Resource and Energy Economics 31 (2009) 210–220

Contents lists available at ScienceDirect

Resource and Energy Economics

journal homepage: www.elsevier.com/locate/ree

The energy-GDP nexus: Evidence from a panel of Pacific Island countries

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ARTICLE INFO

Article history:
Received 26 November 2008
Received in revised form 8 April 2009
Accepted 9 April 2009
Available online 18 April 2009

JEL classification:
C22

Keywords:
Energy consumption
Panel cointegration
Granger causality
Pacific Island countries

ABSTRACT

The Pacific Island countries are small island economies that are increasingly dependent on energy for growth and development, yet highly susceptible to climate change. Thus, the relationship between energy consumption and GDP is crucial for realizing their future development and growth objectives. This article tests for Granger causality and provides long-run structural estimates for the relationship between energy consumption, GDP and urbanization for a panel of Pacific Island countries. For the panel as a whole in the long-run there is bidirectional Granger causality between energy consumption and GDP and these variables exert a positive impact on each other. A 1% increase in energy consumption increases GDP by 0.11%, while a 1% increase in GDP increases energy consumption by 0.23%. The findings suggest that for the panel as a whole these countries should increase investment in energy infrastructure and regulatory reform of energy infrastructure to improve delivery efficiency, continue to promote alternative energy sources and put in place energy conservation policies to reduce unnecessary wastage. These strategies seek to realize the dual objectives of reducing the adverse effects of energy use on the environment, while avoiding the negative effect on economic growth of reducing energy consumption.

1. Introduction

One topic that has been much studied in the energy economics literature is the direction of causality between energy consumption and Gross Domestic Product (GDP). To examine causality the

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doi:10.1016/j.reseneeco.2009.04.002

literature has used the concept of Granger causality. Despite the large number of empirical studies in this area of research, the literature has failed to reach a consensus about the direction of Granger causality. One explanation for the failure to reach a consensus is that methodological limitations have plagued much of the literature. One problem is that the power of unit root tests, such as the augmented Dickey–Fuller test, and cointegration tests, such as the Johansen (1988) test, is low with short spans of data of 20–30 observations, commonly employed in single country studies. A second problem is that many studies suffer from omitted variables bias. Bivariate models which include just energy consumption and GDP may be biased due to the omission of other variables such as capital, labor or prices. Thus, many of the more recent studies have employed multivariate models, in which, in addition to energy consumption and GDP, one or more other variables such as capital and/or labor or energy prices are included.

Given these methodological problems that certainly impeded much of the earlier literature, it is important to re-examine the relationship between energy consumption and GDP using more recent techniques that address these methodological limitations. This article makes three contributions to the literature. First, it examines the relationship between energy consumption and GDP for a panel of Pacific Island countries (PICs). Existing research on the energy-GDP nexus is conspicuous by its absence for virtually all PICs. The only studies, of which we are aware, are two single country studies for Fiji (Reddy, 1998; Narayan and Singh, 2007). Second, it uses panel unit root, panel cointegration, panel Granger causality and long-run structural estimation. The studies which use a panel framework are recent and most of these panel-based studies use a bivariate model. The only panel-based studies which use a multivariate model are Mahadevan and Asafu-Adjaye (2007), who include energy prices in addition to energy consumption and GDP; Narayan and Smyth (2009), who include exports in addition to energy consumption and GDP; and Lee and Chang (2008) and Narayan and Smyth (2008) who include capital stock in addition to energy consumption and GDP. Third, we use a multivariate model in which, in addition to energy consumption and GDP, we incorporate urbanization. While some studies of the determinants of energy demand have used urbanization as an explanatory variable it has only been used once before in the energy-GDP Granger causality literature. It is an apt variable to consider in a study of the energy-GDP nexus in the PICs, because most have undergone rapid urbanization.

2. The Pacific Islands context

There are 22 countries in the South Pacific, spread over an area of ocean estimated to be 30 million km^2. Papua New Guinea is the largest of the PICs, accounting for around 80% of the region's population (just over seven million people) and 83% of the land (402,700 km^2). A study of the energy-GDP nexus is of direct relevance to the PICs. The PICs face a difficult trade-off. On the one hand, the PICs are among the countries that will be most directly affected by climate change, resulting from the increase in fossil fuel use by industrialized countries. The fact that the PICs are so vulnerable to climate change means that while on a world-scale their consumption of energy has traditionally been miniscule, they have been at the forefront of exploring alternative sources of energy, such as wind and wave power, and promoting energy conservation. On the other hand, the PICs themselves are increasingly dependent on fossil fuels, with important implications for development. Specifically, at the Pacific Energy Ministers Meeting in the Cook Islands in 2007 it was agreed that energy is a key driver of economic growth with bearing on education, the environment, health and social welfare of the PICs. The irony is that while the PICS are at the forefront of advocating the use of cleaner energy options to reduce greenhouse gas emissions in world forums, the PICs are suffering greater air and marine pollution from fossil fuel use.

Overall, the economic performance of the PICs over the last two decades has been disappointing. None of the PICs realized a real GDP per capita growth rate of 2% per annum over the period 1985–2006. The PICs are highly dependent on imported petroleum for their commercial energy requirements. Petroleum imports account for over 90% of overall energy requirements, making the PICs extremely vulnerable to shocks in international energy markets. Two negative effects of fossil fuel use are ever present throughout the PICs. First, the high and increasing cost of crude oil places considerable strain on the trade balances of the Pacific Island countries, crowding out other imports, increasing the cost of transport fuel and electricity and having an adverse effect on real income and poverty rates. Second, because several of the Pacific Island countries are low-lying islands with no hinterland, they are particularly susceptible to climate change. Several countries in the Pacific are vulnerable to changing rainfall and seasonal patterns resulting from climate change which have a direct impact on those who depend on agriculture and fisheries for their livelihood and nutritional intake.

Increased demand for energy has been exacerbated by rapid urbanization in the PICs. While traditionally most people lived in rural areas, the last two decades have witnessed substantial rural to urban migration in some PICs. The proportion of the population living in urban areas is still relatively low in countries such as Papua New Guinea, Solomon Islands and Tonga, but the proportion of the population living in urban areas exceeds 40% in Kiribati, 50% in Fiji and French Polynesia and 60% in New Caledonia. While only 20% of Samoa's total population is urbanized, this masks significant differences across islands in the country. On the island of Upolu, more than 70% of the population is urbanized. An increase in squatter settlements has accompanied higher rates of urbanization, visible in cities such as Honiara, Suva and Port Vila. In Fiji, there are in excess of 140 squatter settlements and people living in squatter settlements account for 13% of Fiji's population (Duncan and Voigt-Graf, 2008).

3. Hypotheses and existing literature

3.1. Energy consumption and GDP

We test a series of competing hypotheses concerning Granger causality between energy consumption and GDP, GDP and urbanization and energy consumption and urbanization for the PICs. The first set of competing hypotheses concerns the relationship between energy consumption and GDP. The competing hypotheses are that there is unidirectional Granger causality running from energy consumption to GDP; unidirectional Granger causality running from GDP to energy consumption; bidirectional Granger causality between these variables or no Granger causality in either direction. The reason why energy might Granger cause GDP is that energy is an input in the production process. The reason why GDP might Granger cause energy is that an expansion in output might create demand for further energy. These hypotheses have important policy implications. If there is unidirectional Granger causality running from GDP to energy consumption or no Granger causality in either direction, it may be implied that energy conservation policies have little or no adverse effect on economic growth. On the other hand, if unidirectional Granger causality runs from energy consumption to GDP, it follows that reducing energy consumption could lead to a fall in income, while increases in energy consumption could contribute to high rates of economic growth in the PICs.

Several studies have tested for Granger causality between GDP and energy use for a range of countries using myriad methodologies. There are four generations of studies. First generation studies used a traditional vector autoregression (VAR) methodology and Granger causality testing. The results from these studies are suspect because these studies assume the data are stationary. Second- and third-generation studies apply unit root and cointegration testing for single countries. These studies have adopted increased levels of econometric sophistication, but in most instances still suffer from relatively short time series. Fourth generation studies apply a panel-based approach. Across the literature, there is no consensus about which hypothesis holds. As Mehrara (2007, p. 2940) states, "when it comes to whether energy use is a result of, or a perquisite for, economic growth, there are no clear trends in the literature. Depending on the methodology, used, and country and time period studied, the direction of causality between energy consumption and economic variables has remained empirically elusive and controversial".

3.2. GDP and urbanization

The second set of competing hypotheses concerns the relationship between GDP and urbanization. One hypothesis is that GDP Granger causes urbanization. Economic development involves the transformation of a country from a rural agricultural based economy to an industrial service based economy. As labour saving technologies are introduced in agriculture, agricultural productivity increases and labour is released. The transformation from an agricultural to an industrial based economy results in urbanization as firms and workers cluster in cities to take advantage of Marshall's localized external economies of scale in manufacturing and services. The competing hypothesis is that urbanization Granger causes GDP. There are several possibilities. Production of manufacturing and services is more efficient when concentrated in industrial districts in cities. Close spatial proximity promotes information spillovers amongst producers and more efficient functioning labour markets. Cities offer increased opportunities for division of labour and make intra-industry specialization more likely. Relatively cheaper transport combines with proximity to customers and suppliers to reduce the costs of trade. Creative and educated people are concentrated in fewer locales, making it easier to realize the full social returns to increased human capital. There are relatively few studies of Granger causality between GDP and urbanization. The most comprehensive study is by Bloom et al. (2008) who tested for unidirectional Granger causality running from urbanization to GDP for panel of 163 countries over the period 1960–2000. These authors found that urbanization does not Granger cause GDP.

3.3. Energy consumption and urbanization

The third set of competing hypotheses concerns the relationship between energy consumption and urbanization. One hypothesis is that urbanization Granger causes energy consumption. There are two possible reasons why higher urbanization might lead to higher energy use (Holtedahl and Joutz, 2004). First, urbanization implies greater access to electricity, since households can be more readily connected to the grid. Second, households who already had access to electricity in rural areas are likely to increase their consumption in urban areas because of increased use of existing appliances and purchase of new ones. The latter occurs in response to increased exposure to advertising that is common place in most large cities. However, Lariviere and Lafrance (1999) find in Canada that more urbanized areas have lower energy consumption per capita. One explanation is that high density cities use less gasoline than low density cities because the distances travelled are smaller and inhabitants are more likely to use public transport. A second explanation is that the electricity need for street lighting seems to be largely invariant to city density so larger cities reduce electricity consumption per capita. The competing hypothesis is that energy consumption Granger causes urbanization. One avenue through which increased energy consumption could generate higher rates of urbanization is indirectly through higher energy consumption generating higher GDP.

Halicioglu (2007) is the only study, of which we are aware, that tests for Granger causality between energy consumption, energy prices, GDP and urbanization in a single country study for Turkey over the period 1968–2005. The main findings from that study were that in the long-run Granger causality runs from GDP, prices and urbanization to energy consumption, but in the short-run the Granger causality tests were inconclusive.

4. Data

The empirical analysis is based on a panel of nine PICs (Fiji, French Polynesia, Kiribati, New Caledonia, Papua New Guinea, Samoa, Solomon Islands, Tonga and Vanuatu) over the period 1980–2005. The sample is restricted to those PICs for which data on energy consumption per capita, real GDP per capita and urbanization is available over this period. Annual data on energy consumption per capita, measured in million btu, was obtained from the Energy Information Agency (EIA, 2008). Annual data on real GDP per capita, measured in US dollars at 2000 prices and urbanization, defined as the percentage of the population living in urban areas, was obtained from the World Bank (2008). All the data were converted into natural logarithms prior to conducting the analysis.

5. Econometric methodology and results

5.1. Panel unit root tests

While a number of panel unit root tests have been proposed we use the panel unit root tests proposed by Im et al. (2003), Maddala and Wu (1999) and Breitung (2000). The *t*-bar test proposed by

Im et al. (2003) assumes that all countries converge towards the equilibrium value at different speeds under the alternative hypothesis. There are two stages in constructing the t-bar test statistic. The first is to calculate the average of the individual Augmented Dickey–Fuller (ADF) t-statistics for each of the countries in the sample. The second is to calculate the standardized t-bar statistic as follows:

$$t\text{-}bar = \frac{\sqrt{N}(t_\alpha - \kappa_t)}{\sqrt{\nu_t}} \tag{1}$$

where N is the size of the panel, t_α is the average of the individual ADF t-statistics for each of the countries with and without a trend and κ_t and ν_t are, respectively, estimates of the mean and variance of each $t_{\alpha i}$. Im et al. (2003) provided Monte Carlo simulations of κ_t and ν_t and tabulate exact critical values for various combinations of N and T. A problem with the t-bar test is that if there is cross-sectional dependence in the disturbances, the test is no longer applicable. However Im et al. (2003) suggested that in the presence of cross-sectional dependence, the data can be adjusted by demeaning and that the standardized demeaned t-bar statistic converges to the standard normal in the limit.

Maddala and Wu (1999) criticized the Im et al. (2003) test on the basis that in many real world applications, cross correlations are unlikely to take the simple form proposed by Im et al. (2003) that can be effectively eliminated by demeaning the data. Maddala and Wu (1999) propose a panel unit root test developed from Fisher (1932). The test essentially combines the p-values of the test statistic for a unit root in each residual cross-sectional unit. The test is non-parametric and has a chi-square distribution with $2N$ degrees of freedom, where N is the number of cross-sectional units or countries. Using the additive property of the chi-squared variable, the following test statistic can be derived:

$$\lambda = -2\sum_{i=1}^{N} \log_e \pi_i \tag{2}$$

Here, π_i is the p-value of the test statistic for unit i. The Maddala and Wu (1999) test has the advantage over the Im et al. (2003) test that it does not depend on different lag lengths in the individual ADF regressions. Maddala and Wu (1999) performed Monte Carlo simulations showing their test is superior to that proposed by Im et al. (2003).

The Breitung (2000) panel unit root test has the following form:

$$y_{it} = \alpha_{it} + \sum_{k=1}^{p+1} \beta_{ik} x_{i,t-k} + \varepsilon_t \tag{3}$$

In Eq. (3) the Breitung (2000) test statistic tests the following null hypothesis that the process is difference stationary: $H_0: \ \sum_{k=1}^{p+1} \beta_{ik} - 1 = 0$. The alternative hypothesis assumes that the panel series is stationary; that is, $\sum_{k=1}^{p+1} \beta_{ik} - 1 < 0$ for all i. Breitung (2000) uses the following transformed vectors to construct the test statistic:

$$Y_i^* = AY_i = [y_{i1}^*, y_{i2}^*, \ldots, y_{iT}^*]'$$

$$X_i^* = AX_i = [x_{i1}^*, x_{i2}^*, \ldots, x_{iT}^*]'$$

leading to the following test statistic:

$$\lambda_B = \frac{\sum_{i=1}^{N} \sigma_1^{-2} Y_i' * X_i' *}{\sqrt{\sum_{i=1}^{N} \sigma_1^{-2} X_i' * A' A X_i^*}}$$

which is shown to have a standard normal distribution.

The results of the panel unit root tests are reported in Table 1. The test statistics for the log levels of energy consumption, GDP and urbanization are statistically insignificant with the exception of the Maddala and Wu (1999) test applied to energy consumption. Taken as a whole, the log levels results suggest that all three variables are panel non-stationary. When we apply the panel unit root tests to the first difference of the three variables, all three tests reject the joint null hypothesis for GDP and energy consumption. The results for urbanization are ambiguous; however, the Breitung (2000) test suggests that urbanization is integrated of order one. A large-scale Monte Carlo simulation study by

Table 1
Panel unit root tests.

Unit root test	GDP per capita	Energy consumption per capita	Urbanization
Levels			
IPS test	−0.698	−0.998	−1.217
MW−Fisher ADF	22.939	30.301**	23.561
Breitung test	−1.116	1.288	−0.527
First difference			
IPS test	−7.303***	−8.449***	−0.576
MW−Fisher ADF	79.349***	95.392***	23.831
Breitung test	−6.993***	−4.982***	−1.744**

Notes: All unit root tests were performed with individual trends and intercept for each series. The optimal lag length was selected automatically using the Schwarz information criteria. The null hypothesis is unit root for all the tests. *** (**) denote statistical significance at the 1% (5%) level.

Hlouskova and Wagner (2006) found that the Breitung (2000) panel unit root test generally had the highest power and smallest size distortions than the other panel unit root tests. Thus, overall, it is safe to conclude that all variables contain a panel unit root.

5.2. Panel cointegration

Having established that all three variables contain a panel unit root, we proceed to test whether there is a long-run relationship between energy consumption, GDP and urbanization using the Pedroni (2000) heterogeneous panel cointegration test. Pedroni (2000) provides seven statistics for the test of the null of no cointegration in heterogeneous panels. One group of tests are termed 'within dimension' (panel tests) and the other group of tests are 'between dimension' (group tests). The 'within dimension' tests take into account common time factors and allow for heterogeneity across countries. The 'between dimension' tests are 'group mean cointegration tests' and allow for heterogeneity of parameters across countries. The seven Pedroni (2000) test statistics are:

- Within dimension (panel tests):
  (a) Panel ν-statistic.
  (b) Panel Phillips–Perron type rho-statistics.
  (c) Panel Phillips–Perron type t-statistic.
  (d) Panel Augmented Dickey–Fuller (ADF) type t-statistic.
- Between dimension (group tests):
  (e) Group Phillips–Perron type rho-statistics.
  (f) Group Phillips–Perron type t-statistic.
  (g) Group ADF type t-statistic.

Pedroni's (2000) seven statistics are based on the estimated residuals from:

$$\mathrm{EC}_{i,t} = \alpha_i + \beta_i\, GDP_{i,t} + \phi_i U_{i,t} + \varepsilon_{i,t} \tag{5}$$

Here EC is energy consumption, GDP is GDP and U is urbanization and $\varepsilon_{it} = \eta_i \varepsilon_{i(t-1)} + \mu_{it}$ are the estimated residuals from the panel regression. The null hypothesis tested is whether η_i is unity. The finite sample distribution for the seven statistics is tabulated in Pedroni (2004) using Monte Carlo simulations. If the test statistic exceeds the critical values in Pedroni (2004), the null hypothesis of no cointegration is rejected, implying a long-run relationship exists between EC, GDP and U.

The results are reported in Table 2 under the assumption of alternative dependent variables. The Pedroni test statistics reject the null of no cointegration when they have large negative values except for the panel ν-statistic, which rejects the null of no cointegration when it has a large positive value. Karaman Örsal (2007) compares the relative performance of Pedroni's (2000) test statistics and concludes that the panel ADF-statistic performs better than the other three within-dimension-based statistics and the three group-mean statistics. Thus, we base our conclusions primarily on the panel

Table 2
Pedroni panel cointegration tests.

	Dependent variable		
	GDP per capita	Energy consumption per capita	Urbanization
Panel ν-statistic	0.740	1.334*	−0.770
Panel rho-statistic	−0.204	−1.019	0.215
Panel PP-statistic	−0.945	−2.185**	−0.748
Panel ADF-statistic	−1.484*	−1.911**	−0.522
Group rho-statistic	1.145	−0.142	1.260
Group PP-statistic	−0.068	−2.404***	−0.117
Group ADF-statistic	−0.851	−3.224***	0.333

Notes: *** (**) (*) denote statistical significance at the 1% (5%) (10%) level.

ADF-statistic, which suggests the null of no cointegration is rejected when energy consumption and GDP is the dependent variable, but not when urbanization is the dependent variable.

We also implement the panel cointegration test of Larsson et al. (2001), which allows for multiple cointegration relations. The Larsson et al. (2001) likelihood-based panel test for cointegration rank in heterogeneous panel models is based on the average of individual rank trace statistics. The key statistic – $\gamma_{\bar{LR}}(H(r)|H(3))$ – is the average of the N individual trace statistics (see Larsson et al., 2001). Table 3 reports the individual country-by-country and panel test results. The country-by-country results indicate the presence of a cointegrated vector equal to one (Fiji, Kiribati and the Solomon Islands), two (Papua New Guinea, Samoa and Tonga) or three (French Polynesia, New Caledonia and Vanuatu). For the panel as a whole, there are three cointegrating vectors.

Pedroni's (2000) and Larsson et al.'s (2001) cointegration tests differ on the number of cointegrating vectors. Studies by Gutierrez (2003), Karaman Örsal (2007) and Wagner and Hlouskova (2006) compare the performance of the Pedroni (2000) and Larsson et al. (2001) cointegration tests using Monte Carlo simulations and all three studies indicate that Pedroni's (2000) test out-performs Larsson et al.'s (2001) test. Thus, we proceed on the basis of the number of cointegrating vectors indicated by the Pedroni (2000) test.

5.3. Panel Granger causality

Having established that there is a long-run relationship between energy consumption, GDP and urbanization, next we examine the direction of causality between the variables in a panel context. We specify a model with a dynamic error correction representation.

Table 3
Larsson et al. (2001) panel cointegration test.

	$LR_{iT}(H(r)|H(3))$			Rank(r_i)
	$r=0$	$r=1$	$r=2$	
Country				
Fiji	40.88***	13.07	1.19	1
French Polynesia	65.86***	28.87***	8.50***	3
Kiribati	34.88***	6.13	0.41	1
New Caledonia	50.96***	21.36***	4.44**	3
Papua New Guinea	29.10**	14.31*	1.83	2
Samoa	35.59***	16.47**	0.27	2
Solomon Islands	43.80***	8.37	0.18	1
Tonga	30.36**	13.90*	0.36	2
Vanuatu	42.09***	18.20**	4.96**	3
Panel tests				
$\gamma_{\bar{LR}}(H(r)|H(3))$	16.01***	8.82***	2.66***	3

Notes: * (**) *** indicate significance at 10% (5%) 1% levels, respectively. For the individual trace statistics MacKinnon et al. (2001) p-values are used. The panel trace statistics follows a normal distribution ($N(0,1)$) under the null hypothesis of no-cointegration.

Table 4
Panel Granger causality tests.

	$\Delta\ln(GDP)$	$\Delta\ln(EC)$	$\Delta\ln(U)$	ECM_{t-1}
$\Delta\ln(GDP)$	–	0.032 (1.118)	0.363 (1.135)	0.012* (1.681)
$\Delta\ln(EC)$	0.065 (0.482)	–	−1.324** (−1.992)	−0.034** (−2.143)
$\Delta\ln(U)$	0.001 (0.272)	−0.0005 (−0.252)	–	−0.0003 (−0.586)

Notes: * (**) *** denote rejection of the null hypothesis at 10% (5%) 1% levels, respectively. The *t*-statistics are given in parenthesis.

The Granger causality test is based on the following regressions:

$$\Delta\ln GDP_{it} = \pi_{iGDP} + \sum_{p}\pi_{11ip}\,\Delta\ln GDP_{it-p} + \sum_{p}\pi_{12ip}\,\Delta\ln EC_{it-p} + \sum_{p}\pi_{13ip}\,\Delta\ln U_{it-p} + \psi_{1i}\,ECT_{it-1} + \varepsilon_{it} \quad (6)$$

$$\Delta\ln EC_{it} = \pi_{iEC} + \sum_{p}\pi_{21ip}\,\Delta\ln EC_{it-p} + \sum_{p}\pi_{22ip}\,\Delta\ln GDP_{it-p} + \sum_{p}\pi_{23ip}\,\Delta\ln U_{it-p} + \psi_{2i}\,ECT_{it-1} + \varepsilon_{it} \quad (7)$$

$$\Delta\ln U_{it} = \pi_{iu} + \sum_{p}\pi_{31ip}\,\Delta\ln U_{it-p} + \sum_{p}\pi_{32ip}\,\Delta\ln GDP_{it-p} + \sum_{p}\pi_{33ip}\,\Delta\ln EC_{it-p} + \psi_{3i}\,ECT_{it-1} + \varepsilon_{it} \quad (8)$$

The explicit definition of the error correction term is as follows:

$$\hat{ECT}_{it} = \ln GDP_{it} - \hat{\alpha}_i - \hat{b}_t - \hat{\beta}_{1i}\ln GDP_{it} - \hat{\beta}_{2i}\ln EC_{it} - \hat{\beta}_{3i}\ln U_{it}$$

Here *GDP*, *EC* and *U* are as previously defined, Δ denotes the first difference of the variable, *ECT* is the error-correction term, and *p* denotes the lag length. The optimal lag length was selected automatically using the Schwarz information criteria. The panel Granger causality results are reported in Table 4. The findings in Table 4 indicate that there is short-run panel Granger causality running from urbanization to energy consumption. There is long-run Granger causality running from electricity consumption and urbanization to GDP and from GDP and urbanization to electricity consumption.

5.4. Panel long-run estimates

Once the direction of long-run causality is established, the final step is estimation of the long-run structural coefficients. To estimate the long-run structural estimates we use a panel version of dynamic ordinary least squares (DOLS) (Pedroni, 2001). Consider the regression $y_{it} = \alpha_i + \beta_i X_{it} + \mu_{it}$ such that y_{it} is the log of GDP (as in Table 5) or log of energy consumption (as in Table 6) and *X*

Table 5
DOLS long-run elasticities (GDP as dependent variable).

	ln(*GDP*) is dependent variable	
	ln(*EC*)	ln(*U*)
Country		
Fiji	0.08 (0.05)	1.05 (0.07)
French Polynesia	0.18 (0.11)	−2.14 (0.75)
Kiribati	0.22 (0.09)	1.09 (0.15)
New Caledonia	0.17 (0.90)	5.25*** (2.63)
Papua New Guinea	−0.29 (0.71)	0.06* (1.31)
Samoa	0.09 (0.50)	5.61** (1.67)
Solomon Islands	0.75** (1.89)	1.28*** (2.36)
Tonga	−0.02 (0.06)	5.26 (0.87)
Vanuatu	−0.15 (0.12)	−0.30 (0.33)
Panel	0.11* (1.48)	1.91*** (3.38)

Notes: * (**) *** indicate significance at 10% (5%) and 1% levels, respectively.

Table 6
DOLS long-run elasticities (energy consumption as dependent variable).

	ln(*EC*) is dependent variable	
	ln(*GDP*)	ln(*U*)
Country		
Fiji	0.07** (1.97)	0.59** (2.09)
French Polynesia	3.21 (0.94)	8.51** (2.11)
Kiribati	1.13 (0.84)	−1.83 (0.83)
New Caledonia	0.13 (0.23)	−0.31* (1.55)
Papua New Guinea	−0.38 (0.50)	−0.77 (0.81)
Samoa	0.30 (0.29)	1.91** (1.77)
Solomon Islands	0.11 (0.19)	−1.21 (0.24)
Tonga	−1.29*** (9.26)	17.03*** (47.28)
Vanuatu	−1.23** (1.65)	−2.26 (0.85)
Panel	0.23*** (5.29)	2.41*** (19.16)

Notes: * (**) *** indicate significance at 10% (5%) 1% levels, respectively.

represents the corresponding vector of the independent variables. We augment the above cointegrating regression with lead and lagged differences of the regressor to control for endogenous feedback:

$$y_{it} = \alpha_i + \beta_i X_{it} + \sum_{k=-K_i}^{K_i} \gamma_{ik}\,\Delta X_{it-k} + \mu_{it}^*$$

From this regression, the group-mean panel DOLS estimator can be constructed as

$$\hat{\beta}_{GD}^* = \left[N^{-1} \sum_{i=1}^{N} \left(\sum_{t=1}^{T} Z_{it} Z_{it}' \right)^{-1} \left(\sum_{t=1}^{T} Z_{it} \tilde{s}_{it} \right) \right]$$

where Z_{it} is the $2(K+1) \times 1$ vector of regressor $Z_{it} = (X_{it} - \bar{X}_i, \Delta X_{it-K}, \ldots, \Delta X_{it+K})$, $\tilde{s}_{it} = s_{it} - \bar{s}_i$ and as the expression following summation over i is identical to the conventional DOLS estimator, we can see that the panel DOLS estimator can be constructed as $\hat{\beta}_{GD}^* = N^{-1} \sum_{i=1}^{N} \hat{\beta}_{D,i}^*$, where $\hat{\beta}_{D,i}^*$ is the conventional DOLS estimator, applied to the ith member of the panel. The t-statistics for the panel DOLS estimator can be constructed as

$$t_{\hat{\beta}_{GD}^*} = N^{-1/2} \sum_{i=1}^{N} t_{\hat{\beta}_{D,i}^*}$$

where

$$t_{\hat{\beta}_{D,i}^*} = (\hat{\beta}_{D,i}^* - \beta_0) \left(\hat{\sigma}_i^{-2} \sum_{t=1}^{T} (X_{it} - \bar{X}_i)^2 \right)^{1/2}$$

The long-run elasticities of the impact of energy consumption and urbanization on GDP for each of the nine PICs and for the panel of PICs based on the DOLS estimator are reported in Table 5. Beginning with the country specific results, we find that energy consumption has a positive and statistically significant impact on GDP in the Solomon Islands. Turning to the effect of urbanization on real GDP, we find that for New Caledonia, Papua New Guinea, Samoa and the Solomon Islands, urbanization has a positive effect on GDP. The magnitude of the impact ranges from 0.06 in Papua New Guinea to 5.61 in Samoa. The panel long-run elasticities suggest that energy consumption and urbanization have a positive and statistically significant effect on GDP, but the income elasticity for energy consumption is small relative to the income elasticity for urbanization. A 1% increase in energy consumption increases GDP by 0.11%, while a 1% increase in urbanization increases GDP by 1.9%.

The long-run elasticities of the impact of GDP and urbanization on energy consumption for each of the nine PICs and for the panel of PICs based on the DOLS estimator are reported in Table 6. The coefficient on GDP is positive and statistically significant for Fiji. The coefficient on GDP is negative and statistically significant for Tonga and Vanuatu. Over the period of the study, Vanuatu experienced moderate growth – real GDP per capita in US dollars at 2000 prices increased from $US1016.63 in 1980 to $US1188.17 in 2005 (World Bank, 2008) – while energy consumption per capita actually fell from 14.7 million btu in 1980 to 6.5 million btu in 2005 (EIA, 2008). As discussed above, conceptually higher rates of urbanization could have a positive or negative effect on energy consumption. We find that urbanization has a positive effect on energy consumption in Fiji, French Polynesia, Samoa and Tonga, but a negative effect on energy consumption in New Caledonia. For the panel as a whole both GDP and urbanization has a positive and statistically significant effect on energy consumption. A 1% increase in GDP generates a 0.23% increase in energy consumption. A 1% increase in the rate of urbanization generates a 2.41% increase in energy consumption.

6. Discussion and policy implications

The main finding in terms of the energy-GDP nexus is that there is bidirectional Granger causality between energy consumption and GDP and that for the panel as a whole energy consumption and GDP have a positive effect on each other. A 1% increase in energy consumption increases GDP by 0.11%, while a 1% increase in GDP increases energy consumption by 0.23%. Bidirectional Granger causality implies that energy consumption and economic growth are jointly determined and affected at the same time. An expansion in GDP increases energy consumption for two reasons. First, economic growth results in an expansion in the commercial and industrial sectors, which requires energy inputs. Second, higher disposable income increases demand for electronic gadgets for entertainment and comfort for households. An increase in energy consumption results in higher GDP because, in addition to the direct effect of energy consumed for commercial use which generates higher rates of economic growth, higher energy consumption results in an increase in energy production, which has the indirect effect of generating employment and infrastructure in energy services.

The findings suggest that, for the panel as a whole, these countries should adopt the multi-pronged strategy of increasing investment in energy infrastructure and regulatory reform of energy infrastructure to improve delivery efficiency, continuing to promote alternative energy sources and putting in place energy conservation policies to reduce unnecessary wastage. These strategies seek to realize the dual objectives of reducing the adverse effects of energy use on the environment, while avoiding the negative effect on economic growth of reducing energy consumption. These findings and policy suggestions are consistent with the dual challenges that the PICs face as discussed above. On the one hand, the PICs are becoming increasingly dependent on energy to stimulate economic growth and realize broader development goals. On the other hand, given their susceptibility to climate change, the PICs need to be at the forefront of developing and advocating the use of energy conservation strategies and alternative energy technologies to strengthen their case that the industrialized nations should be doing likewise.

A practical approach to realizing the dual objectives of reducing the adverse effects of energy use on the environment and the negative effect of curtailing energy consumption on economic growth is for the PICs to invest in renewable energies. The PICs started invested in renewable energies from the early 1980s. Successful efforts to develop renewable energy in the PICs have focused on solar photovoltaic power for remote islands, solar water heaters and the use of biomass for agroindustries (Jafar, 2000). Several other avenues forward have been suggested. For example, it has been said that many PICs have the potential to replace up to 30–50% of their current diesel imports with biodiesel produced from coconut oil (Mace, 2006). The replacement of diesel imports with biodiesel from coconuts offers several benefits including job creation, reduced carbon dioxide emissions and increased energy security.

7. Conclusions: limitations and directions for future research

One of the limitations of this study is that the analysis is at an aggregated level. Different industries have different intensities of energy, and over time the importance of a specific industry will change. To this point, there are few studies that examine the relationship between energy consumption and GDP at a disaggregated level and no such panel-based studies. It would be difficult to obtain disaggregated data on energy consumption for a panel of PICs; however, even if such data could be obtained for a single country, such as Fiji, such a project would be a useful topic for future research. A second direction for future research would be to examine the determinants of the commercial or residential demand for energy, either for a single country or a panel of PICs. A third direction for future research would be to examine the relationship between energy consumption and food security in the PICs. In several PICs there is evidence that the high cost of oil is exacerbating poverty levels. Overall, there are few studies exploring the various dimensions of energy consumption in the PICs including how energy is impacting on the PICs and people's lives. Given the importance of energy to the PICs, future research examining its use will have direct relevance to PIC policy-makers.

Acknowledgements

We thank two anonymous referees for several helpful suggestions on an earlier version of this article.

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