is vital in macroeconomic discussions it influences economic development, national growth and ecological sustainability (Tinta et al., 2018). However, such agricultural accomplishments exacerbate environmental issues from extensive energy consumption (Michler, 2020; Yu et al., 2020). According to Doğan et al. (2023), the agricultural sector contributes one-quarter of global GHG emissions and energy transition for irrigation, and related activities must be prioritised to help lower GHG emissions (Figure 1) from the agricultural sector (Leitão, 2018).

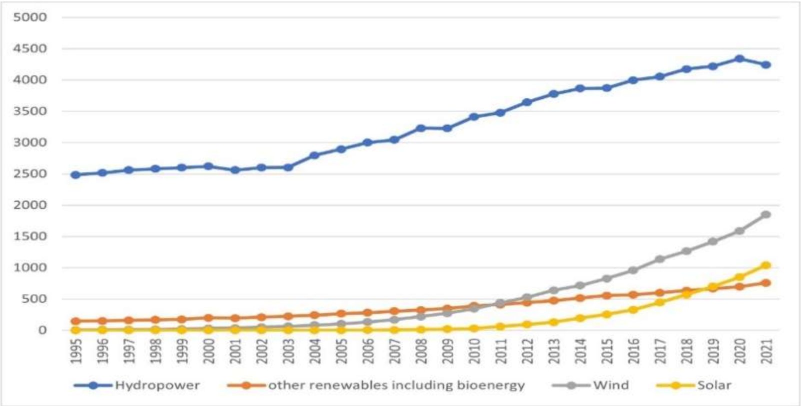

Figure 1: Renewable energy generation by source in TWh (Source: Statistical Review of World Energy)

The Asia-Pacific Economic Cooperation (APEC)[1] organisation was established in 1989 to promote regional economic prosperity and regional ties in the Asia-Pacific region. APEC member nations account for around 39% of the global population, two-thirds of global GDP and 50% of world trade (Bashir et al., 2023b). For this reason, APEC economies are vital in international sustainable development efforts and solve climate and environmental factors. Despite industrial

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[1] Appendix Table A1

progress, the share of the agricultural sector remains critical in regional GDP, with agriculture acting as the primary employment source. Moreover, besides top exports of seafood, cashew nuts, coffee and rice, the region is the leading producer of rubber, palm oil and coconut. UN Food and Agriculture Organisation (Liu et al., 2017a) concluded that from 1990 to 2020, the global deforestation trend (Figure 2) severely impacted the APEC region, with global demand for rubber, timber and palm oil identified as the primary reasons for such rapid deforestation (Russell, 2020). The APEC region dominates the global palm oil market due to favourable atmospheric conditions, especially in Malaysia and Indonesia; however, massive energy consumption associated with the burning agricultural residuals, transportation and fuel conversion poses significant environmental challenges (Ahmad et al., 2024a; Ahmad and Singh, 2023).

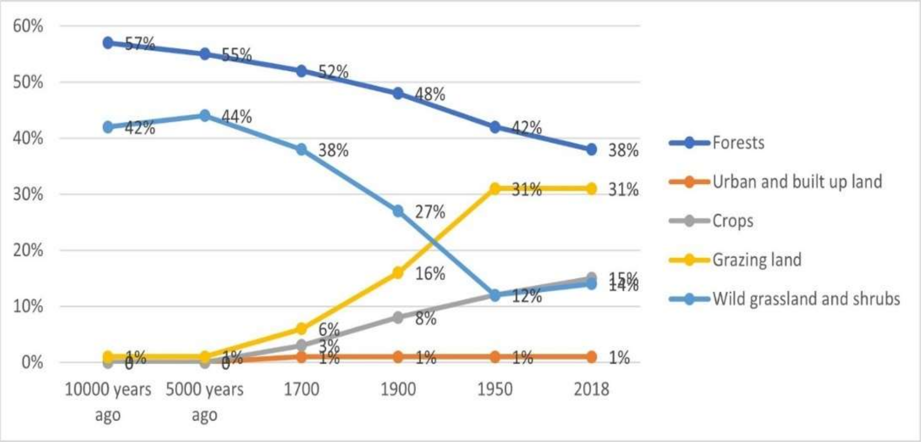

Figure 2: Deforestation and agriculture (Source: UN Food and Agriculture Organization)

APEC region is blessed with natural resource availability, this region has generally avoided the natural resource curse, which stipulates that dependence on natural resources may lower transformation towards the industrial and services sector (Kułyk and Augustowski, 2020). However, the region's continued dependence on natural resources (Sovacool, 2010) has impacted economic productivity excessive exploitation and harms agricultural growth by constituting the resource curse hypothesis. Dorinet et al. (2021) suggested that lax enforcement of environmental policies has roots in the absence of political stability, long-term policymaking and institutional corruption (Russell, 2020). However, the adoption of SDGs 2030 has attracted the attention of stakeholders to address social, economic and environmental needs. The APEC region's overemphasis on traditional agriculture and deforestation to cultivate cash crops has emerged as a substantial policy impediment in compliance with UN SDGs.

Against the above backdrop, the current study shows the main determinants affecting agricultural productivity in the APEC region. Based on our extensive analysis, we extend agriculture, environmental and energy literature in the following ways: First, to the best of our knowledge, the current study is a novel attempt to constitute novel environmental degradation, natural resources and agricultural productivity indexes to estimate agricultural productivity. Second, we evaluate the role of global economic integration, energy transition, and total forest area with the presumption that these indicators are critical elements in environmental efforts' outcomes. Third, we also analyse if agricultural productivity can influence economic balance as higher trade integration allows APEC economies to reduce export marketing expenditures and serve commodity markets more efficiently. Fourth, we use CS-ARDL, AMG and CCEMG to estimate and verify the statistical accuracy of our econometric analysis and report novel policy suggestions to ensure ecological and environmental sustainability.

The organisation for the rest of the paper is as follows: Section 2 reviews available literature, Section 3 details variables selection and econometric methodology, Section 4 discusses empirical findings, and Section 5 provides conclusion and policy suggestions.

2. Literature review

2.1. Environment sustainability and agriculture

From a policy perspective, environmental degradation is critical as environmental externalities are linked to rising GHG emissions (Ahmad et al., 2024b; Crippa et al., 2021). Recent studies have suggested that agricultural practices such as fossil fuel consumption, soil management, deforestation and livestock emissions are integral for agricultural productivity (Farooq et al., 2022). However, researchers have reported mixed findings on the environment-agriculture nexus, with the EKC hypothesis receiving the most attention. Zhangwei and Xungang (2011) researched Chinese agricultural emissions to confirm the EKC hypothesis for Sichuan province. Gokmenoglu and Taspinar (2018) used FMOLS to test the empirical association from 1971 to 2014 between agriculture, energy consumption, GHG emissions and income growth to affirm similar findings for Pakistan. However, Kułyk & Augustowski (2020) sampled data from a European dataset and used the GLS panel estimation approach to contradict the EKC hypothesis for environmental degradation in the agriculture sector.

A section of researchers has analysed the role of climate change and deforestation on agricultural output. Olalekan Oshota and Adeniyi Badejo (2014) analysed the interconnectedness between deforestation and agricultural economic growth from 1975 to 2010 and reported an inverse association between deforestation and agricultural productivity. Ehuitché (2015) researched a similar association for the Ivory Coast by examining data from 1962 to 2010 to suggest that higher deforestation negatively impacts agricultural productivity. Another Leitão (2018) study used Granger causality and vector autoregression to study the interconnection between agricultural exports, labour productivity, land productivity, carbon emissions and energy consumption from 1960 to 2015. Based on empirical analysis, the researchers reported a favourable association between carbon emissions, raw material exports and land productivity.

2.2. Energy consumption and agriculture sector

The demand and consumption of energy resources is critical to environmental protection. It has been widely reported that fossil energy resources exacerbate environmental quality, and energy transition must be prioritised to overcome climate challenges (Ahmad et al., 2023b). Several studies have scrutinised the association between various environmental pollutants and renewable energy (Bashir et al., 2023c) and GDP (Rahman and Velayutham, 2020) to unanimously conclude that advancements in renewable and environmental technologies help improve environmental sustainability. Li et al. (2023) studied environmental progress in Tunisia and concluded that higher renewable energy consumption leads to fewer long-term emissions. Jiang et al. (2024) suggested that energy transition overcomes adverse environmental implications in emerging countries. Another study by Vural (2020) researched the empirical association between economic growth, trade and environmental pollutants to report that renewable energy improves while trade and fossil energy degrade ecological sustainability. (Waheed et al., 2018) analysed energy transition, agricultural productivity and forest area to suggest that due to poor technological infrastructure, renewable energy and forest area lowers GHG emissions substantially.

Aziz et al. (2020) investigated environmental deterioration, forest area, agricultural output, energy transition and GDP to confirm the EKC hypothesis. Additionally, energy transition and forest areas negatively correlate with environmental pollutants, whereas agricultural productivity exacerbates environmental challenges in the short run. Eyuboglu & Uzar (2020) researched the interconnection between GHG emission, the agriculture sector and renewable energy consumption to mention that agricultural output degrades while renewable energy improves environmental quality. Naseem & Guang (2021) used fixed effects regression and GMM approach to study the dynamic association between GDP, fossil fuel consumption, environmental emissions and agricultural productivity to conclude that gradual energy transition and trade integration are the most critical factors in improving ecological sustainability. Ruzzante et al. (2021) used meta-analysis to determine that technological integration improves agricultural productivity and ecological sustainability. Lastly, Michler (2020) suggested that the agricultural sector can benefit from technological advancements in improving productivity and ecological footprint in India.

2.3. Natural resource consumption and agriculture sector

The emphasis on industrial and economic transformation has led to higher utilisation of labour demand, industrialisation, capital resources and remaining means of production inputs. This has also impacted energy consumption, which has surged due to requests from industrial and manufacturing sectors. Additionally, excessive dependence on natural resource consumption has contributed to excessive environmental pollutants and threatens ecological sustainability. A. Khan et al. (2020). This has allowed policymakers to examine environmental degradation and natural resource nexus critically. However, the available literature has mostly documented natural resources' association with globalisation, poverty, emission, and economic growth, with only a few studies analysing how natural resource consumption impacts agricultural productivity. Dorinet et al. (2021) sampled economic data from sub-Saharan countries from 19910 to 2016, suggesting that higher resource acquisition costs regressed agricultural productivity to validate the resource curse hypothesis. Abdlaziz et al. (2018) investigated the association between fossil fuels and agricultural output in 25 oil-exporting countries to report that higher energy costs negatively impacted agricultural productivity. Li et al. (2024)

2.4. Trade & economic integration and agriculture sector

Global and regional trade integration is an effective barometer as it directly impacts economic transformation through employment prospects, industrial growth and higher competitiveness. This also helps optimise the industrial sector, stabilise food prices, strengthen market competitiveness, rural income distribution and rural developments, and ecogical integration (Tinta et al., 2018). These developments have allowed researchers to study the association between agricultural productivity, GDP, carbon emissions and energy transition across geographical regions. Lee &

Chang (2008) researched co-movements in labour input, capital stock, real GDP and energy demand in ASEAN and APEC countries through the ECM approach from 1971 to 2002. The study concluded that considering diverse country impacts leads to a positive association between energy needs and economic developments. H. Khan et al. (2020) examined the association between technological innovations and natural resource consumption within the environment-growth-energy nexus for BRICS economies to determine that technological developments boost domestic growth and higher ecological quality. Liu et al. (2017) examined the intercorrelation between agricultural value addition and fossil energy demands on ecological quality in ASEAN countries to discover that higher agricultural output and renewable energy consumption lower GHG emissions, while fossil energy resources degrade environmental quality.

2.5. Literature gap

Due to its complex nature, the agricultural sector is a vital component of environmental fortification, as ecological sustainability is linked with an array of agricultural activities that can either promote or endanger environmental sustainability. In addition, the agricultural sector interacts with environmental, economic and industrial policies to influence the outcome of environmental reforms. However, APEC economies continue to battle environmental degradation despite rapid economic transformation. According to our review of available literature, most studies have investigated environmental degradation from a single indicator, i.e., ecological footprint, carbon emissions, and GHG emissions. The current study uses novel environmental degradation to extend policy scope and scientific debate further. In addition, the current study is a novel attempt to consider how energy transition-deforestation-global trade integration-natural resource consumption influence agricultural productivity and ecological sustainability. Lastly, the current study undertakes an extensive econometric investigation to identify and understand the complex association between the variables above and help propose effective policy strategies and interventions to achieve sustainable development practices in the agricultural sector and lower environmental degradation.

3. Theoretical framework and research methodology

3.1. Theoretical framework

The continued dependence on the agricultural sector in the APEC region means that agricultural activities remain critical in overcoming food shortages, unemployment, and poverty. However, the demand for energy resources and infrastructure growth has been a crucial factor in environmental degradation and deforestation. The ecological impact of energy resources has compelled policymakers and researchers to evaluate renewable energy developments within industrial, economic and agricultural expansion as available evidence suggests that energy transition lowers GHG emissions; a similar transition in the agricultural sector is critical in relation to carbon and environmental progress (Waheed et al., 2018). APEC economies have overseen rapid economic developments where fossil remain dominant, and green and renewable energy resources have promoted sustainable practices in the agricultural sector. Due to its wider macroeconomic impact, the agriculture sector is central to infrastructure growth; other factors also influence it due to its dynamics. Dorestation is a complex issue affected by policy and institutional factors and requires us to investigate how deforestation affects agricultural productivity (López and Galinato, 2005). Lastly, trade integration is key in addressing APEC economies' common economic challenges. It helps develop an effective theoretical framework to study and document agricultural productivity in the long run. The current study follows the Cobb-Douglas function to conduct an econometric investigation. According to Cobb-Douglas, the output of any function becomes zero if any input is zero; hence, each determinant of the production function is required, as no individual factor can replace others. The Cobb-Douglas production model considers technology, labour and capital as key input elements to evaluate and forecast industrial transformation (Qin, 2021). Agricultural production is significantly distinct compared to industrial output and must not be explained by economic or environmental variables. In light of this discussion, the current study considers trade integration, natural resource abundance, energy transition, deforestation, and environmental degradation necessary to study agricultural productivity and help bridge the gap in the available literature.

Generally, the standard Cobb-Douglas function requires two elements as basic input with the assumption of constant returns to scale, but it can be extended to include more elements. For the current study, the basic Cobb-Douglas function (Qin, 2021) can be stated as:

$$AGPR_{it} = AK_{it}^{\alpha} L_{it}^{\beta} e^{\varepsilon ti} \qquad (1)$$

Where AGPR, K, and L mention agricultural productivity, capital and labour, while α and β represent the marginal impact of labour and capital on the agricultural sector and must be within the range of 0 to 1. Lastly, ε denotes the error term. This allows us to provide basic econometric functions as:

$$AGPR = f\ (ENV, FR, EGYT, NRI, GTI) \qquad (2)$$

3.2. Data description and model construction

Current research studies the linkage between environmental degradation, forest area, natural resource consumption, energy transition, and trade integration on agricultural productivity in APEC economies. The data for energy transition measured as a percentage share of RE in total energy consumed has been taken from statistical review of world energy. Next, forest area is represented by forest area in hectares from world development indicators, and global trade integration is explained as the global trade integration for each country calculated under the ARIC integration indicators database. The current study uses novel composite indexes for environmental degradation, natural resource rents, and agricultural productivity for comprehensive econometric evaluation. The index for environmental degradation contains particulate matter 2.5, greenhouse gases, methane, carbon dioxide and nitrous oxides. The natural resource index tabulates rents from forest, mineral, oil and coal resources. Finally, the agricultural productivity index considers the share of value addition by the fishing, forest, and agriculture sectors. Creating these composite indexes is important as no single indicator can fully account for social, economic or environmental transformation. Keeping in mind these arguments, we estimate AGPR, ENVD and NRI as:

$$lnENVD_{it} = \alpha_{0it} + \alpha_{1it}CO_{2it} + \alpha_{2it}CH_{4i} + \alpha_3 N2O_{it} + \beta_4 \mathrm{PM2.5}_{it} + \beta_{5it}GHGO_{it} + \varepsilon_{it} \qquad (3)$$

$$NRI_{it} = \beta_{0i} + \beta_{1it}Mineral_{it} + \beta_{2it}Forest_{it} + \beta_3 Coal_{it} + \beta_4 Oil_{it} + \varepsilon_{it} \qquad (4)$$

$$AGPR_{it} = \beta_{0it} + \beta_{1it}AVA_{it} + \beta_{2it}FRVA_{it} + \beta_3 FIVA_{it} + \beta_4 Oil_{it} + \varepsilon_{it} \qquad (5)$$

Considering our theoretical and empirical arguments, equation-1 can be transformed as:

$$lnAGR_{it} = \beta_1 lnENVD_{it} + \beta_2 lnFR_{it} + \beta_3 lnEGYT_{it} + \beta_4 lnNRI_{it} + \beta_5 GTI_{it} + \varepsilon_{it} \qquad (6)$$

Moreover, we also check the interaction effect between $EGYT * ENVD$ and $NRI * ENVD$. This further transforms equation-6 into the following:

$$lnAGPR_{it} = \beta_1 lnENVD_{it} + \beta_2 lnFR_{it} + \beta_3 lnEGYT_{it} + \beta_4 lnNRI_{it} + \beta_5 GTI_{it} + \beta_6 EGYT * ENVD_{it} + \varepsilon_{it} \qquad (7)$$

$$lnAGPR_{it} = \beta_1 lnENVD_{it} + \beta_2 lnFR_{it} + \beta_3 lnEGYT_{it} + \beta_4 lnNRI_{it} + \beta_5 GTI_{it} + \beta_6 NRI * ENVD_{it} + \varepsilon_{it} \qquad (8)$$

3.3. Preliminary Tests

The rise in trade and global economic cooperation has increased the likelihood that any natural or economic event shocks can have a catastrophic global impact. Such a situation can be impacted by evaluating the existence of CSD within the dataset to overcome unidentified shocks and geographical influence. The current paper has used Pesaran-scaled LM, Bias-corrected scaled LM, Breusch-Pagan LM and Pesaran CSD as econometric measures to evaluate CSD. In addition, we also fix the degree of homogeneity for cointegrated coefficients or if such coefficients vary from one unit to another. The Pesaran and Yamagata (2008) SH test can be expressed as:

$$\tilde{\Delta}_{SH}= (N)^{\frac{1}{2}}(2K)^{\frac{1}{2}}\left(\frac{1}{N}\tilde{S}-k\right) \tag{9}$$

$$\tilde{\Delta}_{ASH}= (N)^{\frac{1}{2}}\left(\frac{2k(T-k-1)}{T+1}\right)^{-\frac{1}{2}}\left(\frac{1}{N}\tilde{S}-k\right) \tag{10}$$

In equations 9 and 10, $\tilde{\Delta}_{SH}$ and $\tilde{\Delta}_{ASH}$ denote delta and adjusted delta tilde.

Next, we use unit root tests to evaluate unit root properties for variables under consideration. Our primary justification is that approaches belong to second-generation tests and are more reliable than first-generation tests to tackle CSD and slope homogeneity. The CADF unit determines each cross-section's stationary tests, assuming time affects every cross-section. At the same time, CIPS extended Im et al.'s (2003) IPS to evaluate CSD by considering the average for every cross-section.

After CSD and unit root tests, this study proceeds to Westerlund's (2007) cointegration tests and determine whether or not a long-standing association exists within data variables. Additionally, an accurate assessment of cointegrated variables helps formulate policymaking from the long-term perspective. Moreover, our reason for choosing Westerlund tests is that it is suitable for small datasets and data with structural breaks

3.4. Long-run econometric strategy

In the current section, we outline the selection of a long-term econometric strategy. We have chosen CS-ARDL, AMG, CCEMG and CS-DL to analyse the empirical dataset. The choice of CS-ARDL is justified because it outperforms other cointegrated approaches by tackling non-stationarity, slope heterogeneity, cross-sectional dependency and endogeneity to provide short and long-term coefficients. CS-ARDL also cogitates one-year lags for the dependent variables as uncertainty regressors as $ECT_{(t-1)}$. Such a procedure allows CS-ARDL to control for unobservable indicators while estimating long-run coefficients for variables under consideration in the econometric model. Additionally, CS-ARDL authorises CSD adjustments in the short and long run on the stipulation that such a process is asymptotically unbiased with $N \rightarrow \infty$ for $T \rightarrow \infty$ and T.

In addition to CS-ARDL, this study uses AMG, CCEMG and CS-DL as robustness checks. We have chosen AMG and CCEMG as these strategies can handle non-stationary, cointegration breakdown and heterogeneity. Moreover, to minimise disruptions in the statistical outcomes, AMG and CCEMG use explanatory and dependent variables' cross-sectional averages to provide more reliable and accurate findings. We have also used CS-DL as this approach tackles the possible cross-sectional dependence within dataset and is sensible to the issue of the existence of multi-collinearity from the variables' average CSD and can drop them out during econometric estimation procedures. Lastly, we use the DH causality test to estimate whether or not a causal association exists within data indicators. DH is preferable as it can be used if error terms are CSD-dependent and for heterogeneous and balanced panel datasets.

4. Empirical Findings and Discussion

The current section provides a detailed interpretation of empirical findings from the econometric investigation. Before, we discussed and analysed how environmental degradation, deforestation, energy transition, natural resources, and trade integration impact agricultural productivity in APPEC economies. We begin with tables 1 and 2, summarising basic data statistics to outline data properties. The current study's empirical analysis suggests that kurtosis and skewness values were not zero. The empirical estimates for skewness show mixed order as reported values are -0.092, -0.261, -1.029, -1.004, 0.347, and 0.750. Moreover, the kurtosis estimates for the current study are 1.889, 2.046, 3.684, 2.881, 2.229 and 4.862 to indicate uniformity with data normality.

Table 1 Descriptive statistics

	AGPR	ENVD	FR	EGYT	NRI	GTI
Mean	9.569	4.119	4.521	1.295	0.477	0.776
Median	9.698	4.283	4.825	1.552	0.436	0.836
Maximum	12.069	6.716	6.911	1.981	1.625	3.797
Minimum	7.481	1.250	0.913	-0.721	-0.597	0.008
Std. Dev.	1.163	1.324	1.4180	0.607	0.419	0.523
Skewness	-0.092	-0.261	-1.029	-1.004	0.347	0.750
Kurtosis	1.889	2.046	3.684	2.881	2.229	4.862
Jarque-Bera	50.714	47.337	188.301	162.152	43.500	228.810
Observations	960	960	960	960	960	960

Table 2: Correlation matrix

	AGPR	ENVD	FR	EGYT	NRI	GTI
AGPR	1.000					
ENVD	0.538	1.000				
FR	0.494	0.469	1.000			
EGYT	0.059	-0.171	0.221	1.000		
NRI	0.159	0.110	0.470	0.210	1.000	
GTI	0.356	0.374	0.102	-0.172	-0.290	1.000

During the initial phase of empirical analysis, this study evaluates CSD & slope heterogeneity (Table 3), unit root tests (Table 4) and cointegration tests (Table 5). We begin our econometric investigation through CSD and slope heterogeneity tests. The empirical findings reported in Table 3 show that data variables are significant at a 1% level of significance and help us conclude that the existence of CSD in the dataset shows APEC economies are interconnected; however, economic or geopolitical shocks can impact other member countries. Also, the slope heterogeneity test findings indicate that the delta and its adjusted are significant at 1%.

Table 3: CSD and slope heterogeneity

Cross-sectional dependence	AGPR	ENVD	FR	EGYT	NRI	GTI
Breusch-Pagan LM	7246.181	7951.995	6616.054	5879.838	1880.379	2804.062
Pesaran scaled LM	230.920	254.850	209.557	184.597	49.002	80.318
Bias-corrected scaled LM	230.436	254.366	209.073	184.113	48.519	79.834
Pesaran CD	57.396	75.046	-3.047	34.878	8.121	12.433
Slope heterogeneity	Coefficients			p-value		
Delta	32.286			0.000		
adj. Delta	36.527			0.000		

All findings are significant at 1%

The findings reported in Table 3 outline findings from unit root tests to determine the existence of unit root properties for data variables. The empirical estimates from Table 5 specify that data variables possess mixed order for CIPS and CADF.

Table 4: C.I.P.S. and C.A.D.F. unit root tests

	CIPS		CADF	
Variables	Level	Difference	Level	Difference
AGPR	-2.338*	-	-2.177**	-
ENVD	-1.827	-4.552*	-1.971	-3.212*
FR	-1.045	-3.042*	-1.814	-3.632*
EGYT	-1.831	-4.839*	-1.626	-3.404*
N.R.I.	-2.401*	-	-2.390*	-
GTI	-2.383*	-	-1.909	-4.275*

Note: ***, ** and * indicates significance level at 10%, 5%, and 1%, respectively.

The confirmation of CSD, slope heterogeneity, and unit root allows us to test data through Westerlund cointegration tests to investigate the association between agricultural productivity, energy transition, forest area, environmental degradation, natural resource index, and trade integration. Table 5 confirms that data indicators are cointegrated at 1% significance, meaning we can continue the primary econometric strategy.

Table 5: Results of Westerlund cointegration test

Statistics	Value	Z-value	Robust P-value
Gτ	-3.579	-3.358	0.000
Gα	-10.893	4.973	0.000
Pτ	-25.177	-9.959	0.000
Pα	-14.334	0.818	0.000

Note: ***, ** and * indicates significance level at 10%, 5%, and 1%, respectively.

The current study relies on CS-ARDL as the foremost econometric approach to articulate the association between forest area, natural resource index, energy transition, environmental degradation and trade integration on agricultural productivity for APEC economies from 1995 to 2021. First, environmental degradation and agricultural economic growth share a negative association. Our findings get support from Zhai & Zhuang (2012), who studied environmental changes in China to mention that climate-related changes harm agricultural productivity. Moreover, the researchers argued that the severity of extreme weather events will increase due to GHG and other environmental pollutants; additionally, changes in rain patterns, pests, and related issues will also be affected by climate change and impact agricultural productivity. However, Crippa et al. (2021) challenged these findings by mentioning that anthropogenic GHG emissions have minimal impact on agricultural productivity. Hu et al. (2023) examined the changes in temperature, sea level, and precipitation predictions to conclude that environmental factors significantly affect agricultural yields. The study allowed the researchers to suggest environmental policies must be linked with SDG targets to overcome adverse climate change and avoid implementing ad hoc environmental policies, as coherent policies are key to achieving environmental goals. Bashir et al. (2023) suggested that tailoring environmental policies through stakeholder cooperation must be preferred to a one-size-fits-all solution.

The coefficient value of EGYT is positive across all models, meaning energy transition preserves environmental sustainability. Ben Jebli & Ben Youssef (2017) researched the MENA region to report that renewable energy consumption is key to environmental sustainability and agricultural productivity. Moreover, hydropower, a key RE source, fulfils energy needs and provides water for infertile lands. However, Liu et al. (2017a) studied the agricultural sector in ASEAN countries to mention that RE has no causal association with agricultural economic productivity. Yu et al. (2020) noted that lower fossil fuel costs and higher availability lead to environmental deterioration in agriculture. In addition, Li et al. (2023), Bashir et al. (202, and Lee and Yang (2019) concluded that emerging economies must shift their focus on RE to increase agricultural productivity and long-term environmental sustainability.

Next, the empirical coefficient of NRI has a negative association with agricultural economic growth, meaning an increase in NRI has degraded agricultural productivity by 0.095. APEC economies have vast natural resources, especially for Coal, and exports of such resources mean that the contribution of NRI to GDP is significantly higher than that of the remaining global economies (Kongbuamai et al., 2020). However, these countries have failed to utilise such resources to increase agricultural contribution to the domestic economy. This argument was justified by Dorinet et al. (2021), whose resource curse hypothesis for Sub-Saharan economies suggests that natural resource extraction had a detrimental impact on growth in agricultural productivity. In line with these studies, we support the resource curse hypothesis for APEC countries. However, we further suggest that these economies can utilise natural resources more efficiently through responsible agricultural policies and overcome environmental externalities. However, institutional policy guidelines must be reinforced to introduce sustainable practices and protect natural resources in the long run (Setyadharma et al., 2021).

The association between forest area and the agricultural sector is negative, meaning agricultural growth in APEC countries has come at the cost of forest deprivation, as a 1% reduction in forest reserves increases agricultural productivity by 0.417. Our estimates are similar to those reported by Imai et al. (2018), who researched Southeast Asian economies to report that farmers use deforestation to increase agricultural land available for food production. Farooq et al. (2022)further suggested that the loss of trees means deforestation reduces agricultural productivity and negatively impacts natural nutrient recycling management. Another study by Ehuitché (2015) reported a similar outcome. Those who researched Ivory Coast concluded that deforestation causes soil erosion, meaning agricultural lands lose fertility and productivity quicker than any other natural cause. To overcome this, the researcher suggested that regulating stream flows and retarding erosion must be encouraged so that forestry transforms top soils and structures so that natural nutrients increase agricultural productivity. Hence, the design of agricultural policies must consider the role of forestry to prevent environmental damage and increase economic productivity.

Lastly, trade integration has a significant and positive association with agricultural productivity in the APEC region, meaning that integrating local, regional and international cooperation has significantly boosted agricultural productivity. We attribute these findings to the fact that APEC member nations are more likely to facilitate an issue if it has no negative impact on domestic growth ambitions. Such preference has also allowed APEC countries to address environmental by at least finding a minimal solution (Islam and Kieu, 2020). APEC significantly emphasised food security pledges during the global financial crisis to create balanced macroeconomic growth. Mat & Othman (2017) researched agricultural developments in developing economies to suggest that regional cooperation and commitments remain the key drivers of addressing global food security challenges. Additionally, APEC economies have attempted to strengthen the role of forestry and agriculture sectors in food security through multi-sectoral frameworks and climate initiatives.

In addition, Table 6 also provides long-run coefficients from CS-ARDL, which are similar to short-term findings. For instance, environmental degradation, forest reserves and NRI are negatively associated with agricultural economic growth, while energy transition and regional & global integration have a positive impact.

Table 6: CS-ARDL

	Model 1		**Model 2**		**Model 3**	
Short Run Est.	**Short run**	**Long run**	**Short run**	**Long run**	**Short run**	**Long run**
ENVD	-0.250**	-0.198*	-0.557*	-0.585**	-0.135**	-0.069**
FR.	-0.417*	-0.776**	-0.144**	-0.376*	-0.222**	-0.931**
EGYT	0.082**	0.067**	0.864**	0.859**	0.106**	0.071**
N.R.I.	-0.095**	-0.039**	-0.022**	-0.010**	-0.947*	-0.357**
GTI	0.029**	0.009*	0.028*	0.015*	0.030**	0.015*
EGYT * ENVD	-	-	0.578**	0.513**	-	-
NRI* ENVD	-	-	-	-	0.487**	0.201**
ECT -1	-0.822***	-	-0.734***	-	-0.732***	-

Note: ***, ** and * indicates significance level at 10%, 5%, and 1%, respectively.

Our study also uses AMG, CCEMG & CS-DL (Table 7) as additional robustness checks to verify the findings from CS-ARDL further counter. Our results reported by AMG show that ENVD, FR, and NRI have negative associations, while EGYT and GTI have positive associations with agricultural economic contribution. Next, the interaction terms between ENVD*EGYT and NRI*ENVD align with models II and III, respectively. The findings reported by CCEMG and CS-DL are similar to those of AMG and CS-ARDL. Our results suggest that APEC economies must devise consistent economic, environmental and agricultural agendas to progress towards sustainable development goals and carbon neutrality. Our findings from the main and robustness analysis help us to report policy proposals to protect environmental and agricultural sustainability in the APEC region.

Table 7: AMG, CCEMG & CS-DL

	AMG			**CCEMG**			**CS-DL**		
	Model 1	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**
ENVD	-0.217**	-0.196**	-0.171**	-0.279**	-0.307*	-0.254*	-0.177*	-0.353*	-0.253**
FR.	-0.501**	-0.548**	-0.441**	-0.723**	-0.510**	-0.699*	-0.517**	-0.257**	-0.219**
EGYT	0.055**	0.320*	0.077**	0.069**	0.026**	0.072**	0.059*	0.255**	0.044*
N.R.I.	-0.252**	-0.219**	-0.466*	-0.019*	-0.011**	-0.258*	-0.033**	-0.034*	-0.328*
GTI	0.015**	0.021**	0.014*	0.011**	0.019**	0.015**	0.020**	0.027**	0.040*
EGYT * ENVD	-	0.486**	-	-	0.392*	-	-	0.348**	-
NRI* ENVD	-	-	0.087**	-	-	0.135**	-	-	0.669**

Note: ***, ** and * indicates significance level at 10%, 5%, and 1%, respectively.

Finally, we use DH panel causality analysis to investigate the existence of panel causality within variables of interest, namely AGPR, ENVD, FR, EGYT, NRI and GTI. The findings in Table 8 indicate that AGPR has unidirectional causality with ENVD and GTI, while a similar association can be observed between ENVD and GTI. Next, FR has bidirectional causality between GTI and unidirectional causality with NRI. Next, EGYT has a unidirectional causal association with AGPR and ENVD. Lastly, we report a unidirectional casual association between GTI and NRI for APEC economies. In addition, we use Figure 3 to illustrate econometric and causal association within variables under investigation graphically.

Table 8: Dumitrescu-Hurlin Panel Causality Analysis

	AGPR	ENVD	FR	EGYT	NRI	GTI
AGPR	-	4.87415**	1.35652	0.02510	1.87538	10.2153***
ENVD	1.60822	-	1.97730	0.22432	0.05546	12.3068***
FR	0.86627	0.23812	-	0.70552	4.24279**	3.34187**
EGYT	5.43857**	3.46137**	1.24429	-	1.05825	1.18417
NRI	1.82783	0.53739	0.44928	0.37911	-	1.10214
GTI	0.16156	0.54039	7.72585**	0.71247	2.38613*	-

Note: ***, ** and * indicates significance level at 10%, 5%, and 1%, respectively

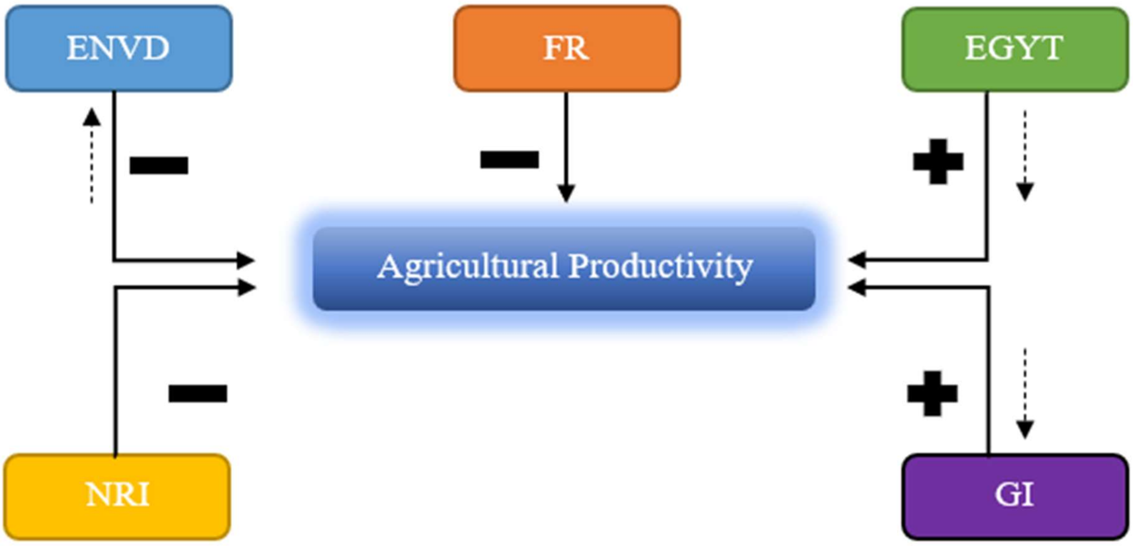

Figure 3: Empirical outcomes summary

5. Conclusion and policy recommendations

The passing of COP 28 helped in Dubai, United Arab Emirates, and has helped prioritise environmental policy shifts to emphasise that environmental and climate challenges must be urgently solved to protect ecological sustainability. Within environmental discussion, the agriculture sector is a critical driver in decarbonisation and environmental sustainability. The current study carefully extends agricultural sustainability by evaluating the role of forest area, energy transition, natural resource index, environmental degradation, and trade integration over agricultural economic productivity for APEC economies. We extend academic discussion through extensive econometric investigation: (i) CSD, slope heterogeneity, CIPS & CADF unit root tests and Westerlund test we used to confirm compliance with initial econometric analysis. (ii) We use CS-ARDL as the main analytical approach to reveal that environmental degradation, deforestation and natural resources have negative. In contrast, energy transition and trade integration positively affect agricultural productivity. (iii) AMG, CCEMG and CS-DL as robustness checks validate the empirical estimates from the main analysis. (iv) DH causality analysis confirmed unilateral and bilateral directional causality between data indicators.

Our novel theoretical and econometric analysis provides sufficient facts to present suggestions for improving agricultural and environmental sustainability. First, to offset the effects of climate change, APEC economies must promote an advanced agriculture approach that does not exacerbate soil quality and GHG emissions. Among such solutions, artificial intelligence and green technologies can be used so that precision farming can efficiently utilise limited resources and inputs. Policy interventions must be communicated to the agricultural sector to yield higher productivity and sustainability. Second, we encourage APEC economies to use public-private partnerships to find regional and global export markets for agricultural products. Moreover, public-private joint ventures must be enabled to establish an integrated framework to strengthen sustainability practices in the domestic agricultural sector.

Third, we encourage APEC economies to adopt an agri-ecology approach to achieve an adaptable and productive agricultural sector and minimise environmental emissions from chemical fertilisers, fossil fuel consumption, and conventional agricultural practices. Moreover, policymakers must promote an environment-friendly nutritional management system and remove policy barriers to facilitate energy transition and higher carbon sequestration. Fourth, we encourage APEC economies to synchronise natural resource and forest regulations to improve agricultural productivity and ensure long-term acceptance of sustainable agricultural practices. Within this discussion, integration of energy transition structure, environmental regulations, regional integration and balanced agricultural productivity remains key to solving environmental challenges from the agricultural sector.

Finally, despite extending academic discussion through an extended econometric approach, the current study has identified research areas to be explored by future studies. First, the data for environmental degradation has been used to evaluate its role in the productivity of the agriculture sector. To further extend the academic discussion, we encourage researchers to use emissions residual statistics for crops and livestock sectors to help formulate sector-specific agricultural sustainability practices. Second, we encourage researchers to use Artificial Neural Networks and Machine Learning experiments to analyse the impact of policy changes on the agriculture sector. Lastly, the moderating effect of institutional quality over the agricultural energy mix can be used to determine how the regulatory environment can help balance environmental and agricultural sustainability.

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Appendix

Table A1: List of Countries

Australia	Bangladesh	Bhutan	Cambodia	China
Fiji	India	Indonesia	Japan	Kiribati
Laos	Malaysia	Maldives	Mongolia	Nepal
New Zealand	Pakistan	Papua New Guinea	Philippines	Russia
Samoa	Singapore	Solomon Islands	South Korea	Sri Lanka
Thailand	Timor-Leste	Tonga	Vanuatu	Vietnam

Table A2: List of abbreviations

Abbreviation	Full term	Abbreviation	Full term
APEC	Asia-Pacific Economic Cooperation	EKC	Environmental Kuznets curve
A.M.G.	Augmented mean group estimator	FMOLS	Fully modified ordinary least squares
ASEAN	Association of South East Asian Nations	G.D.P.	Gross domestic product
BRICS	Brazil, Russia, India, China, South Africa	GHG emissions	Greenhouse gas emissions
C.C.E.M.G.	Common Correlated Effects Mean Group	G.L.S.	Generalised least squares
CS-ARDL	Cross-sectionally augmented autoregressive distributed lag	G.M.M.	Generalised method of moments
C.S.D.	Cross sectional dependence	SAARC	South Asian Association for Regional Cooperation
CS-DL	Cross-sectionally augmented distributed lag	SDGs	Sustainable development goals
DH test	Dumitrescu-Hurlin panel granger causality test	UN.	United Nations