GeoJournal (2018) 83:1339–1348
https://doi.org/10.1007/s10708-017-9839-y

Biomass energy consumption and economic growth: panel data evidence from ASEAN member countries

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Published online: 20 December 2017

Abstract The present study investigates the dynamic impact of biomass energy consumption on economic growth across nine (9) ASEAN economic union member countries for the period of 1980–2011. We applied heterogeneous panel cointegration techniques. The result based on Pedroni panel cointegration test shows that, variables have long-run relationship as the null hypothesis of no cointegration was rejected at 1% and 5% respectively. Kao residual cointegration test also shows the same result as null hypothesis of no cointegration is rejected at 1% level of significance. The main empirical finding based on dynamic OLS, fully modified OLS and panel OLS reveals that; there is a positive and significant relationship between biomass energy consumptions and economic growth in the region. Moreover, the result based on dynamic ordinary least square (DOLS) also shows that; capital stock and human capital have a positive and significant impact on economic growth. Same result is also obtained from fully modified OLS (FMOLS) with the exception of human capital which is insignificant on economic growth. Panel ordinary least square also reconfirmed the finding of DOLS as all the three variables significantly influences economic growth. The policy suggestion remains that, authorities in ASEAN economic union should focus more on encouraging the use of renewable sources of energy, particularly biomass source of energy considering its positive impact on enhancing economic growth with little or no environmental degradation.

Keywords Biomass energy · Economic growth · Capital stock · Human capital · Panel cointegration · ASEAN

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Introduction

The importance of energy in the global economy cannot be over emphasized; this is linked to its essential functions of promoting regional and global economic growth. Global energy crisis, energy insecurity, energy price volatilities, environmental degradation caused by the consumptions of fossil fuels necessitated the researchers and policy makers to come up with the alternative sources of energy that may have less environmental problems. One of the best options is the renewable sources of energy that has little negative environmental implication when compared with fossil fuels.

The aggregate energy consumption had increased by 4% in the Association of South East Asian Nations (ASEAN) region in 2013. The energy demand increases by over 80% in Southeast Asia between now through 2035; this increase is attributed to the current Japan's energy demand. Moreover, the increase is related to the region's population growth that increases by nearly one-quarter. Southeast Asia's oil demand expected to increase from 4.4 to 6.8 mb/d in 2035 which is virtually one fifth of the global projected growth. Coal demand is growing at double digit since 1990, it is expected to triples during 2011–2035 which fundamentally account for 30% global growth. Demand for natural gas in the region increases by 80% to 250 bcm. The primary renewable energy demand promptly decline due to the use of modern renewable sources which includes; hydro, geothermal and wind. The carbon emissions related to energy in Southeast Asia is almost double which is expected to reach 2.3 GT in 2035 (International Energy Agency 2013). Biomass energy uses remain an essential source of energy among the ASEAN member countries and its consumption is still rising.

The main objective of this article is to empirically examine the dynamic impact of biomass energy consumption on economic growth across nine (9) ASEAN member countries. We applied panel cointegration technique, dynamic ordinary least square (DOLS) and fully modified ordinary least square (FMOLS) in order to achieve the stated objective. Majority of biomass energy used in ASEAN member countries is from wood fuels with projected value of US$7 billion annually. Biomass energy consume in this region is mainly applied for domestic uses and small-scale productions. Furthermore, the use of power heat and power generation increases the demand for more biomass energy in the region. The policy direction and planning on energy consumption should be focus on the use of alternative source of energy that has little environmental problems. We select ASEAN member countries because energy from biomass source which includes woods and agricultural residues represents about 40% of the overall energy consumption in the region, i.e. more than 2.5 million Terajoules annually.

There is no single article that in the current literature that study the impact of biomass energy consumption on the overall economic performances, even though the ASEAN region consumes high level of biomass energy. Our study therefore filled the gap in the literature by documenting this essential relationship based on heterogeneous panel estimation techniques. The remaining part of this article is organized as follows; "Review of related literature" section deals with the review of related literature, "Brief history of ASEAN member countries" section give a brief summary of ASEAN member countries, "Data, sources and measurements" section highlights data source, measurements of the variables and its corresponding sources. "Model and econometric methodology" section deals with econometric methodology, and "Dynamic ordinary least squares (DOLS) estimator" section discuss the empirical findings. Lastly "Conclusion and policy recommendations" section seven conclude and propose the policy recommendations based on the research outcomes.

Review of related literature

There are numerous studies that empirically examined the link between consumption of energy and overall economic growth in the literature. Considering different economic environment, variations in the institutional and environmental policies as well as application of different econometric techniques, different results were obtained. For example, Apergis and Danuletiu (2014) based on Canning and Pedroni long-run estimation technique investigated the impact of renewable energy consumption on economic growth of 80 countries. The finding suggests the presence of a positive long-run causal nexus that run from renewable energy to economic growth on both regional and overall sample.

In their study Ozturk and Bilgili (2015) examined the cointegrating association between biomass energy consumption and economic growth based on dynamic panel data approach during 1980–2009 across 51 Sub-Sahara African countries. The key result shows that consumption of biomass energy, population and trade openness significantly influences economic growth in the countries investigated. Bildirici and Özaksoy (2013) examined the causal relationship between biomass energy uses and economic growth for a sample of 10 European nations based on the two approaches i.e. autoregressive distributed lag (ARDL) and vector error correction method (VECM). The causality result shows the existence of one way causal link running from economic growth to the consumption of biomass energy for Australia and Turkey, and opposite one way causal relationship that run from biomass energy uses to economic growth exist for Hungary and Poland. However, two ways causal relationship exist between the variables in the case of France, Sweden and Spain. Moreover, Payne (2011) also found similar result with what is obtained in the case of Hungary and Poland on Bildirici and Özaksoy (2013) study for the U.S based on multivariate framework.

The nexus between biomass energy consumption and economic growth was also analysed by Bildirici (2013) across developing and emerging countries based on ARDL estimation technique. The finding reported that, one way causality that run from economic growth to biomass energy consumption exist in Colombia, moreover one way causality that run from uses of biomass energy to economic growth exist in Bolivia, Brazil and Chile. However, bidirectional causality exists in the case of Guatemala. However, in the long-run, bi-directional causal relationship is presence for all the studied countries. Apergis and Payne (2010a, b) applied Granger-causality approach and examined the causal relationship between renewable energy consumption and economic growth across 20 OECD member countries. The finding claimed that; there exists bidirectional causality among the variables in the short run as well as in the long-run.

Apergis and Payne (2010a, b) empirically examined the causal relationship between renewable energy consumption and economic growth across 13 Eurasian countries during 1992–2007. They applied multivariate panel data approach for the analysis. The heterogeneous panel cointegration test shows that; there is a long-run relationship among real GDP, labour force, real gross fixed capital formation and renewable energy consumption. The results based on error correction models signify bidirectional causality between renewable energy consumption and economic growth in both the short-run and long-run. Therefore, the empirical finding tends to support a feedback hypothesis of the co-dependent relationship between renewable energy consumption and economic growth.

Apergis and Payne (2011) analysed the effect of renewable energy uses on economic performance for a sample of six (6) Central American countries for the period of 1980–2006. The finding based on causality shows bidirectional causal relationship between the variables in short run as well as the long-run. Also, Apergis and Payne (2012) also examined the impact of renewable and non-renewable energy consumption on economic growth across 80 countries during 1990–2007. They applied a multivariate panel framework for the analysis. The Pedroni panel cointegration test shows the presence of long-run relationships among the variables. The result further reveal that, bidirectional causality exist between renewable and non-renewable energy consumption and economic growth in the short and long-run.

The impact of renewable and non-renewable energy consumption on economic growth was studied by Uçan et al. (2014) for the period of 1990–2011 across 15 E.U member countries. The result shows the presence of long-run association among the variables based on panel cointegration approach. However, Granger-causality result proved that unidirectional causal relationships that run from non-renewable energy consumption to economic growth exist. Abid and Sebri (2011) applied VECM technique and studied the effect of energy consumption on economic growth in Tunisia during 1980–2007. The result discloses that, generally energy consumption enhances economic growth in Tunisia, while on sectoral basis it negatively affects growth. Islam et al. (2013) examined the impact of financial sector development, economic growth and population on energy consumption in Malaysia. The finding suggests that, consumption of energy enhances financial sector development and economic growth in the short run as well as long run. While, its effect on the growth of the population is only present during short run period.

In their study Al-Mulali and Sab (2012a) examined the effect of energy uses and carbon dioxide emissions on economic growth and financial sector boost across 30 sub-Sahara African countries during 1980–2008. The result shows that energy consumption positively improves GDP and financial sector development which shows its environmental repercussion of increasing carbon dioxide emissions thereby polluting the environment. Al-Mulali and Sab (2012b) also investigated the impact of energy uses on economic growth across 19 countries during 1980–2008. The result reported that energy consumption promote financial sector development as well as the overall economic performance but attached with a negative environmental implications. Based on their study on the energy consumption-growth nexus by incorporating the variables of trade and financial sector development during the period of 1971–2011 in China, Shahbaz et al. (2013a) applied ARDL estimation technique and found that; energy consumption, financial development and trade openness positively influences economic growth in China.

Shahbaz et al. (2013b) examined the effect of energy consumption, financial development, trade openness and carbon dioxide emission on economic growth in Indonesia. This study used ARDL framework for the period of 1975Q1–2011Q2. The outcome reveals that when the amount of energy consumed and GDP increases, the level of CO_2 emissions also increase, whereas financial sector development reduces CO_2 emission. However, the VECM causality shows the presence of bidirectional causality between CO_2 emissions and the overall growth of the economy. However, unidirectional causality running from financial development to CO_2 emissions exists. In their study on the dynamic impact of financial sector development on energy consumption in Nigeria and incorporate growth variable as one of the control variable, Ali et al. (2015) applied ARDL estimation method for the period of 1972Q1–2011Q4. The result reveals that, economic growth adversely affects energy consumption in Nigeria which might be related to the level of income distribution in the country as claimed by the authors. Bilgili and Ozturk (2015) examine the influence of biomass energy consumption on economic growth during 1980–2009. They applied panel unit root analyses, panel cointegration analyses, conventional OLS and dynamic OLS. Their finding reveals that, there is a positive and significant relationship among capital stock, human capital biomass energy consumption and economic growth. Thus, consumption of biomass energy remains an important determinant of the economic growth in G7 countries. Ali et al. (2016) empirically examine the impact of biomass energy consumption on economic growth of 25 sub-Sahara African countries during 1980–2011. They applied dynamic heterogeneous panels of a mean group (MG) and pooled mean group (PMG) methods. The result based on PMG reveals that; biomass energy consumption has a positive and significant impact on economic growth of the sample countries. Furthermore, same result was also obtained when an alternative techniques of FMOLS and panel OLS are used.

Brief history of ASEAN member countries

Association of Southeast Asian nations (ASEAN) is a regional economic union formed on 8th August 1967 in Bangkok, Thailand with the signing of Bangkok declaration by five founding members such as; Indonesia, Malaysia, Philippines, Singapore and Thailand. Brunei Darussalam joined on 7th January, 1984, Viet Nam became a member on 28th of July 1995, Lao PDR and Myanmar also joined on 23 July 1997 and Cambodia joined on 30 April 1999. Part of the ASEAN's aims is to enhance economic growth, support regional peace and stability, encourage active partnership and related assistance on matters of common interest in the economic, social, technical, cultural, administrative and scientific areas. Other areas of benefiting from being an ASEAN member is to assist each one another in the areas of training and research services of the professional, technical and academic arena. They also shared a common interest of greater agricultural and industrial utilization, expand trade and sustain close and useful cooperation in line with international and regional union with common purposes and aims.

To fully understand ASEAN, it is essential to give a highlight about each member country used in this study. Therefore, an excerpt of the countries is underline as follows; Brunei-Darussalam is richly endowed with the extensive petroleum and natural gas fields. It is the second to Singapore in terms of human development index (0.865) and it is classified as a "developed country". It has a population of 0.429 million, with a GDP of $11,963 and GDP per-capita of $27,893. Cambodia has a population of 16.03 million people, with a nominal GDP of $22,252 and a per-capita GDP of $1389. The country is among the least developed nations among ASEAN member countries because its human development index is as low as 0.563. Indonesia is the most densely populated country in the ASEAN region, with a total population of 261.989 million people. The country is also considered as the fourth largest populated country in the world. Indonesia is blessed with the adequate natural resources among which includes; oil and natural gas, gold, copper and tin. The country's GDP stood at $1,010,937, and per-capita GDP of $3858. The country's human development index remains at 0.689. Lao PDR is a Southeast Asian country with a total number of 6.680 million people. It has a GDP of $17,152 and GDP per-capita of $2567. Considering its Lan Xang's fundamental geographical location in the Southeast Asia, the country become renowned business hub which translates to its economic buoyancy. The human development index of the country is 0.586.

Malaysia is among the Asian tigers, it's a country with a population of 32.077 million people. It's a third best ASEAN member country apart from Singapore and Brunei-Darussalam in terms of human development, the index stood at 0.789. Malaysia's GDP is $309,858, and per-capita GDP remains at $9659. Philippines a country with total population of 106.268 million inhabitants, hence consider as the second largest densely populated ASEAN country apart from Indonesia. The current GDP of the country is $321,189, and the GDP per-capita stood at $3022. The human development indicator of the country is 0.682. Singapore is known as the global commerce centre, financial and global transport hub. It is also recognize as the most technology driven nation and top international meeting city with the superior investment prospective. Singapore is the second most competitive country in the global economy and third largest foreign exchange market. Moreover, the country is the third largest financial and oil refining and trade centre as well as the second busiest container port. Its current GDP is $305,757, and GDP per-capita stood at $53,880. The country's human development index is 0.925. Thailand is a country with a total population of 69.095 million people, and its current GDP is $437,807. The GDP per-capita stood at $6336 and the country's human development index is 0.740. Thai's economy is consider the world's largest 20th by GDP and became a newly industrialized country as well as major exporter in the 1990s. The country's major economic strength is manufacturing, agriculture, and tourism. Vietnam is also among the highly populated country among the ASEAN members, with a population of 93.643 million people. The current GDP of the country is $215, 963, and GDP per-capita stood at $2306. The rate of Vietnam's economic growth is recognize among the highest in the world since 2000. Vietnam also has the highest global growth generators index among 11 major economies. The country's human development index is 0.683 (Table 1). (Brief About ASEAN, 2015)

Data, sources and measurements

The data used for the study was sourced from two different data bases. Biomass energy consumption as proxied by used extraction of biomass is sourced from global material flow data base 2012 version. While, economic growth as proxied by the expenditure-side of the real GDP at chained PPPs (in mil. 2005US$). Capital stock as proxied by stock of capital at current PPPs (in mil. 2005US$) and human capital as proxied by human capital index per individual according to years of schooling and returns to education were all obtained from Penn World Table 8.1, 2013 version. The sample of the nine (9) ASEAN member countries used for the analysis of this paper includes; Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Philippines, Singapore, Thailand and Vietnam. However, Myanmar was excluded from the sample because there is no available data for the country.

Model and econometric methodology

To study the impact of biomass energy consumption on economic growth, the present study specified the following log-linear growth model:

$$lny_{it} = \alpha_i + \beta_1 lnbio_{it} + \beta_2 lncs_{it} + \beta_3 lnhc_{it} + \varepsilon_{it} \quad (1)$$

where *lny* reflect the log of economic growth, *lnbio* means the log of biomass energy consumption, *lncs* refers to the log of capital stock and *lnhc* is the log of human capital, ε is the unobservable error term, i denote country and t denote time period. In order to analyse the long-run equilibrium relationship among the variables, Pedroni (1999, 2004) cointegration relationship is estimated. The key objective of panel cointegration approach is to group information on common long-run nexus and concurrently allows for dynamics in the short-run and fixed effects to be varied through different panel members. The heterogeneity

Table 1 Summary of some key ASEAN economic indicators

Country	GDP	GDP per-capita	Population	HDI
Brunei-Darussalam	$11,963	$27,893	0.429	0.865
Cambodia	$22,252	$1,389	16.013	0.563
Indonesia	$1,010,937	$3,858	261.989	0.689
Lao PDR	$17,152	$2,567	6.680	0.586
Malaysia	$309,858	$9,659	32.077	0.789
Myanmar	$66,966	$1,272	52.645	0.556
Philippines	$321,189	$3,022	106.268	0.682
Singapore	$305,757	$53,880	5.675	0.925
Thailand	$437,807	$6,336	69.095	0.740
Vietnam	$215,963	$2,306	93.643	0.683

HDI Human Development Index, closer to 1signify higher HDI. GDP, GDP per-capita and population are in millions

establishes an advantage because it is unlikely to presume that, cointegrating vectors of the individual panel members is the same. Pedroni (1999, 2004) suggest various test statistics constructed on the Engle and Granger (1987) cointegrating regression in a panel data that give room for substantial heterogeneity. Therefore, the test statistics are built based on the residuals from the subsequent hypothesized cointegrating regression based on Eq. (1). It tests for the null hypothesis of no cointegration created on the residuals $\hat{\varepsilon}_{it}$ using:

$$\hat{\varepsilon}_{it} = \rho_i \, \hat{\varepsilon}_{it-1} + v_{it} \tag{2}$$

Since α_i and the numerous β_i of Eq. (1) are permitted to differ across the panel members. This technique allows for both short-run and long-run heterogeneity. The dynamic and fixed effect can vary through the individuals in the panel data; the vector of cointegration can also vary across panel members based on alternative hypothesis. Pedroni (1999, 2004) used cointegrating residuals $\hat{\varepsilon}_{it}$ and advances seven panel cointegration statistics. Four out of seven statistics which are known as the panel cointegration statistics are within-dimension based statistics built by summing both the numerator and denominator terms over the N dimension individually. The remaining three statistics known as group mean panel cointegration are between-dimension based statistics and are built by dividing the numerator and denominator before summing over the N dimension. With regard to power between the two, Pedroni argues that group-ADF statistics does the best followed by the panel-ADF statistics, whereas the panel variance and group statistics poorly perform.

Dynamic ordinary least squares (DOLS) estimator

In order to get unbiased estimator of the cointegrating parameters of Eq. (1), the present study applied dynamic ordinary least squares (DOLS) suggested by Kao and Chiang (2000). It is the advancement of Stock and Watson's (1993) estimator which incorporates regression with the leads and lags and concurrent values of the regressors in the first differences. Let's for example have a panel model with fixed effect:

$$y_{it} = \alpha_i + x'_{it}\beta + \mu_{it}, \quad i = 1, \ldots\ldots N; \quad t = 1, \ldots\ldots, T \tag{3}$$

where y_{it} refers to matrix (1, 1), β is the vector of slopes (k, 1) dimension, α_i refers to individual effect and μ_{it} is the error term. The presumption is that x_{it} (k, 1) vector is the first difference of autoregressive process.

$$x_{it} = x_{it-1} + \varepsilon_{it} \tag{4}$$

The estimator of DOLS is derived from the following equations:

$$y_{it} = \alpha_i + x'_{it}\beta + \sum_{j=q1}^{j=q2} c_{ij}\Delta x_{it+j} + v_{it} \tag{5}$$

c_{ij} is the coefficients of a lead and lags of first difference independent variables.

Fully modified ordinary least squares (FMOLS) estimator

The group-mean FMOLS estimator proposed by Pedroni (2000) is also applied to get a panel data estimates based on Eq. (1). This estimator includes semi-parametric of Phillips and Hansen (1990) into the OLS estimator to remove expected endogeneity bias of regressors. Pedroni (2000) specially indicated that the group mean of panel t-statistic for β is as follows:

$$t_{\bar{\hat{\beta}}NT} = \mathrm{N}^{-1} \sum_{i=1}^{N} \hat{L}_{11i} \left(\sum_{t=1}^{T} (x_{it} - x_i)^2 \right)^{-1/2} \left(\sum_{t=1}^{T} (x_{it} - \bar{x_i}) y_{it} - T \hat{\tau}_i^{*} \right) \rightarrow N(0,1) \quad (6)$$

where

$$y_{it}^{*} = (y_{it} - \bar{y_{it}}) - \frac{\Omega_{21_i}}{\Omega_{22_i}} \Delta x_{it}$$

$$\tau_i \equiv \Gamma_{21_i} + \Omega^0{}_{21_i} - \frac{\Omega_{21_i}}{\Omega_{22_i}} \left(\Gamma_{22_1} + \hat{\Omega}^0{}_{22_i} \right) \quad (7)$$

where $\hat{\Omega} i$ and $\bar{\Gamma}$ refers to the covariances and total of autocovariances got from the long-run Eq. (1) covariance matrix, and related t-statistics that is in line with standard normal distribution. Also, between-group panel fully modified OLS (FMOLS) tests which have more advantages than within-group panel (Pedroni 2000) is applied in this study.

Estimation results

Several unit root tests related to panel data ranging from Breitung (2000), Levin et al. (2002), Im et al. (2003) and Maddala and Wu (1999) was employed so as to test the order of integration of the variables. This is because of theoretical provision of conducting unit root test before testing the cointegrating relationship among the variables. The test as reported in Table 2 includes intercept, intercept and linear trend which shows that the four (4) variables are non-stationary at level but become stationary after taking the first difference. This means there exist unit root at levels, but no any unit root present after taking the first difference.

Pedroni (1999, 2004) cointegration test is reported in Table 3 based on Eq. (1). The empirical result shows that; null hypothesis of no cointegration can be rejected in three out of seven statistics. Therefore based on this finding, element of long-run relationship is established among biomass energy consumption, capital stock, human capital and economic growth. The second panel cointegration test of Kao (1999) cointegration test based on ADF shows that; null hypothesis of no cointegration is also rejected which means variables have long-run relationship.

Having established the long-run equilibrium relationships among the variables, DOLS and FMOLS are employed to determine the long-run equilibrium relationship among the variables. The empirical results of these models are reported in Table 4. The finding based on DOLS shows that; biomass energy consumption, capital stock and human capital are all statistically significant on economic growth. Therefore, null hypothesis of no cointegration was rejected at 1 and 5% for biomass energy consumption, capital stock and human capital respectively. Moving to FMOLS biomass energy consumption and capital stock are statistically significant at 1% which means they also positively influence economic growth, whereas human capital is statistically insignificant on economic growth. Panel OLS also shows that biomass energy consumption, capital stock and human capital are statistically significant as null hypothesis of no cointegration was rejected at 5% for biomass energy consumption and 1% for capital stock and human capital respectively. Hence, our finding confirmed that of Apergis and Payne (2010a, b) for Eurasian countries, Apergis and Payne (2012) for OECD countries, Ozturk and Bilgili (2015) for 51 Sub-Sahara African countries, Bilgili and Ozturk (2015) for G7 countries, and Ali et al. (2016) for 25 Sub-Sahara African countries.

Conclusion and policy recommendations

The present article studies the dynamic impact of biomass energy consumption on economic growth for the period of 1980–2011 across nine (9) ASEAN member countries. The empirical results shows that; variables were cointegrated based on Pedroni and Kao residual cointegration tests as null hypothesis of no cointegration was rejected at 1% level of significance. Dynamic ordinary least square (DOLS) result shows that; biomass energy consumption, capital stock and human capital have significant positive impact on economic growth. FMOLS also reported same result

Table 2 Panel unit root estimation results dependent variable: ln of real GDP (9 countries, 1980–2011)

	Yit	BIOit	CSit	HCit
Level				
No trend				
LLC	1.25 (0.89)	0.67 (0.75)	2.19 (0.98)	− 4.13 (0.99)
IPS	4.72 (1.00)	4.11 (1.00)	6.15 (1.00)	0.15 (0.56)
ADF	2.46 (1.00)	4.04 (0.99)	2.79 (1.00)	23.6 (0.17)
Breitung	–	–	–	–
With trend				
LLC	− 0.32 (0.37)	− 0.02 (0.49)	− 3.01 (0.00)	− 0.27 (0.39)
IPS	0.14 (0.55)	− 0.83 (0.20)	− 0.64 (0.26)	2.69 (0.99)
ADF	13.9 (0.73)	30.5 (0.03)	18.5 (0.41)	13.2 (0.77)
Breitung	− 1.00 (0.16)	0.24 (0.59)	0.66 (0.75)	8.34 (1.00)
First difference				
No trend				
LLC	− 10.0 (0.00)***	− 14.5(0.00)***	− 2.40 (0.00)***	2.74 (0.00)***
IPS	− 9.34 (0.00)***	− 14.9(0.00)***	− 2.53 (0.00)***	1.15 (0.00)***
ADF	114 (0.00)***	187(0.00)***	33.5 (0.01)**	11.2 (0.00)***
Breitung	–	–		–
With trend				
LLC	− 9.37 (0.00)***	− 13.2 (0.00)***	− 1.45 (0.07)*	5.05 (0.00)***
IPS	− 8.01 (0.00)***	− 13.9 (0.00)***	− 1.60 (0.05)*	1.05 (0.05)*
ADF	9.38 (0.00)***	166 (0.00)***	26.9 (0.08)*	14.4 (0.00)***
Breitung	− 6.75 (0.00)***	− 7.2 (0.00)***	− 2.77 (0.00)***	7.85 (0.00)***

Y economic growth, *BIO* biomass energy consumption, *CS* capital stock, *HC* human capital, *LLC* Levin et al. (2002), *IPS* Im, Pesaran and Shin (2003) panel unit root test, *ADF* Augmented Dickey Fuller, Maddala and Wu (1999), Breitung (2000)

The values in parentheses are respective *p* values, ***, ** and * are used as a benchmark for null hypothesis rejection of non-stationary at 1, 5 and 10% respectively

Table 3 Panel cointegration estimation results

Pedroni cointegration test	
Panel v-statistic	0.41 (0.33)
Panel rho-statistic	0.37 (0.64)
Panel PP-statistic	− 1.78 (0.03)**
Panel ADF-statistic	− 2.64 (0.00)***
Group rho-statistic	1.94 (0.97)
Group PP-statistic	− 0.04 (0.48)
Group ADF-statistic	− 2.59 (0.00)***
Kao cointegration test	
ADF	− 3.49 (0.00)***

Number of countries (N) = 9 and sample period (T) = 31. ***, ** and * indicated the significance level of null hypothesis rejection at 1, 5 and 10% respectively

with the exception of human capital which has insignificant relationship with the economic growth. Moreover, panel ordinary least square result reconfirmed the outcome obtained for DOLS. The energy policy direction in these countries should focus on encouraging the use of renewable energy sources that promote economic growth and have a little negative environmental consequence. Biomass energy consumption is considered among the best alternative source of energy and therefore should be placed as top priority by the policy makers in the ASEAN economic union member countries.

Due to the problems of fossil fuel consumptions that lead to much destruction of physical environments and creates numerous damages to immediate environments through carbon dioxide emissions, renewable sources of energy should be one of the better options in these countries that have less cost with minimum environmental problems. It is imperative for the ASEAN union to apply policies that might reduce the level of the carbon dioxide emissions in the region, so as to mitigate the dangers exacerbated by many emissions that deteriorate environmental quality. Furthermore, encouraging the adoption of renewable sources of energy could be a key policy direction of the union (ASEAN) which would offset the damages created by the non-renewable forms of energy.

Table 4 Panel OLS, DOLS and FMOLS estimation results, Dependent variable log of real GDP (9 countries, 1980–2011)

	Model 1a: panel OLS	Model 1b: DOLS (lag = 1, lead = 1)	Model 1c: FMOLS
Biomass energy consumption	0.02 (2.07)**	0.44 (2.89)***	0.45 (7.21)***
Capital stock	0.95 (56.7)***	0.98 (6.64)***	0.53 (5.78)***
Human capital	− 0.49 (− 3.14)***	− 2.21 (− 1.76)*	0.62 (0.92)

Panel OLS panel ordinary least square, *DOLS* dynamic ordinary least square, *FMOLS* fully modified ordinary least square

Values in parentheses are t-statistics and ***, ** and * are significance values at 1, 5 and 10% respectively

Acknowledgements All the papers cited in this manuscript are fully acknowledged.

Compliance with ethical standards

Conflict of interest There is no any conflict of interest in this paper.

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