



# Should Asia Pacific economic cooperation countries put all their eggs in one energy basket? Examining the linkage between energy diversification and sustainable development

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## ABSTRACT

Energy diversification is critically important from an economic, political and environmental point of view. In this research, we try to investigate the role of energy diversification for sustainable development in Asia Pacific Economic Cooperation or APEC member countries. We utilize data from different sources which range from 1990 to 2020. Apart from energy diversification, other independent variables such as public sector corruption, ICT, economic globalization and social globalization are utilized according to the theory and empirical literatures which utilize these parameters in order to see how growth or environment of an economy is affected. The study implements second generation econometric methodologies in order to tackle the cross sectional dependence issue among the countries. The result reveals that energy diversification positively and significantly affect sustainable development in APEC nations. ICT and economic globalization were also found to be positively affecting the sustainable development. However, social globalization negatively affected the sustainable development while the effect of public sector corruption was not significant. Bidirectional causality was revealed between sustainable development and energy diversification. The study recommends diversifying energy sources for achieving the sustainable development goals (SDGs) agenda for these economies.

## 1. Introduction

Humankind has started to use energy since the industrial revolution. The increase in energy consumption has led to the growth of the global economy by increasing the output per unit. As the global economy grows, the demand for energy increases even more. Most of the global energy demand is met by fossil fuels. Using fossil fuels causes many problems, including air pollution, environmental pollution and climate change. Especially in the 1980s, environmental pollution became more evident worldwide and countries started to come together to solve environmental problems. In 1987, the World Economic Development Commission convened and the concept of sustainable development was introduced by Brundtland (1987) in the Our Common Future report.

This concept refers to meeting the needs of the present without harming the resources of future generations. The concept of sustainable development is addressed through three themes -economic, social and environmental sustainability- (Harris, 2000; McKeown et al., 2002) and it simplifies the complex nature of political, economic, cultural and ecological processes (Sharpley, 2000).

APEC was established in 1989 to further the economic development and prosperity in the Asia-Pacific region and to strengthen the ties between the Asia-Pacific Community and has 21 members.<sup>1</sup> APEC members account for 38% of the world's population, 62% of the world GDP (\$52 trillion) and 48% of world trade volume (APEC, 2021). For this reason, the contribution of APEC countries is vital to establish a sustainable development path and solve the problems such as

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environmental pollution and climate change.

Energy diversification is critically important from an economic, political and environmental point of view. It means incorporating different energy sources and increasing the number of different sources in the energy mix (Stirling, 2010). Energy diversification first contributes to productivity by increasing technological capacity (Ahmed et al., 2022; Gozgor and Paramati, 2022). Thanks to technological development, many countries are trying to diversify their energy mix from fossil fuels to renewable sources (Gallagher, 2006). Energy diversification has not only economic but also political importance, especially in the context of ensuring energy security (Aslani et al., 2013; Vivoda, 2019) and reducing foreign dependency on energy. In addition, energy diversification is vital in reducing emissions and tackling climate change without compromising sustainable development (Freitas and Kaneko, 2011). UNDP identifies 17 sustainable development goals (SDGs) and APEC countries commit to achieve several SDGs by 2030 and 2050 (Sinha and Sengupta, 2019). In addition, several APEC countries made ambitious commitments to achieve net zero targets and submitted their INDCs (Intended Nationally Determined Contributions) to the UNFCCC secretariat. As of June 2021, eleven economies representing the world's 83.3% of total CO<sub>2</sub> emissions in 2018 had made formal commitments to reach net-zero emissions in 2030 and 2050, respectively. APEC countries also participate in Conference of Parties (COP) and try to protect their interest and be a part of the solution. COP27 which was held in Sharm El Sheikh in 2022 was the latest summit and The Paris Agreement, the Glasgow Climate Pact, and other accords to boost the fight against climate change were all discussed at this negotiation. However, it stands out that the disagreements are more than the treaties at COP27 (Arora & Arora, 2023) such as loss and damage mechanism, phasing out fossil fuels, keeping the 1.5 °C goal alive and the US-China collaboration.

Globalization triggers trade in goods and services by increasing trade liberalization (Jorgenson and Givens, 2014), leads to an increase in energy use (Cole, 2006) and CO<sub>2</sub> emissions (You and Lv, 2018). In countries where trade leads to environmental pollution, it is challenging to establish strict environmental regulations (Le et al., 2016). Developments in the field of ICT can positively affect sustainable development, primarily by increasing productivity. For example, environmental informatics can contribute to sustainable development by providing strategies for environmental policies in the long term (Lorenz et al., 2011). Institutional quality is an essential sustainable development indicator since it decreases environmental pollution by reducing energy consumption (Godil et al., 2021) and increasing environmental performance (Hunjra et al., 2020).

The motivation of this study is to examine the relationship between energy diversification and sustainable development. In this context, the study has different contributions to the literature. First of all, i) to the best of our knowledge, there is no empirical study yet exploring the impact of energy diversification on sustainable development in terms of APEC economies. The closest to our study is that of Gozgor and Paramati (2022) who investigated the nexus between energy diversification and economic slowdown and that of Ahmed et al. (2022) who examined the link between energy diversification and growth for Nordic countries. But these studies only consider economic growth as their dependent variables. However, energy diversification may also bring social and environmental challenges. Our utilization of sustainable development index to reflect sustainable development from Hickel (2020) accounts for economic, social as well as environmental degradation in the form of CO<sub>2</sub> emissions and material footprint. Therefore, our study is more comprehensive in terms of its analysis on the role that energy diversification plays on an entire economy from different dimensions. ii) We investigate the APEC countries since they are responsible for the largest share of global GDP and emissions. We conduct this research to investigate how APEC countries might reduce CO<sub>2</sub> emissions and increase growth through energy diversification. We study whether they could benefit from energy diversification as a policy instrument to achieve sustainable development, combat climate change, and fill emission gaps

towards net-zero targets. iii) We also include globalization, ICT, and institutional quality to the empirical model. This way, we had the opportunity to examine the other dimensions of sustainable development. iv) We applied second-generation unit root and cointegration and long-term coefficient tests (CADF and CIPS unit root tests, Westerlund cointegration test, CCE-GMM, CCEMG estimators). These approaches give robust empirical results by considering cross-section dependency. Cross sectional dependency may exist when shocks in one APEC economy affect another economy in various ways. Therefore, it is necessary to see if this scenario happens by conducting cross sectional dependency and accounting for it in all the tests. The advantage of CCE-GMM estimator compared to CCEMG is that it can account not only for cross sectional dependency, but it can also account for endogeneity which we suspect to exist between energy diversification and sustainable development since sustainable development may influence the diversification of energy sources in APEC. Therefore, if endogeneity is not accounted for, it might produce biased result. We apply both CCE-GMM and CCEMG to see if the result differ because of the presence of endogeneity.

The design of this study is as follows: the second part presents literature review; third part introduces the empirical method and data description while the fourth part reports empirical findings. In the conclusion, various policy recommendations are suggested to the policymakers.

## 2. Review of literature

Extensive studies on the link between energy consumption and economic growth have preoccupied the literature albeit conflicting outcomes (Adedoyin et al., 2021; Ahmed et al., 2022; Bekun et al., 2021). Some studies opined that energy consumption positively influences economic growth while some other studies pointed to an indirect implication on growth and sustainable development. Tang et al. (2016) examine the link between energy consumption and economic growth in Vietnam between 1971 and 2011. The result found that energy consumption exerts a positive effect on economic growth within the period under review. Similarly, Rahman & Velayutham (2020) found a positive link between renewable, non-renewable, and economic growth of selected South Asian countries between the period 1990 and 2014.

However, studies have raised concerns and projects detrimental impact of energy consumption on growth in the long run, thus leading to recommendations for sustainable policies for renewable energy in the country (Adedoyin et al., 2021; Bekun, 2022; Tang et al., 2016). Chen et al. (2020) enquired on the threshold effect of renewable energy consumption on economic growth in 103 countries between 1995 and 2015. Using the threshold regression analysis, the study found that renewable energy consumption has positive and significant effect on growth of developing countries when optimal threshold level is determined.

In examining the threshold effect, some scholars opined that the individual contribution of energy sources and diversification mix may produce more empirical validation of the impact of energy consumption on economic growth and sustainable development. For instance, Sharif et al. (2021) enquired on the implications of renewable sources of energy on CO<sub>2</sub> emission in the United States of America. The study which employed quantile on quantile regression analysis revealed that optimal mix of renewable energy sources significantly reduces the emission of CO<sub>2</sub> in the United States. Similar position was found in the works of Chien et al. (2022) which pointed that clean energy sources plays critical roles in reducing the effects of greenhouse gas emissions in top Asian countries.

Díaz et al. (2019) counterargue that energy mix should corroborate energy intensity for the achievement of a sustainable growth of countries. The study opined that improving energy intensity is growth enhancing across the globe and that other factors such as the quality of institutions is crucial in achieving sustainable economic development. The indirect position of scholars on the immediate impact of energy

diversification led to the enquiry on the contributions of energy diversification to growth of Nordic countries. The outcome in the works of Viana Espinosa de Oliveira and Moutinho, 2022 opined both social and economic globalization exerts positive and significant impact on the link between energy diversification and economic growth. Similarly, Rahman & Sultana (2022) pointed to a bidirectional linkage between energy security, corruption, and economic sustainability amongst 19 emerging countries between 2002 and 2019. Moreso, Ahmed et al. (2022) pointed to cultural and ethnic diversification in explaining the link between energy consumption and economic growth.

Based on the outcome of the empirical review, it is instructive to note that energy diversification, socioeconomic factors are crucial to sustainable development (Ahmed et al., 2022) and the evidence on this linkage is under researched in the literature. Therefore, this study establishes a linkage between institutional factors, globalization and other factors that could mediate the link between energy diversification and sustainable development.

### 3. Data and methodology

#### 3.1. Data description

The linkages of energy diversification, globalization, corruption, and information technology to sustainable development in the 15 Asian-Pacific Economic Cooperation countries was examined using data for the period between 1990 and 2020. APEC's sustainable development is measured by the relative impact of ecological efficiency to the interrelationship between health, income, and education. Accordingly, the ecological efficiency of human capital development must recognize the planetary boundaries for a true existence of sustainable development. The sustainable development index data is collected from Hickel (2020). This index measures sustainable development by combining social, economic, and environmental issues.

Energy diversification is the variable of enquiry for this study. Different Studies show that countries have not been able to demonstrate a uniform diversification model due to the different sources of energy inherent in the countries (British Petroleum, 2021; Li, 2005; Wen et al., 2021). As a result, the diversification of energy portfolio for countries may transit from the use of fossil fuel to renewable sources. This study follows Gozgor and Paramati (2022) in measuring the level of energy diversification and interpolates the data when there is presence of missing observations. The diversification was calculated using dataset from the British petroleum through the Herfindahl-Hirshman diversification index (British Petroleum, 2021).

Economic globalization was obtained from the KOF globalization index. The index measures the economic dimension of globalization through the international movement of technology, goods physical, human and financial capital (Dreher and Langlotz, 2020). This invariably increases efficiency thus increasing sustainable development of countries. Similarly, social globalization measures the dimension at which social interactions between family, government, and the society influence globalization. This indicator is measured using the KOF social globalization index (Gygli et al., 2019). Information and communication technology data was collected from the Notre Dame – Global Adaptation Initiative Index (ND-GAIN) database where ICT is an index of phone, mobile, internet and broadband subscription measures. (Chen et al., 2015; Epule et al., 2017).

#### 3.2. Pre-test diagnostics

Literature suggests that panel data often exhibit dependence amongst its cross-sectional units. This mainly presents itself due to the presence of common shocks, unobserved components and interdependence amongst its residuals (Pesaran, 2007). The increasing presence of cross-dependence may be associated with increasing international trade, financial integration, or globalization. Consequently, the presence of

CSD may reflect inconsistent, invalid, and weakly efficient results. Moreso, the presence of cross-sectional dependence in the dataset may erode the efficiency gains one is set to achieve in a pooled population (Hoyos and Sarafidis, 2006; Shah et al., 2022). To address this, Pesaran (2007, 2021) test is used to check cross-sectional dependence in situations where the number of cross-sections is greater than the time period (Wursten, 2017). The test statistics is stated as follows:

$$CSD = \frac{[TN(N-1)]^{1/2}}{2} \delta N \tag{1}$$

The term  $\delta N$  is the pairwise correlation coefficient while  $T$  is the timeframe and  $N$  is the number of cross sections.

The existence of unit roots for the panel data set was also tested using the cross-sectional Augmented Dickey Fuller test. This is essential to control for the non-stationarity of the data to avoid spurious, inconsistent, and biased estimates. The model CADF is stated as

$$\Delta E_{i,t} = \delta_i + \rho_i E_{i,t-1} + \vartheta_i \bar{E}_{t-i} + \alpha_i \Delta \bar{E}_i + \varepsilon_{i,t} \tag{2}$$

Where  $\delta_i, \rho_i, \vartheta_i, \alpha_i$  are the indicators of the slope obtained from the calculated ADF for each cross section  $i$ ,  $\Delta E_{i,t}$  and  $\bar{E}_{t-i}$  are the averages of the first difference and its lagged differences;  $\varepsilon_{i,t}$  denotes the error term. Going by this, the CIPS test is obtained from the mean values derived through CADF. The equation is specified below

$$CIPS = \frac{1}{N} \sum_{i=1}^N t_i(N, T) \tag{3}$$

Where  $CIPS$  is the obtained from the t-statistics;  $t_i(N, T)$  of the estimates for the analysis  $E_{i,t} = E_{i,t} + E_{it}^0$ . More so, this study tests for the long-run relationship between the variables using the Westerlund (2007) test for error correction. The model is specified as thus

$$\Delta U_{it} = \delta_i C_t + \rho_i U_{t-1} + \tau_i X_{t-1} + \sum_{l=1}^{\omega_l} \rho_{il} \Delta U_{it-l} + \sum_{l=-q}^{\omega_l} \varphi_{il} X_{it-l} + \mu_{it}$$

Where the equation is modelled with a constant trend, then  $C_t = 1$  and if not then  $C_t = 0$ . The stationary procedure given CS averages is written as

$$\varepsilon_{it} = \rho_i FM_t + \mu_{it}$$

Where  $FM_t$  is the matrix Factor and  $\mu_{it}$  is the unobserved error term. Theoretically, the model is expected to depict the acceptance of the alternative hypothesis through the assumption of a long-term relationship between the variables.

#### 3.3. The CCE-GMM estimator

This study applies the CCE-GMM technique to handle the persistent issues in large panel data estimation. This robust estimator is an extension of the Pesaran (2007) and Chudik and Pesaran (2015) CCE estimation to accommodate other large panel data issues. Unlike the CCE which uses the least square individual-specific regressors, this estimator replaced it with the generalized Methods of Moment using the variables lagged observations as their instrument set. Accordingly, Monte Carlo simulation suggests affirms that the replacement of OLS with GMM in the CCE model increases the estimates efficiency and robustness in the dynamic and static models (Neal, 2015). The advantage of CCE-GMM estimator compared to CCEMG is that it can account not only for cross sectional dependency, but it can also account for endogeneity which we suspect to exist between energy diversification and sustainable development since sustainable development may influence the diversification of energy sources in APEC. Indeed, after 2015, when SDG agenda was adopted, countries around the world have started to fullfill these agenda by transitioning towards clean energy sources from fossil fuels. Therefore, if endogeneity is not accounted for,

it might produce biased result. The CCE-GMM is said to be robust to the presence of any regressors which are endogenous. Besides CCE-GMM, we also implement the Common Correlated Effects Mean Group (CCEMG) of Pesaran (2006) as a robustness analysis.

#### 4. Empirical results

Table 1 presents the descriptive statistics of this data used in the study. From the analysis, it shows that the mean of the sustainable development for the countries is -0.74 while the maximum and minimum values are -0.2 and -2.5. The energy diversification index suggests that the rate of energy has an average increase of about 1.13% while the maximum and minimum increase in the rate of energy diversification fall between 1.12% and 1.15% during the period in review. The statistics further revealed that the mean values of public sector corruption and ICT are -2 and -1.03. In terms of economic and social globalization, the mean values are higher than all the other parameters included in the table. Moreover, variables are also not normally distributed as can be seen from the Jarque-Bera test.

Table 2 shows the result of correlation matrix, according to which ED, PUBCOR has negative relation and EG, SG, ICT has negative relation with SDI.

Table 3 presents the outcome of the cross-sectional dependence test using four tests namely the Breusch-Pagan LM, Pesaran scaled LM, Bias-corrected scaled LM and the Pesaran CD.

The test revealed the presence of cross-sectional dependence amongst the variables. Thus, the null hypothesis of the tests is rejected at 1% level of significance for all the variables except for public corruption which was insignificant in the Pesaran cross sectional dependence test. This suggests that there are possibilities of unobserved shocks among the countries thereby exhibiting strong evidence for cross sectional dependence. Moreso, Table 4 shows the findings on the second-generation unit root tests. From the tables, statistics reveal that the null hypothesis of non-stationarity of the variables at levels were accepted at above 5% level of significance whereas, they became stationary at 1% significance level at first difference.

The CCE-GMM estimation reveals the link between energy diversification, globalization, corruption, information technology and sustainable development in Table 5. The table shows that a point increase in energy diversification has about 0.174% equivalent increase in sustainable development. This finding aligns with the works of Gozgor and Paramati (2022) who confirms that energy diversification positively influences growth and sustainable development. In essence, the mixture of renewable energy sources has considerable effect of synthetic synergy of health, income levels, education, and ecology. However, this study contradicts the position of Tang et al. (2016) which raises a long run detrimental impact of energy consumption on growth of Vietnam.

In similar instance, economic globalization also poses a strong and positive contributions to sustainable development for countries in the Asian Pacific. The findings revealed that a point increase in the level of economic globalization through the movement of human, tangible and

**Table 1**  
Descriptive statistics.

	LNSDI	LNED	LNPUBCOR	LNED	LNSG	LNICT
Mean	-0.74385	1.130275	-2.00683	4.075306	4.108506	-1.03016
Median	-0.42465	1.125752	-0.89894	4.112932	4.209288	-0.98915
Maximum	-0.20089	1.508253	-0.12443	4.549965	4.502163	-0.35879
Minimum	-2.53831	0.782722	-5.116	3.293021	2.575202	-1.71002
Std. Dev.	0.594999	0.170106	1.711882	0.23079	0.365589	0.424988
Skewness	-1.29989	0.194344	-0.41286	-0.48948	-1.73535	-0.12137
Kurtosis	3.666504	2.595982	1.553683	3.545617	6.500785	1.704751
Jarque-Bera	139.5599	6.089726	53.73904	24.33634	470.838	33.64647
Probability	0.0000	0.047603	0.0000	0.000005	0.0000	0.0000
Sum	-345.89	525.5778	-933.178	1895.017	1910.455	-479.023
Sum Sq. Dev.	164.2669	13.42625	1359.771	24.71457	62.01612	83.80527
Observations	465	465	465	465	465	465

**Table 2**  
Correlation matrix.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
(1) lnSDI	1.000					
(2) lnED	0.023	1.000				
(3) lnEG	-0.519	-0.085	1.000			
(4) lnSG	-0.474	-0.382	0.727	1.000		
(5) lnPUBCOR	0.400	-0.224	-0.307	-0.250	1.000	
(6) lnICT	-0.538	-0.436	0.581	0.782	-0.228	1.000

technological amongst countries contributes about 0.16% increase in the level of sustainable development. This empirical outcome aligns with the position of Samimi and Jenatabadi (2014) who found that economic globalization improves growth thus having an indirect effect on sustainable development. Similarly, information technology which measures the vulnerability of countries to climate change assumes a positive and significant impact on sustainable development. The findings suggest that a percentage increase in vulnerability exerts 0.054% increase in the level of sustainable development in APEC countries. The outcome of this research aligns the position of Adebayo et al. (2022) who posits that sustainable consumption of information technology and communication increases sustainable development in 10 most versed ICT nations in the world.

In contrast, the results revealed that both public sector corruption and social globalization exhibited negative effects on sustainable development. For instance, public sector corruption shows an insignificant and negative impact in advancing sustainable development. This indicated that public sector corruption could slow down the rate of sustainable development, however, its overall impact may be inconsequential. This finding relates to the outcome in Fhima et al. (2023) which points to the ill-effect of public sector corruption in developed countries. However, the study further stressed that corruption effect on sustainable development is regime-specific in developing countries.

Also, social globalization is negative and could significantly reduce the rate of sustainable development in the APEC countries. The outcome of this study aligns with the works of Deng et al. (2022) which affirms that social globalization aggravates environmental pollution thereby reducing the level of sustainable development. (Deng et al., 2022; Zhao and Huang, 2022). However, it contradicts the position of Ahmed et al. (2022) who opines that globalization reduces the level of sustainable development in Nordic countries. This may be attributed to the state of development of urbanization and globalization (Viana Espinosa de Oliveira and Moutinho, 2022).

The CCEMG, an alternate estimation procedure, was used in generating estimates to ascertain the robustness of the main estimation. Table 6 presents the estimates of the link between energy diversification, globalization, corruption, and information technology to sustainable development in the 15 Asian-Pacific economic cooperation nations. The findings appeared similar to the CCE-GMM; however, the level of significance differs from the latter. For instance, energy diversification

**Table 3**  
Cross sectional Dependence Test.

Test	lnSDI	lnED	lnEG	lnSG	lnPUBCOR	lnICT
Breusch-Pagan LM	1784.606***	1777.966***	2256.025***	3113.481***	696.6636***	2996.732***
Pesaran scaled LM	115.9038***	115.4456***	148.4349***	207.6049***	40.82867***	199.5485***
Bias-corrected scaled LM	115.6538***	115.1956***	148.1849***	207.3549***	40.57867***	199.2985***
Pesaran CD	1.639127	19.92573***	46.6533***	55.7917***	-1.14789	54.7045***

Note: \*\*\* indicates significance level at 1%.

**Table 4**  
Second Generation Unit root test.

Variables	CIPS		CADF	
	Level	First difference	Level	First difference
lnSDI	-1.906	-5.278 ***	-1.712	-3.498***
lnED	-1.892	-4.884 ***	-1.973	-3.767 ***
lnEG	-1.888	-5.320 ***	-2.109	-4.244 ***
lnSG	-2.373	-5.483 ***	-2.367	-3.967***
lnPUBCOR	-2.494	-5.048 ***	-1.655	-3.902***
lnICT	-2.551	-3.532 ***	-2.535	-2.908 **

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

**Table 5**  
CCE-GMM estimation.

Variables	Coef.	t-stat
lnED	0.174**	2.040
lnPUBCOR	-0.016	-0.350
lnEG	0.161**	1.880
lnSG	-0.144***	-2.550
lnICT	0.054***	2.850
Constant	-0.068	-0.230
Number of groups	15	
No of obs.	420	
Wald Chi2	19.2***	

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

**Table 6**  
Common corrected effects mean group estimator.

Variables	Coef.	t-stat
lnED	0.098**	2.020
lnPUBCOR	0.029	0.630
lnEG	0.151*	1.730
lnSG	-0.116**	-2.540
lnICT	0.078***	3.720
Constant	0.047	0.879
Number of groups	15	
No of obs.	465	
Wald Chi2	18.68***	

Note: \*\*\*, \*\*, \* indicate significance level at 1%, 5% and 10%.

exerts the same positive impact on sustainable development, but its level of significance weakened from 1% to 5% level of significance. Similarly, the impact of economic and social globalization exerts the same direction to sustainable development but rather than the effects being at 99% confidence level, it reduced to 95% and 90% respectively. The result only indicated that only information technology remained positive and significant at 1% level of significant in both estimations. We also noticed that public sector corruption had a negative impact in CCEGMM, while it has positive impact in CCEMG. This indicates the need to account for both endogeneity and cross-sectional dependency and how results may change if endogeneity is not accounted for.

To see if our model suffers from multicollinearity, we conducted a Variance Inflation Factor (VIF) test. Table 7 shows the result of VIF and tolerance, implying that there is no problem of multicollinearity in our

**Table 7**  
VIF result.

Variables	VIF	1/VIF
lnED	1.39	0.722
lnEG	2.45	0.408
lnSG	4.12	0.243
lnPUBCOR	1.67	0.6
lnICT	2.76	0.362
Mean VIF	2.48	

model.

Lastly, the direction of causality amongst the variables was examined using the Pairwise Dumitrescu Hurlin Panel Causality Test of Dumitrescu and Hurlin (2012). Table 8 presents the result of the direction of causality of the variables. The heterogenous panel non-causality test shows that ED granger causes SDI but the causality also runs from SDI to ED. Bidirectional causality have been found between SDI and SG, ICT and SDI, EG and ED, ED and ICT, SG and EG, ICT and EG, ICT and SG. Unidirectional causality runs from SDI to PUBCOR, EG to SDI, ED to PUBCOR, SG to ED, PUBCOR to EG, ICT to PUBCOR.

### 5. Conclusion and policy implications

This study examines the impact of energy diversification, corruption, ICT and economic and social globalization on SDI in 15 APEC countries over the period 1990–2020. To this extent, we employed the Westerlund cointegration test, CCEGMM and CCE-MG long-term coefficient estimators and Dumitrescu and Hurlin causality test considering cross-section dependency. According to the findings, there is a long-term between the variables. The summary of the empirical findings are as follows.

- i) Energy diversification has a positive significant effect on the SDI.
- ii) Corruption has insignificant influence on SDI
- iii) Economic globalization has positive impact on the SDI.
- iv) Social globalization negatively influences the SDI
- v) ICT shows a positive and significant effect on SDI

As seen above, energy diversification, economic globalization and ICT have a positive impact on sustainable development in APEC countries. Therefore they can be used as a policy tool to achieve SDGs. However, we could not find any proof that public sector corruption impacts the SDI in APEC countries. The causality result also demonstrated several bidirectional and unidirectional relationship between the variables.

Due to its high share in global energy consumption and CO<sub>2</sub> emissions, it is vital that APEC countries take an active role in solving climate change and environmental problems. However, APEC Energy Outlook (2019) claims that APEC countries might not achieve the targets they submitted to UNFCCC in the context of the Paris Agreement (COP21) due to the current energy trends. As it is known, the dirtiest fossil fuel is coal, while the relatively clean fossil fuel is natural gas. Therefore, energy diversification is vital for APEC countries. However, since fossil fuel costs are lower than renewable energy (Sinha and Sengupta, 2019), the transition to renewable energy may be challenging in practice. Energy

**Table 8**  
Direction of Causality of the variables.

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.	Significant Result
LNED → LNSDI	3.36160	1.91178	0.0559*	LNED ↔ LNSDI
LNSDI → LNED	5.02086	4.60054	4. E-06***	
LNPUBCOR → LNSDI	1.79183	-0.63196	0.5274	LNSDI → LNPUBCOR
LNSDI → LNPUBCOR	3.28475	1.78726	0.0739*	
LNEG → LNSDI	4.71861	4.11075	4. E-05***	LNEG → LNSDI
LNSDI → LNEG	3.14293	1.55744	0.1194	
LNSG → LNSDI	5.04847	4.64527	3. E-06***	LNSDI ↔ LNSG
LNSDI → LNSG	3.75491	2.54912	0.0108**	
LNICT → LNSDI	5.24365	4.96155	7. E-07***	LNICT ↔ LNSDI
LNSDI → LNICT	5.88416	5.99947	2. E-09***	
LNPUBCOR → LNED	2.57507	0.63725	0.5240	LNED → LNPUBCOR
LNED → LNPUBCOR	7.69163	8.92839	0.0000***	
LNEG → LNED	3.48856	2.11751	0.0342**	LNEG ↔ LNED
LNED → LNEG	3.68621	2.43780	0.0148**	
LNSG → LNED	6.76974	7.43451	1. E-13***	LNSG → LNED
LNED → LNSG	2.50506	0.52379	0.6004	
LNICT → LNED	6.79596	7.47700	8. E-14***	LNED ↔ LNICT
LNED → LNICT	3.39617	1.96780	0.049**	
LNEG → LNPUBCOR	2.21042	0.04635	0.9630	LNPUBCOR → LNEG
LNPUBCOR → LNEG	0.76800	-2.29103	0.0220**	
LNSG → LNPUBCOR	2.92280	1.20073	0.2299	LNSG ↔ LNPUBCOR
LNPUBCOR → LNSG	1.59474	-0.95133	0.3414	
LNICT → LNPUBCOR	3.58783	2.27838	0.0227**	LNICT → LNPUBCOR
LNPUBCOR → LNICT	2.23078	0.07933	0.9368	
LNSG → LNEG	4.03029	2.99536	0.0027***	LNSG ↔ LNEG
LNEG → LNSG	3.22163	1.68497	0.0920*	
LNICT → LNEG	4.20565	3.27952	0.0010***	LNICT ↔ LNEG
LNEG → LNICT	7.40596	8.46547	0.0000***	
LNICT → LNSG	3.78547	2.59865	0.0094***	LNICT ↔ LNSG
LNSG → LNICT	9.56916	11.9708	0.0000***	

Note: \*\*\*, \*\*, \* show the statistical significance at 1%, 5%, and 10% levels.

conversion practices have to be long-term and gradual. Therefore, transitioning to cleaner energy sources among fossil fuels in the first phase might be an effective strategy. In particular, a gradual transition from coal to natural gas could be a strategic environmental policy of APEC countries. For example, thanks to the shale gas revolution, the US has explored and extracted massive natural gas and decreased its CO<sub>2</sub> emissions below the 1990 levels by decreasing coal consumption (Sofuoğlu, 2014). In addition, increasing the share of renewable energy and biofuels in the energy mix will be in favor of APEC countries in terms of achieving the SDGs and energy security. Several studies also recommend policymakers to diversify energy sources for sustainability (Sharif et al., 2021; Amin et al., 2022; Chien et al., 2022).

The study also reveals that economic globalization might be used as an instrument for sustainability. This is an advantage for the APEC countries since globalization leads to increase in economic growth, energy consumption and environmental degradation. Furthermore, incentivizing ICT activities can also enhance economic growth and sustainable development. Promoting ICT will ease the establishment of low-carbon technologies in several sectors, such as transportation, aviation, agriculture and chemical. Therefore, APEC countries could achieve sustainable development without facing degrowth issues. However,

APEC countries should form long-term policies to minimize corruption and promote accountability in order to ensure sustainable development. ICT, institutional quality and globalization can help to achieve three SDGs directly (Goal 9,<sup>2</sup> Goal 12,<sup>3</sup> Goal 13<sup>4</sup> and Goal 16<sup>5</sup>).

This study has critical future recommendations. As it is known, countries have submitted their INDCs to the UNFCCC secretariat to achieve the net-zero emission target and 1.5 C surface temperature. However, even if the reduction targets are met, it seems complicated to achieve these targets because of the rising energy demand. Therefore, we will probably see requests for revision of realistic INDCs in the coming years. From this point of view, we believe that a study examining the effectiveness of existing INDCs will significantly contribute to the literature.

The limitation of this study is not to consider structural breaks over the period 1990–2020. However, APEC economies have experienced several shocks during this period which could be detected using structural breaks. Therefore, it is recommended to account for structural breaks in modeling sustainable development agenda for APEC countries. It is also suggested that researchers focus on future scenarios to see if net zero targets by 2050 are reachable for the APEC countries by employing scenario modeling techniques such as general equilibrium modeling framework.

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### CRedit authorship contribution statement

**Bofan Liu:** Formal analysis, Investigation, Resources. **Olohunlana Aminat Olayinka:** Resources, Writing – original draft, Writing – review & editing. **Emrah Sofuoğlu:** Writing – original draft, Writing – review & editing. **Shujaat Abbas:** Conceptualization, Resources, Writing – original draft, Formal analysis. **Avik Sinha:** Conceptualization, Resources, Writing – original draft, Writing – review & editing, Formal analysis.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Data availability

Data will be made available on request.

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### References

Adebayo, T.S., Agyekum, E.B., Altuntaş, M., Khudoyqulov, S., Zawbaa, H.M., Kamel, S., 2022. Does information and communication technology impede environmental degradation? fresh insights from non-parametric approaches. *Heliyon* 8 (3). <https://doi.org/10.1016/j.heliyon.2022.e09108>.  
 Adedoyin, F.F., Agboola, P.O., Ozturk, I., Bekun, F.V., Agboola, M.O., 2021. Environmental consequences of economic complexities in the EU amidst a booming

<sup>2</sup> SDG 9: “Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.”

<sup>3</sup> SDG 12: “Ensure sustainable consumption and production patterns.”

<sup>4</sup> SDG 13: “Take urgent action to combat climate change and its impacts.”

<sup>5</sup> SDG 16: “Peace, justice and strong institutions.”

- tourism industry: accounting for the role of brexit and other crisis events. *J. Clean. Prod.* 305, 127117–undefined.
- Ahmed, N., Sheikh, A.A., Mahboob, F., Ali, M. S. e, Jasińska, E., Jasiński, M., Leonowicz, Z., Burgio, A., 2022. Energy diversification: a friend or foe to economic growth in Nordic countries? A novel energy diversification approach. *Energies* 15 (15), 5422. <https://doi.org/10.3390/en15155422>.
- APEC, 2021. APEC Energy Overview 2021. Access date. <https://aperc.or.jp/file/2021/10/26/APEC+Energy+Overview+2021.pdf>. (Accessed 28 January 2022).
- APEC Energy Outlook, 2019. APEC Demand and Supply Outlook –, fifth ed. Access date. <https://aperc.ieej.or.jp/2019>. (Accessed 26 January 2022).
- Aslani, A., Naaranoja, M., Helo, P., Antila, E., Hiltunen, E., 2013. Energy diversification in Finland: achievements and potential of renewable energy development. *Int. J. Sustain. Energy* 32 (5), 504–514.
- Bekun, F.V., 2022. Mitigating emissions in India: accounting for the role of real income, renewable energy consumption and investment in energy. *Int. J. Energy Econ. Pol.* 12 (1), 188–192.
- Bekun, F.V., Gyamfi, B.A., Onifade, S.T., Agboola, M.O., 2021. Beyond the environmental Kuznets Curve in E7 economies: accounting for the combined impacts of institutional quality and renewables. *J. Clean. Prod.* 314 <https://doi.org/10.1016/j.jclepro.2021.127924>.
- British Petroleum, 2021. Statistical Review of World Energy. British Petroleum.
- Brundtland, G.H., 1987. Our common future—call for action. *Environ. Conserv.* 14 (4), 291–294.
- Chen, C., Noble, I., Hellmann, J., Coffee, J., Murillo, M., Chawla, N., 2015. University of Notre Dame Global Adaptation Index Country Index Technical Report.
- Chen, C., Pinar, M., Stengos, T., 2020. Renewable energy consumption and economic growth nexus: evidence from a threshold model. *Energy Pol.* 139 <https://doi.org/10.1016/j.enpol.2020.111295>.
- Chien, F., Hsu, C.-C., Ozturk, I., Sharif, A., Sadiq, M., 2022. The role of renewable energy and urbanization towards greenhouse gas emission in top Asian countries: evidence from advance panel estimations. *Renew. Energy* 186, 207–216. <https://doi.org/10.1016/j.renene.2021.12.118>.
- Chudik, A., Pesaran, M.H., 2015. Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. *J. Econ.* 188 (2), 393–420, 2015.
- Cole, M.A., 2006. Does trade liberalization increase national energy use? *Econ. Lett.* 92 (1), 108–112.
- De Freitas, L.C., Kaneko, S., 2011. Decomposing the decoupling of CO2 emissions and economic growth in Brazil. *Ecol. Econ.* 70 (8), 1459–1469.
- Deng, Q.S., Alvarado, R., Cuesta, L., Tillaguango, B., Murshed, M., Rehman, A., Işık, C., López-Sánchez, M., 2022. Asymmetric impacts of foreign direct investment inflows, financial development, and social globalization on environmental pollution. *Econ. Anal. Pol.* 76, 236–251. <https://doi.org/10.1016/j.eap.2022.08.008>.
- Díaz, A., Marrero, G.A., Puch, L.A., Rodríguez, J., 2019. Economic growth, energy intensity and the energy mix. *Energy Econ.* 81 <https://doi.org/10.1016/j.eneco.2019.05.022>.
- Dreher, A., Langlotz, S., 2020. Aid and growth: new evidence using an excludable instrument. *Can. J. Econ. Rev. Canadienne d'économique* 53 (3). <https://doi.org/10.1111/caje.12455>.
- Dumitrescu, E.I., Hurlin, C., 2012. Testing for Granger non-causality in heterogeneous panels. *Econ. Modell.* 29 (4), 1450–1460. <https://doi.org/10.1016/j.econmod.2012.02.014>.
- Epule, T., Ford, J., Lwasa, S., Lepage, L., 2017. Vulnerability of maize yields to droughts in Uganda. *Water* 9 (3). <https://doi.org/10.3390/w9030181>.
- Fhima, F., Nouira, R., Sekkat, K., 2023. How does corruption affect sustainable development? A threshold non-linear analysis. *Econ. Anal. Pol.* 78 <https://doi.org/10.1016/j.eap.2023.03.020>.
- Gallagher, K.S., 2006. Limits to leapfrogging in energy technologies? Evidence from the Chinese automobile industry. *Energy Pol.* 34 (4), 383–394.
- Godil, D.I., Sharif, A., Ali, M.I., Ozturk, I., Usman, R., 2021. The role of financial development, R&D expenditure, globalization and institutional quality in energy consumption in India: new evidence from the QARDL approach. *J. Environ. Manag.* 285, 112208 <https://doi.org/10.1016/j.jenvman.2021.112208>.
- Gozgor, G., Paramati, S.R., 2022. Does energy diversification cause an economic slowdown? Evidence from a newly constructed energy diversification index. *Energy Econ.* 109, 105970 <https://doi.org/10.1016/J.ENERCO.2022.105970>.
- Gygli, S., Haelg, F., Potrafke, N., Sturm, J.-E., 2019. The KOFglobalisation index – revisited. *Rev. Int. Organ.* 14 (3) <https://doi.org/10.1007/s11558-019-09344-2>.
- Harris, J.M., 2000. Basic principles of sustainable development. *Dimens. Sustain. Dev.* 21–41.
- Hickel, J., 2020. The sustainable development index: measuring the ecological efficiency of human development in the anthropocene. *Ecol. Econ.* 167, 106331.
- Hoyos, R., Sarafidis, V., 2006. Testing for cross-sectional dependence in panel-data models. *STATA J.* 6 (4), 482–496.
- Hunjra, A.I., Tayachi, T., Chani, M.I., et al., 2020. The moderating effect of institutional quality on the financial development and environmental quality nexus. *Sustainability* 12, 3805. <https://doi.org/10.3390/su12093805>, 2020.
- Jorgenson, A.K., Givens, J.E., 2014. Economic globalization and environmental concern: a multilevel analysis of individuals within 37 nations. *Environ. Behav.* 46 (7), 848–871.
- Le, T.H., Chang, Y., Park, D., 2016. Trade openness and environmental quality: international evidence. *Energy Pol.* 92, 45–55.
- Li, X., 2005. Diversification and localization of energy systems for sustainable development and energy security. *Energy Pol.* 33 (17), 2237–2243. <https://doi.org/10.1016/j.enpol.2004.05.002>.
- Lorenz, H., Lohmann, W., Huang, E.M., 2011. Sustainability and ICT—an overview of the field. *Notizie di POLITEIA* 27 (104), 13–28.
- McKeown, R., Hopkins, C.A., Rizi, R., Chrystalbridge, M., 2002. Education for Sustainable Development Toolkit. Energy, Environment and Resources Center, University of Tennessee, Knoxville, 2002.
- Neal, T., 2015. Estimating Heterogeneous Coefficients in Panel Data Models with Endogenous Regressors and Common Factors.
- Pesaran, M.H., 2006. Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica* 74 (4), 967–1012.
- Pesaran, M.H., 2007. A simple panel unit root test in the presence of cross section dependence. *J. Appl. Econom.* 22, 265–312.
- Pesaran, M.H., 2021a. General diagnostic tests for cross-sectional dependence in panels. *Empir. Econ.* 60 (1) <https://doi.org/10.1007/s00181-020-01875-7>.
- Pesaran, M.H., 2021b. General diagnostic tests for cross-sectional dependence in panels. *Empir. Econ.* 60 (1) <https://doi.org/10.1007/s00181-020-01875-7>.
- Rahman, M.M., Sultana, N., 2022. Impacts of institutional quality, economic growth, and exports on renewable energy: Emerging countries perspective. *Renew. Energy* vol. 189. <https://doi.org/10.1016/j.renene.2022.03.034>.
- Rahman, M.M., Velayutham, E., 2020. Renewable and non-renewable energy consumption-economic growth nexus: new evidence from South Asia. *Renew. Energy* 147. <https://doi.org/10.1016/j.renene.2019.09.007>.
- Samimi, P., Jenatabadi, H.S., 2014. Globalization and economic growth: empirical evidence on the role of complementarities. *PLoS One* 9 (4), e87824. <https://doi.org/10.1371/journal.pone.0087824>.
- Shah, M.I., Abbas, S., Olohunlana, A.O., Sinha, A., 2022. The impacts of land use change on biodiversity and ecosystem services: an empirical investigation from highly fragile countries. *Sustain. Dev.* <https://doi.org/10.1002/sd.2454>.
- Sharif, A., Bhattacharya, M., Afshan, S., Shahbaz, M., 2021. Disaggregated renewable energy sources in mitigating CO2 emissions: new evidence from the USA using quantile regressions. *Environ. Sci. Pollut. Control Ser.* 28 (41), 57582–57601. <https://doi.org/10.1007/s11356-021-13829-2>.
- Sharpley, R., 2000. Tourism and sustainable development: exploring the theoretical divide. *J. Sustain. Tourism* 8 (1), 1–19.
- Sinha, A., Sengupta, T., 2019. Impact of energy mix on nitrous oxide emissions: an environmental Kuznets curve approach for APEC countries. *Environ. Sci. Pollut. Control Ser.* 26 (3), 2613–2622.
- Sofuoğlu, E., 2014. *Kaya Gazı Devrimi Ve Olası Ekonomik etkileri*. (Master's Thesis. Adnan Menderes University, the Institute of Social Sciences, Department of Economics).
- Stirling, A., 2010. Multicriteria diversity analysis: a novel heuristic framework for appraising energy portfolios. *Energy Pol.* 38 (4), 1622–1634.
- Tang, C.F., Tan, B.W., Ozturk, I., 2016. Energy consumption and economic growth in Vietnam. *Renew. Sustain. Energy Rev.* 54 <https://doi.org/10.1016/j.rser.2015.10.083>.
- Viana Espinosa de Oliveira, H., Moutinho, V., 2022. Do renewable, non-renewable energy, carbon emission and KOF globalization influencing economic growth? Evidence from BRICS' countries. *Energy Rep.* 8 <https://doi.org/10.1016/j.egy.2022.01.031>.
- Vivoda, V., 2019. LNG import diversification and energy security in Asia. *Energy Pol.* 129, 967–974.
- Wen, J., Zhao, X., Wang, Q.-J., Chang, C.-P., 2021. The impact of international sanctions on energy security. *Energy Environ.* 32 (3) <https://doi.org/10.1177/0958305X20937686>.
- Westerlund, J., 2007. Testing for error correction in panel data. *Oxf. Bull. Econ. Stat.* 69, 709–748.
- Wursten, J., 2017. XTCDF: Stata module to perform Pesaran's CD-test for cross-sectional dependence in panel context. Statistical Software Components S458385, Boston College Department of Economics. Available at: <https://ideas.repec.org/c/boc/bocode/s458385.html>.
- You, W., Lv, Z., 2018. Spillover effects of economic globalization on CO2 emissions: a spatial panel approach. *Energy Econ.* 73, 248–257.
- Zhao, X., Huang, L., 2022. Understanding the dynamic role of natural resources, green technology, economic integration and social globalization towards sustainable environment in China. *Resour. Pol.*, 103079 <https://doi.org/10.1016/j.resourpol.2022.103079>.