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A Panel VAR Approach of the Relationship among Economic Growth, CO_2 Emissions, and Energy Use in the ASEAN-6 Countries

Cosimo Magazzino
Department of Political Sciences, Roma Tre University,
Via G. Chiabrera 199, 00145, Rome (RM), Italy.
Tel.: +390657335347. Email: cosimo.magazzino@uniroma3.it

ABSTRACT: The paper analyses the relationship among economic growth, carbon dioxide emissions, and energy use for six ASEAN countries over the 1971-2007 years. Using a panel VAR technique, a 3-variable VAR is estimated. Empirical findings show that the response of economic growth to energy use is positive and statistically significant. The forecast errors in real per capita GDP are mainly due to uncertainty in GDP itself and energy use emissions. The error variances in the carbon dioxide emissions are sensible to disturbances both in the GDP and in CO_2 equations. While the errors in predicting the energy use are sensitive to disturbances in its own equation: after ten steps. Thus, for the estimated sample, these results reinforced the VAR and IRFs analyses, suggesting that for this panel the "growth hypothesis" holds.

Keywords: economic growth; CO_2 emissions; energy use; ASEAN; panel data
JEL Classifications: B22; C33; N55; Q48

1. Introduction

ASEAN is a regional bloc that was established on 8 August 1967 in Bangkok by the five original member countries, namely, Indonesia, Malaysia, Philippines, Singapore, and Thailand, while Brunei Darussalam joined on 8 January 1984. The region's economic growth had a consequential increase in primary energy consumption, which was registered at 3.6% per annum from 1995 to 2007. With the assumed GDP growth rate of 5.2% per annum from 2007 to 2030, final energy consumption in ASEAN will grow at an average annual rate of 4.4% from 375 MTOE to 1,018 MTOE in the Business-as-Usual (BAU) scenario during the same period. ASEAN will continue to be heavily dependent on fossil fuels especially oil in the future. The region as a whole has become a net importer of oil and net imports will further increase in the future in view of stagnating or declining oil production and rapidly increasing demand. The rapid growth of electricity demand will also be a driving force in increasing use of fossil fuels especially coal. To lessen the environmental impact of coal use, ASEAN would need to utilize the latest most efficient and cleaner coal technologies[1].

The relationship between economic growth and energy use, as well as economic growth and environmental pollution, has been the subject of several research projects in the last years. Nevertheless, the empirical results remain mixed and debatable. In addition, many studies concern the relation among energy consumption, CO_2 emissions and economic growth, but very few analyses have been devoted to the ASEAN countries within a panel framework. The Climate Change Performance Index (CCPI) 2013 evaluates and compares the climate protection performance of 58 countries, that are, together, responsible for more than 90 percent of global energy-related CO_2 emissions. In the 2013 CCPI, Thailand, Indonesia, Singapore, and Malaysia ranked, respectively, the 32nd, 36th, 53rd, and 55th place in the rank. According to the classification of the report, Thailand and Indonesia received a "poor" rating, while Singapore and Malaysia a "very poor" one (Germanwatch, 2013).

In this study, the relationship among real GDP, CO_2 emissions, and energy use in six ASEAN countries has been explored for the 1971-2007 years, using a panel Vector AutoRegression (VAR) methodology. The results can help to define and implement the appropriate energy and environmental policies in these countries.

[1] http://energycommunity.org/documents/ThirdASEANEnergyOutlook.pdf.

Besides the Introduction, the rest of the paper is organized as follows. Section 2 gives a brief survey of the literature. Section 3 contains an overview of the econometric methodology and a brief discussion of the data used. Section 4 discusses the applied findings. Section 5 presents some concluding remarks and, finally, Section 6 gives suggestions for future researches.

2. Literature Review

The relationship between carbon dioxide emissions, energy consumption, and real output is a synthesis of the Environmental Kuznets Curve (EKC) and the energy consumption growth literatures (Kuznets, 1955). The literature on the economic growth-energy consumption has been summarized in Magazzino (2014b) and Ozturk (2010), while Magazzino (2014a) and Payne (2010) report an overview of the electricity demand-GDP nexus. Bo (2011) contains a survey on the EKC literature.

The directions that the causal relationship between energy consumption (electricity consumption) and economic growth could be categorized into four types each of which has important implications for energy policy:

1. "Neutrality hypothesis": no causality between energy and GDP; it is supported by the absence of a causal relationship between energy consumption and real GDP;
2. "Conservation hypothesis": unidirectional causality running from GDP to energy; it is supported if an increase in real GDP causes an increase in energy;
3. "Growth hypothesis": unidirectional causality running form energy to economic growth; increases in energy may contribute to growth process;
4. "Feedback hypothesis": bidirectional causality between energy consumption and economic growth; It implies that energy consumption and economic growth are jointly determined and affected at the same time.

Screening the applied literature on the economic growth-energy nexus (Table 1), we can note that for Indonesia the "neutrality hypothesis" emerges in Soytas and Sari (2003) and Chen *et al.* (2007); the "conservation hypothesis" in Masih and Masih (1996), Murry and Nan (1996), Yoo (2006), and Yildirim *et al.* (2014); the "growth hypothesis" in Asafu-Adjaye (2000), Fatai *et al.* (2004).

In the case of Malaysia the "neutrality hypothesis" holds in Masih and Masih (1996); the "conservation hypothesis" in Chen *et al.* (2007), and Yildirim *et al.* (2014); and, the "feedback hypothesis" in Murry and Nan (1996), and Yoo (2006).

The applied literature for Thailand shows that the "neutrality hypothesis" is confirmed in Chen *et al.* (2007); the "conservation hypothesis" in Yoo (2006); the "growth hypothesis" in Masih and Masih (1998); and, finally, the "feedback hypothesis" in Yu and Choi (1985), Asafu-Adjaye (2000), Fatai *et al.* (2004), and Yildirim *et al.* (2014).

For Singapore the empirical evidences is in favor of the "neutrality hypothesis" in Masih and Masih (1996), and Yildirim *et al.* (2014); of the "conservation hypothesis" in Chen *et al.* (2007); of the "growth hypothesis" in Murry and Nan (1996); of the "feedback hypothesis" in Glasure and Lee (1998), and Yoo (2006).

For the Philippines, the "neutrality hypothesis" is discovered in Masih and Masih (1996), and Murry and Nan (1996); the "conservation hypothesis" in Chen *et al.* (2007), and Yildirim *et al.* (2014); the "growth hypothesis" in Yu and Choi (1985); and the "feedback hypothesis" in Asafu-Adjaye (2000), and Fatai *et al.* (2004).

While, for Brunei, at our knowledge, the present paper represents the first applied analysis on this issue. As regards the panel data studies, Lee and Chang (2008), and Lee and Smyth (2009) found evince in line with "growth hypothesis", while Mahadevan and Asafu-Adiaye (2007) with "feedback hypothesis".

Moreover, Binh (2011) showed the existence of a unidirectional causality running from per capita GDP to per capita energy consumption for Vietnam during the 1976-2010 period. Kum (2012) examined the unit root properties of per capita energy consumption for 15 East Asia and Pacific countries for 1971-2007 years. Lau *et al.* (2011) studied the relationship between energy consumption and the gross domestic product in seventeen Asian countries. The panel cointegration results reveal a long-run equilibrium relationship between the two variables. The results of the FMOLS show that the energy consumption variable has a positive sign. Shaari *et al.* (2013) examined the effects of oil price shocks on economic sectors in Malaysia. The results implied that oil price shocks could affect agriculture.

3. Methodology and Data

Our empirical strategy uses a panel-data Vector AutoRegression methodology. This technique combines the traditional VAR approach, which treats all the variables in the system as endogenous, with the panel data approach, which allows for unobserved individual heterogeneity. Here, we follow a similar strategy of Magazzino (2014d).

The impulse-response functions describe the reaction of one variable to the innovations in another variable in the system, while holding all other shocks equal to zero. The identifying assumption is that the variables that come earlier in the ordering affect the following variables contemporaneously, as well as with a lag, while the variables that come later affect the previous variables only with a lag. In other words, the variables that appear earlier in the systems are more exogenous and the ones that appear later are more endogenous.

Table 1. Summary of existing literature on Middle East countries

Author(s)	Countries	Study period	Causality relationship
Yu and Choi (1985)	Thailand, the Philippines	1954-1976	E→Y: the Philippines Y↔E: Thailand
Masih and Masih (1996)	Indonesia, Malaysia, Singapore, the Philippines	1955-1990	Neutrality: Malaysia, Singapore, the Philippines Y→E: Indonesia
Murry and Nan (1996)	Indonesia, Malaysia, Singapore, the Philippines	1970-1990	Neutrality: the Philippines Y→E: Indonesia E→Y: Singapore Y↔E: Malaysia
Glasure and Lee (1998)	Singapore	1961-1990	Y↔E: Singapore
Masih and Masih (1998)	Thailand	1955-1991	E→Y: Thailand
Asafu-Adjaye (2000)	Indonesia, Thailand, the Philippines	1971-1995	E→Y: Indonesia Y↔E: Thailand, the Philippines
Soytas and Sari (2003)	Indonesia	1950-1992	Neutrality: Indonesia
Fatai *et al.* (2004)	Indonesia, Thailand, the Philippines	1960-1999	E→Y: Indonesia Y↔E: Thailand, the Philippines
Yoo (2006)	Indonesia, Malaysia, Singapore, Thailand	1971-2002	Y→E: Indonesia, Thailand Y↔E: Malaysia, Singapore
Chen *et al.* (2007)	Indonesia, Malaysia, Singapore, Thailand, the Philippines	1971-2001	Neutrality: Indonesia, Thailand Y→E: Malaysia, Singapore, the Philippines
Mahadevan and Asafu-Adiaye (2007)	Indonesia, Malaysia, Thailand	1971-2002	Y↔E: Panel
Lee and Chang (2008)	Indonesia, Malaysia, Singapore, Thailand, the Philippines	1971-2002	E→Y: Panel
Lean and Smyth (2009)	Indonesia, Malaysia, Singapore, Thailand, the Philippines,	1980-2006	E→Y: Panel
Yildirim *et al.* (2014)	Indonesia, Malaysia, Singapore, Thailand, the Philippines	1971-2009	Neutrality: Singapore Y→E: Indonesia, Malaysia, the Philippines Y↔E: Thailand

Notes: E→Y denotes causality running from energy consumption to income. Y→E denotes causality running from income to energy consumption. Y↔E denotes bi-directional causality between income and energy consumption.

In our specification, we assume that current shocks to the per capita GDP have an effect on the contemporaneous value of per capita energy use, while the latter has an effect on the aggregate income only with a lag. Moreover, we assume that energy use responds to CO_2 emissions contemporaneously, while the latter responds to GDP only with a lag.

Our main objective is to compare the aggregate income to energy factors in countries on a different level of socio-economic integration, which might aim to build a monetary union.

To avoid the problem of correlation between fixed effects and regressors, we use forward mean-differencing, also referred to as the Helmert procedure (Holtz Eakin *et al.*, 1988; Arellano and Bover, 1995), which removes only the forward mean. The coefficients are estimated by System Generalized Method of Moments (GMM-Sys) (Blundell and Bond, 1997).

Our model also allows for country-specific time dummies, d_{ct}, which are added to model *(1)* in order to capture aggregate, country-specific macro shocks that may affect all firms in the same way. These dummies have been dropped by subtracting the means of each variable calculated for each country-year. In addition, calculate standard errors of the impulse-response functions (IRFs) and confidence intervals (CIs) have been calculated through Monte Carlo (MC) simulations (Love and Zicchino, 2006).

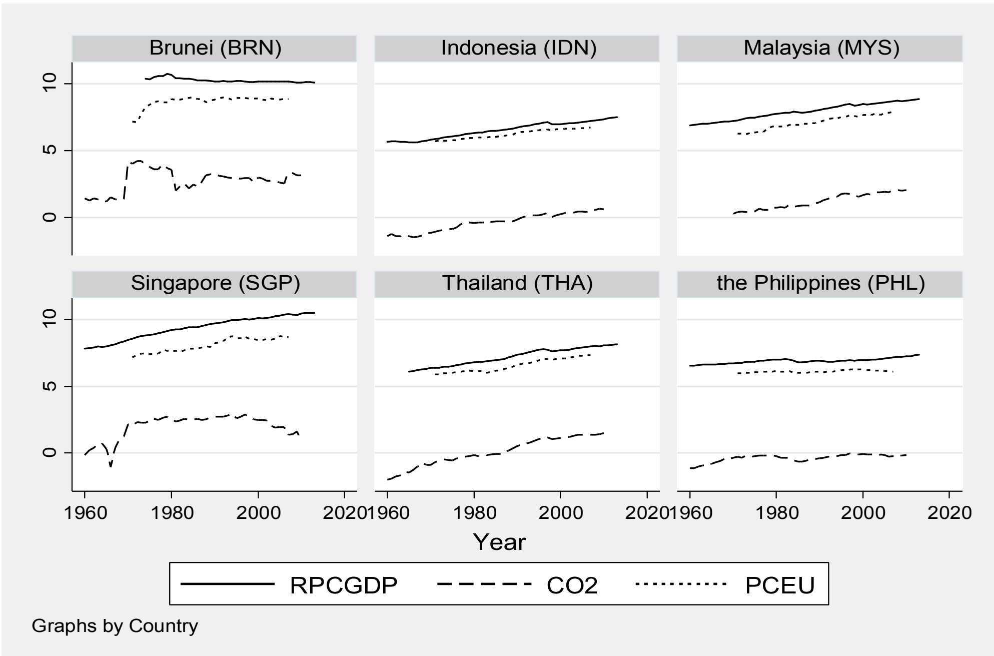
Finally, we also present variance decompositions, which show the percent of the variation in one variable that is explained by the shock to another variable, accumulated over time. The variance decompositions show the magnitude of the total effect. We report the total effect accumulated over the 10, 20, and 30 years, as longer time horizons produced equivalent results.

RPCGDP is per capita GDP expressed in constant 1990 US$, CO_2 represents CO_2 emissions in metric tons per capita, and PCEU concerns per capita energy use in terms of kg oil equivalent. The applied analysis uses annual data from 1971 to 2006 for six ASEAN countries (Brunei, BRN; Indonesia, IDN; Malaysia, MYS; Singapore, SGP; Thailand, THA; the Philippines, PHL). The data are derived from the World Development Indicator[2]. The data starting period was dictated by CO_2 emissions availability. Moreover, we avoid the more recent years, since the current economic-financial crisis has affected substantially the estimated relationships. We use here the log-transformation of variables. Table 1 summarizes all the variables used in the paper. Figure 1 shows the evolution of these variables for each country.

Table 1. Variable definitions

Abbreviation	**Description**	**Source**
RPCGDP	GDP per capita (constant 2000 US$)	WDI
CO_2	CO_2 emissions (metric tons per capita)	WDI
PCEU	Per capita energy use, kg of oil equivalent	WDI

Figure 1. Real per capita GDP, CO_2 emissions, and energy use for ASEAN-6 countries (1960-2007, log-scale)



Sources: WDI data.

[2] See, for more details: http://www.econstats.com/wdi/wdic_MNA.htm.

A visual inspection of the log-series shows an upward trend for all variables. Table 2 reports the summary statistics for the overall sample. However, we remind to Table A in the Appendix, which reports the descriptive statistics for the country-level variables. Mean value of all variables is positive. CO_2 variable has negative value of skewness, indicating that the distribution is left-skewed, with more observations on the right tail. In addition, it is interesting to note how our three variables show similar values for mean and median in each country, indicating that a normal distribution emerges.

Table 2. Exploratory data analyses

Variable	Mean	SD	Minimum	Maximum	IQR	10-Trim	Pseudo SD
RPCGDP	7.9471	1.4290	5.6196	10.7716	2.078	7.884	1.540
CO_2	0.8684	1.4414	-1.9969	4.2109	2.327	0.825	1.725
PCEU	7.1364	1.0494	5.7090	8.9861	1.771	7.067	1.313

Notes: SD: Standard Deviation; IQR: Inter-Quartile Range; PSD: Pseudo Standard Deviation.
Sources: our calculations on WDI data.

Given the fact that for each variable the 10-Trim values are near to the mean, as well as the Standard Deviation to the Pseudo Standard Deviation, the Inter-Quartile Range (IQR) shows the absence of outliers in the observed sample.

Table 3. Correlation matrix

Variable	RPCGDP	CO_2	PCEU
RPCGDP	1.0000		
CO_2	0.8254*** (0.0000)	1.0000 (0.0000)	
PCEU	0.9467*** (0.0000)	0.5884*** (0.0000)	1.0000 (0.0000)

Notes: Bonferroni's correction has been applied, P-Values in parentheses. ***p<0.01, **p<0.05, *p<0.1.

As shown in Table 3 above, the GDP and CO_2 series as well as *RPCGDP* and *PCEU* are strongly correlated, since the corresponding correlation coefficients (r) exceed 0.83, and these pairwise correlations are significant at 1% level. Moreover, the correlation between real CO_2 and energy use is not negligible (0.59).

4. Results

We estimate the coefficients of the system given in *(1)* after the fixed effects and the country-time dummy variables have been removed. In Table 4, we report the results of the model with three variables {RPCGDP, CO_2, PCEU}.

Table 4. Main results of a 3-variable VAR model

Response of	Response to					
	RPCGDP (*t*-1)	CO_2 (*t*-1)	PCEU (*t*-1)	RPCGDP (*t*-2)	CO_2 (*t*-2)	PCEU (*t*-2)
RPCGDP (*t*)	0.6550* (0.3819)	-1.7436 (1.4024)	0.1985 (1.1861)	0.1031 (0.2865)	-1.1281 (1.3220)	1.9340* (0.9752)
CO_2 (*t*)	0.1294* (0.0789)	0.5225** (0.2345)	0.2208 (0.2185)	0.1252** (0.0572)	0.0534 (0.2081)	0.1342 (0.1735)
PCEU (*t*)	0.0592 (0.1094)	1.8628 (3.2953)	0.8997*** (0.3280)	0.0576 (0.0490)	3.5031 (3.0623)	0.0943 (0.2021)
N obs.	201					
N countries	6					

Notes: Three variable VAR model is estimated by GMM, country-time and fixed effects are removed prior to estimation. Countries are split into two groups based on the median level of financial development. Reported numbers show the coefficients of regressing the row variables on lags of the column variables. Heteroskedasticity adjusted *t*-statistics are in parentheses. ***p<0.01, **p<0.05, *p<0.1.

We discuss general results of the 3-variable VAR model first, before proceeding to the ones of variance decompositions. For the six ASEAN countries, we observe that the response of CO_2 emissions to real per capita GDP is positive in the estimated coefficients and impulse responses. This is reasonable, in so much as an increase of aggregate income provokes negative environmental effects via carbon dioxide emissions, although this should represent a constraint for the future economic growth (some steps ahead). The coefficient of *PCEU* two periods lagged (*t-2*) is statistically significant in the real GDP equation, showing that a more intensive use of per capita energy leads to an increase in the economic activity. Instead, the energy is only positively affected by its own first lag. Thus, this variable simply seems to be driven by its own past values. Therefore, on the basis of our results, CO_2 emissions increase in response to a real GDP shock (since higher economic activity imply more pollution and negative externalities).

Table 5. Variance decompositions

Variable	RPCGDP	CO_2	PCEU
Panel A (10 periods ahead)			
RPCGDP	0.6393	0.2468	0.1139
CO_2	0.2069	0.7093	0.0838
PCEU	0.1687	0.0671	0.7642
Panel A (20 periods ahead)			
RPCGDP	0.4991	0.2168	0.2841
CO_2	0.2176	0.6381	0.1443
PCEU	0.1391	0.0748	0.7861
Panel A (30 periods ahead)			
RPCGDP	0.4556	0.2002	0.3442
CO_2	0.2082	0.6047	0.1871
PCEU	0.1250	0.0704	0.8046

Notes: Percent of variation in the row variable explained by column variable.

The variance decompositions for our panel, presented in Table 5 above, are in line with previous findings. In fact, the real GDP explain nearby 21% of variation of carbon dioxide emissions 10 periods ahead (in an increasing way); also, the energy use contributes to the CO_2 dynamic in an increasing way. However, the magnitude of the effect is rather small, as energy use only explains about 14% of total variation in emissions after 20 steps. The errors in predicting the carbon dioxide emissions are sensitive to disturbances both in the GDP and in CO_2 equations: after thirty periods, almost 40% of the error variance in CO_2 forecasts is split between contributions from shocks to the GDP (21%) and emissions (19%) equations. Moreover, as still explained, the variance decomposition of the energy use is mainly due to its own variation, since after 10 periods ahead only 1/4 of its variability is explained by two remaining variables.

To sum up, for the six ASEAN countries real GDP is driven by its own and energy use emissions shocks; carbon dioxide emissions is influenced by its past values as well as real GDP and energy use variations; whilst energy use is sensitive only to disturbances in its equation. Thus, our panel empirical evidence is in line with the "growth hypothesis", as in Lee and Chang (2008), and Lean and Smyth (2009) for panel data analyses. Moreover, Magazzino (2014d) found similar results for a panel of 10 Middle East countries.

5. Conclusions and Policy Implications

This study investigates the relationship between economic growth, carbon dioxide emissions, and energy use in six ASEAN countries over the 1971-2007 years. The empirical strategy uses a recent panel VAR approach. The 3-variable VAR estimates underline that for the six ASEAN countries response of CO_2 emissions to real per capita GDP is positive in the estimated coefficients and impulse responses. The coefficient of *PCEU* two periods lagged is statistically significant in the real GDP equation, showing that a more intensive use of per capita energy leads to an increase in the economic activity. Instead, the energy is only positively affected by its own first lag. The forecast errors in real per capita GDP are mainly due to uncertainty in GDP itself and energy use emissions (at least in this variables' ordering). Twenty steps ahead, 50% of the variance is still attributed to the error in the real GDP equation, 22% is attributed to the error in the CO_2 emissions disturbances equation, and 28% to the energy use. The error variance in the carbon dioxide emissions is sensible to disturbances both in the GDP and in CO_2 equations. The errors in predicting the energy use are sensitive to disturbances in its own equation: after ten steps, almost 76% of the error variance in energy use forecasts is due to its own shocks. Thus, for the estimated sample, these results reinforced the VAR and IRFs analyses, suggesting that for this panel the "growth hypothesis" holds: restrictions on the use of energy may adversely affect economic growth while increases in energy may contribute to economic growth. Consequently, we may conclude that energy is a limiting factor to economic growth and, hence, shocks to energy supply will have a negative impact on economic growth (Ozturk, 2010).

Given the little amount of studies devoted to the analysis of the nexus between economic growth, energy consumption, and emissions for ASEAN countries, new studies may concern the estimation of the EKC. Moreover, new studies on the relationship between disaggregated energy sources and economic growth would be useful for an adequate energy policies planning (Magazzino, 2012).

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Appendix. Table A. Descriptive statistics.

Country	Variable	Mean	Median	Variance	Skewness	Kurtosis	Inter-Quartile Range
Brunei	RPCGDP	10.2721	10.1986	0.0272	1.3816	4.1649	0.2062
	CO_2	2.7596	2.9283	0.7656	-0.3391	2.2639	0.9790
	PCEU	8.6957	8.8535	0.1942	-2.6759	9.3636	0.2000
Indonesia	RPCGDP	6.5241	6.5380	0.3624	-0.1228	1.6521	1.0733
	CO_2	-0.3795	-0.3149	0.4588	-0.2747	1.7717	1.2499
	PCEU	6.2419	6.1886	0.1196	-0.0865	1.5077	0.6168
Malaysia	RPCGDP	7.9268	7.8894	0.3689	-0.1381	1.7147	1.0742
	CO_2	1.2102	1.1339	0.3345	-0.0008	1.4883	1.0397
	PCEU	7.1250	7.0689	0.2712	-0.2286	1.8270	0.7771
Singapore	RPCGDP	9.3783	9.4663	0.7101	-0.4164	1.9202	1.3080
	CO_2	1.9755	2.4196	0.8632	-1.3801	4.0818	1.1718
	PCEU	8.0857	7.9917	0.2538	-0.1265	1.5146	0.8920
Thailand	RPCGDP	7.2068	7.2673	0.4174	-0.1646	1.6028	1.1091
	CO_2	0.0797	-0.0668	1.0477	-0.2801	1.9972	1.6871
	PCEU	6.5582	6.4865	0.2457	0.1910	1.4682	0.9124
the Philippines	RPCGDP	6.9086	6.9105	0.0374	0.2042	2.7369	0.2062
	CO_2	-0.3682	-0.2876	0.0774	-1.2764	3.9359	0.2728
	PCEU	6.1120	6.1040	0.0067	0.2665	2.2666	0.1131