Could Sri Lanka afford sustainable electricity consumption practices without harming her economic growth?

Shanthini, Rajaratnam
University of Peradeniya, Peradeniya, Sri Lanka

20. May 2010

Could Sri Lanka afford sustainable electricity consumption practices without harming her economic growth?

Rajaratnam Shanthini
Professor in Chemical & Process Engineering
Department of Chemical & Process Engineering, Faculty of Engineering, University of Peradeniya, Peradeniya, Sri Lanka (Email: rshanthini@pdn.ac.lk; Tel: 071-5326835)

Abstract: The existence and direction of Granger causality between electricity consumption and economic growth, proxied by gross domestic product (GDP), has been investigated in this study using annual data covering the period 1971 to 2007. The results of the augmented Dickey-Fuller, GLS-detrended Dickey-Fuller and Phillips-Perron tests show that the natural logarithms of both the times series are individually $I(1)$. The autoregressive distributed lag bounds testing approach to cointegration used in this study reveals that the two times series are cointegrated. The estimated long-run equilibrium relationship shows that 1% growth in GDP induces 1.45% growth in electricity consumption, and any deviation from the long-run equilibrium following a short-run disturbance is corrected within 17 months. Granger causality test results reveal uni-directional causality running from economic growth to electricity consumption without any feedback effect. The outcome of such results is beneficial to Sri Lanka's economic growth since it is not dependent on electricity consumption, and thereby production. It is therefore possible to initiate energy policies towards minimizing wasteful electricity production and consumption practices, without compromising Sri Lanka's GDP growth, to take her on an electricity-wise sustainable economic development path.

Keywords: ARDL; cointegration; Granger causality; gross domestic product; sustainable electricity consumption; Sri Lanka

1 Introduction

Unrestrained growth in electricity consumption in a country is seen as a precursor to continual improvement in her people's standard of living, which, on the other hand, is believed to be entwined with economic growth, proxied by gross domestic product (GDP). It is therefore Sri Lanka has been investing heavily in enhancing her electricity production capacity. Hydroelectricity, which had been the dominant source of electricity production in Sri Lanka till the mid 1990s, underwent a 3.6-fold increase in its generation capacity between 1983 and 1995 and oil-based electricity generation capacity experienced a 17-fold increase between 1996 and 2007 (World Bank Group, 2010). Coal-based electricity generation in Sri Lanka is scheduled to commence later this year with a 300 MW coal power plant already installed in Norochcholai, Puttalam. Ceylon Electricity Board (CEB) has planned to increase the total coal-fired power plant capacity to 3,155 MW, which is 88.25% of the estimated additional electricity generation capacity to be installed in Sri Lanka during 2009 to 2022 (CEB, 2008).

Heavy dependence on imported energy sources, such as coal, has the potential to plunge Sri Lanka into acute energy insecurity related issues. Besides, fossil fuel based power, most importantly coal power, comes with great global warming potential. Capital for such mega electricity generation projects must be secured through loans from foreign sources, the repayment of which could heavily burden the future generation. All these factors could lead Sri Lanka into an unsustainable economic development path if the ongoing heavy investment in the unsustainable electricity production technologies does not bring about the anticipated economic growth.

It is therefore essential to carry out scientific research to determine if at all there exists a causal relationship between electricity consumption[1] and economic growth in Sri Lanka. If it does, then it is crucial to determine if electricity consumption causes economic growth or economic growth causes electricity consumption, or if there exists a two-way causal relationship. Because if electricity consumption does not cause economic growth then sustainable electricity consumption policies and less electricity intensive economic development policies could be brought into effect without hampering Sri Lanka's economic development. Consequently, all the projected addition of 3575 MW power generation capacity (CEB, 2008) may not be required, and Sri Lanka could reconsider the unsustainable electricity production path that she is set to traverse.

Ferguson et al., (2000) has shown that the annual electricity consumption growth and annual economic growth for Sri Lanka during the period 1971 to 1995 were tied up by a very high Pearson correlation coefficient of 0.993. The causality relationship between electricity consumption and GDP in Sri Lanka was researched by Morimoto

[1] All electricity produced in Sri Lanka are for local consumption since Sri Lanka does not export electricity.

and Hope (2004) using a slightly modified Yang's model of Granger-causality (Yang, 2000). Analysing Sri Lankan data during the period 1960 to 1998, they concluded that one MWh increase in electricity consumption Granger caused an extra GDP output of 88,000 to 137,000 LKR[2]. The Granger-causality test model of Morimoto and Hope was a simple regression model with first-differenced real GDP as dependent variable and current and lagged first-differenced electricity consumption as explanatory variables along with the lagged first-differenced real GDP.

The above methodology could be incorrect and the results could be misleading if the time-series concerned are integrated of order one and are cointegrated (Engel and Granger, 1987). Morimoto and Hope, however, did not test the times series either for unit-roots or for cointegration. Amarawickrama and Hunt (2008), on the other hand, found the electricity consumption per capita time series and GDP per capita time series of Sri Lanka during 1970 to 2003 were not only integrated of order one, but also cointegrated. They used six different econometric techniques to estimate the long-run income elasticity to forecast the peak demand up to 2025. They, however, did not carryout the causal analyses.

Despite the fact it has been known for several decades (Granger and Newbold, 1974) that the ordinary least square (OLS) regression model developed with integrated time series data violates the standard assumptions for asymptotic analyses such as hypothesis tests about the regression parameters, CEB (2008) used the OLS regression methodology to model for sector-wise electricity consumption with GDP, population and past sector-wise electricity consumption as explanatory variables. The consultants to World Bank Group (ECA, RMA and ERM, 2009) also used OLS regression methodology to generate similar models. None of these two studies tested the time series data for the presence of unit-roots, cointegration or causality.

The primary objective of this study is to seek the nature of the causal relation existing between Sri Lanka's annual electricity consumption and her annual real GDP. The secondary objective is to develop a robust statistical model describing the long-run equilibrium relationship and the short-run dynamic equation prevailing between the two variables. The electricity consumption time series and the real GDP time series data used are described and tested for unit-roots in section 2.

[2] LKR stands for Sri Lankan Rupee.

Econometric methodology used is described in section 3. Results are presented in section 4 and section 5 concludes with policy implications.

2 Data characteristics

Figure 1 shows the time series data on Sri Lanka's annual electricity consumption (in GWh) and her annual real GDP (in constant billion 2002 LKR) for the period 1971 to 2007, obtained from World Development Indicators (World Bank Group, 2010). The drop in the electricity consumption in 1996 was caused by severe draughts (CEB, 1999). This drop could be statistically modelled by employing a suitable dummy, which in turn would add one more parameter to be estimated. This concern was overcome by replacing the real electricity consumption in 1996 with the arithmetic mean of the respective consumptions in 1995 and 1997.

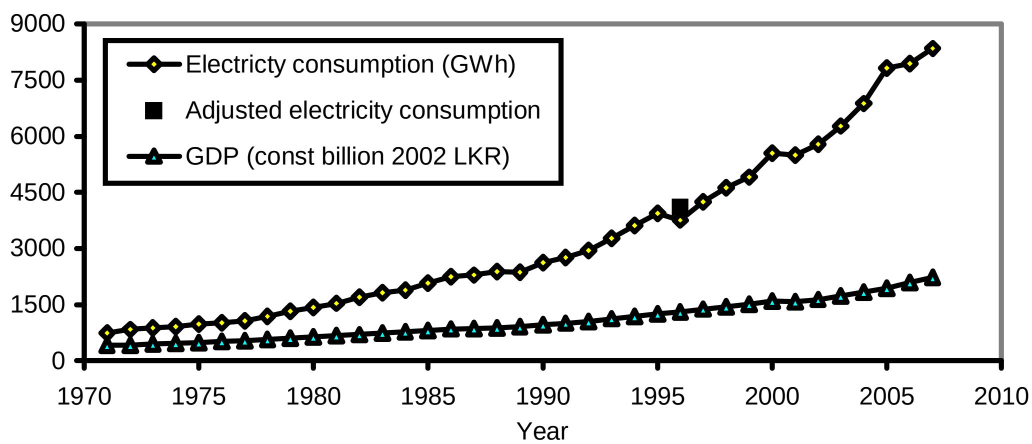

Figure 1 Sri Lanka's annual electricity consumption and her annual real GDP.

Since I am interested in modelling the temporal growths of the variables concerned, I used natural logarithms of the variables for model development. Natural logarithms of electricity consumption and real GDP are denoted by $E(t)$ and $G(t)$, respectively, where t represents the time in years. Time series data on E and G were tested for unit-roots using the augmented Dickey-Fuller test (ADF), GLS-detrended Dickey-Fuller test (DF-GLS) and Phillips-Perron test (PP) of Dickey and Fuller (1979), Elliott, Rothenberg, and Stock (1996) and Phillips and Perron (1988), respectively. These tests have the null hypothesis of a unit root. The test statistics obtained at levels and at first differences of E and G, using the statistical package EViews6 from

Quantitative Micro Software LLC, are listed in Table 1. All test statistics confirm that *E* and *G* are non-stationary at level and stationary at first difference. That is, *E* and *G* are integrated of order 1, which means they are *I*(1) series.

Table 1 Unit-root test statistics for *E* and *G* (which are the respective natural logarithms of electricity consumption and real GDP) and their first differences.

Unit-root tests	*E*	Δ*E*	*G*	Δ*G*
Intercept only				
ADF test	-0.57 [0]^{ns}	-6.28 [0]***	0.78 [0]^{ns}	-6.21 [0]***
DF-GLS test	0.08 [5]^{ns}	-4.70 [0]***	0.65 [2]^{ns}	-3.45 [0]***
PP test	-0.87 {12}^{ns}	-6.99 {11}***	0.76 {2}^{ns}	-6.16 {4}***
Intercept and trend				
ADF test	-2.94 [0]^{ns}	-6.17 [0]***	-3.02 [3]^{ns}	-6.10 [0]***
DF-GLS test	-2.91 [0]^{ns}	-5.64 [0]***	-2.49 [1]^{ns}	-4.79 [0]***
PP test	-3.01 {6}^{ns}	-6.82 {11}***	-2.54 {4}^{ns}	-6.05 {4}***

Note: Symbols Δ, *** and ^{ns} denote first difference, significance at 1% level and no significance even at 5% level, respectively. Given in square bracets are the respective lag lengths of the ADF and DF-GLS test statistics, selected automatically based on Hannan-Quinn Criterion with the user specified maximum lag of 9. Given in curly brackets are the respective Newey-West bandwidth of the PP test statistics automatically selected using Parzen kernel.

3 Econometric methodology

Since *E* and *G* are *I*(1) series, they need to be tested for the probable existence of cointegration between them (Engel and Granger, 1987). The econometric methodology used in this study for that effect is the autoregressive distributed lag (ARDL) bounds testing approach to cointegration (Pesaran and Shin, 1999; Pesaran et al., 2001). In this approach, testing of cointegration between a dependent variable *Y* and an explanatory variable *X* begins with the following unrestricted equilibrium correction model (ECM):

$$\Delta Y(t) = \alpha_0 + \beta_y Y(t-1) + \beta_x X_j(t-1) + \sum_{i=1}^{p} a_i \Delta Y(t\text{-}i) + b_0 \Delta X(t) + \sum_{i=1}^{p} b_i \Delta X(t\text{-}i) + \varepsilon(t) \qquad (1)$$

where Δ denotes the first difference, α_0 is the unrestricted intercept, β_y is the coefficient of the lagged level dependent variable *Y* and β_x is the coefficients of the lagged level explanatory variable *X*, *t* is time in year, a_i are the coefficients of lagged Δ*Y*, b_0 is the coefficient of current Δ*X*, b_i are the coefficients of lagged Δ*X*, *p* denotes the optimum lag length used, and $\varepsilon(t)$ are the serially uncorrelated residuals.

First step in the ARDL bounds testing approach is to determine the optimal value for the lag length *p* so as to maintain the balance between mitigating the residual serial correlation problem in Eq. (1) and refraining from over-parameterizing Eq. (1).

This is done by estimating Eq. (1) using the OLS procedure for different values of lag length *p*. For each regression, Akaike's Information Criterion (AIC) is determined. The lag length corresponding to the regression with extreme value for AIC is chosen as the maximum lag length. The above choice is further fortified by the determination of the Breusch-Godfrey Lagrange multiplier test statistics for testing the null hypothesis of no residual serial correlation.

Having chosen the appropriate lag length *p*, the probable existence of a cointegrating relationship is tested by calculating the *F*-statistic under the null hypothesis $\beta_y = \beta_x = 0$ (that is, no cointegration) against the alternative hypothesis that they are not. The *F*-statistic is then compared with the asymptotic critical value bounds provided in Pesaran et al.(2001) and Narayan (2005) that are reproduced in Table 2. Since the sample size of this study is in the order of 35, the critical value bounds of Narayan (2005), calculated on the basis of small sample sizes in the range of 30 to 80, are more suitable than those of Pesaran et al. (2001), calculated on the basis of large sample sizes.

Table 2 Asymptotic critical value bounds for *F*-statistic and *t*-ratio with a single at (i) 5% level of significance and (ii) 1% level of significance.

Test statistic	Asymptotic critical value bounds			
	(i) at 5% level of significance		(ii) at 1% level of significance	
	Lower bound value	Upper bound value	Lower bound value	Upper bound value
$F_{III}^{\ddagger}$	5.290	6.175	7.870	8.960
F_{III}	4.94	5.73	6.84	7.84
t_{III}	-2.86	-3.22	-3.43	-3.82

Note: F_{III} is the *F*-statistic for testing $\beta_y = \beta_x = 0$ in Eq. (1) and t_{III} is the *t*-ratio for testing $\beta_y = 0$ in Eq. (1). Critical values for $F_{III}^{\ddagger}$ are obtained from the table (case III: unrestricted intercept and no trend) on page 1988 of Narayan (2005). Critical values for F_{III} and t_{III}, are obtained from Tables CI(iii), and CII(iii) of Pesaran et al. (2001), respectively.

If the *F*-statistic falls on the right-hand side of the upper bound critical value then the null of no cointegration is rejected and cointegration among the variables is firmly established. Consequently, a long-run equilibrium relationship among the dependent variable *Y* and the explanatory variable *X* shall be established. If the *F*-statistic falls on the left-hand side of the lower bound critical value then the null cannot be rejected and no cointegration among the variables is firmly established. Finally, if the *F*-

statistic falls between the lower and upper bound critical values, no conclusive decision could be reached.

The above test is complemented by the calculation of *t*-ratio under the null hypothesis of $\beta_y = 0$ in Eq. (1) against the alternative hypothesis that it is not. The *t*-ratio is then compared with the asymptotic critical value bounds tabulated in Table 2. If the *t*-ratio falls on the right-hand side of the upper bound critical value then the null of $\beta_y = 0$ is rejected. If it falls on the left-hand side of the lower bound critical value then the null cannot be rejected. If it falls within the bounds then no conclusive decision could be reached.

Once the non-rejection of cointegration among the variables concerned are established, the long-run equilibrium relationship is estimated using the ARDL approach detailed in Pesaran and Shin (1999). First, the numerical values of the lag orders *m* and *n* of the *ARDL*(*m,n*) model, expressed by Eq. (2), are estimated using the OLS procedure for different combinations of *m* and *n*.

$$ARDL(m,n): \quad Y(t) = \mu_0 + \sum_{i=1}^{m} \gamma_i Y(t\text{-}i) + \sum_{j=0}^{n} \theta_j X(t\text{-}j) + ECT(t) \qquad (2)$$

where μ_0 is the constant term, γ_i are the coefficients of the lagged level dependent variable *Y*, θ_j are the coefficients of the current and lagged level explanatory variables *X*, *m* and *n* denote the maximum lag lengths of *Y* and *X*, respectively, and *ECT(t)* are the serially uncorrelated residuals known as the equilibrium correction term in the cointegration testing methodology.

The lag lengths corresponding to the regression with minimum value for AIC and/or Schwarz Criterion (SC) give the *ARDL*(*m,n*) model representing the long-run equilibrium relationship. The coefficients of the long-run equilibrium relationship are estimated using the OLS procedure, and the corresponding standard errors and *t*-statistics are estimated using the Delta method as suggested in Pesaran and Shin (1999).

In case of cointegrated *I*(1) series, the Granger causality is tested using the following pair of equations (Ghosh, 2002; Narayan and Singh, 2007):

$$\Delta E(t) = \eta_E + \sum_{i=1}^{m} \lambda_i \Delta E(t\text{-}i) + \sum_{j=1}^{n} \tau_j \Delta G(t\text{-}j) + \pi_E ECT(t-1) + \nu_E(t) \qquad (3)$$

$$\Delta G(t) = \eta_G + \sum_{i=1}^{q} \phi_i \Delta G(t\text{-}i) + \sum_{j=1}^{r} \varphi_j \Delta E(t\text{-}j) + \pi_G ECT(t-1) + \nu_G(t) \qquad (4)$$

where η_E and η_G are intercepts, λ_i, τ_j, ϕ_i and φ_j are the coefficients of the lagged first-differenced variables, π_E and π_G are the coefficients of the lagged *ECT* of Eq. (2), *m*, *n*, *q* and *r* are the optimum lag lengths to be selected on the basis of AIC and/or SC, and ν_E and ν_G are the zero mean, serially uncorrelated, random disturbances.

The short-run causality test is conducted by generating χ^2 statistic using the *F*-test of the lagged explanatory variable to establish the rejection or non-rejection of the following null and alternative hypotheses, denoted by H_0 and H_A, respectively. For Eq. (3), ΔG Granger causes ΔE in the short-run if H_0: $\tau_1 = \tau_2 = \mathrm{L} = \tau_n = 0$ is rejected against H_A: = at least one $\tau_j (j = 1,2,...,n) \neq 0$. For Eq. (4), ΔE Granger causes ΔG, if H_0: $\varphi_1 = \varphi_2 = \mathrm{L} = \varphi_r = 0$ is rejected against H_A: = at least one $\varphi_j (j = 1,2,...,r) \neq 0$. The long-run causality tests for Eqs. (3) and (4) are conducted by assessing the significance of the *t*-statistics on the coefficients of the lagged *ECT*, which are π_E and π_G, respectively.

In case of cointegrated *I*(1) series, the Granger causality could also be tested with the *I*(1) data because of the super-consistency properties of the estimation (Ghosh, 2002), in which case the following equations are used:

$$E(t) = \eta_E + \sum_{i=1}^{m} \lambda_i E(t\text{-}i) + \sum_{j=1}^{n} \tau_j G(t\text{-}j) + \nu_E(t) \quad (5)$$

$$G(t) = \eta_G + \sum_{i=1}^{q} \phi_i G(t\text{-}i) + \sum_{j=1}^{r} \varphi_j E(t\text{-}j) + \nu_G(t) \quad (6)$$

For Eq. (5), G Granger causes E in the short-run if H_0: $\tau_1 = \tau_2 = \mathrm{L} = \tau_n = 0$ is rejected against H_A: = at least one $\tau_j (j = 1,2,...,n) \neq 0$. For Eq. (6), E Granger causes G, if H_0: $\varphi_1 = \varphi_2 = \mathrm{L} = \varphi_r = 0$ is rejected against H_A: = at least one $\varphi_j (j = 1,2,...,r) \neq 0$.

Lastly, using the *ECT* of Eq. (2), the short-run dynamics prevailing between *E* and *G* is established by setting up a conditional ECM corresponding to the *ARDL*(*m,n*) model representing the long-run equilibrium relationship. In the conditional ECM, the first difference of *Y* is regressed on a one period lag of *ECT*, lagged first differences of *Y* and current and lagged first differences of *X* using OLS regression (Pesaran et al., 2001).

4 Results and discussion

4.1 Cointegration

Eq. (1) was estimated using the OLS regression for different values of lag length *p*. Since a limited number of annual data were used for the analyses, maximum value of *p* was limited to 2. For each regression, AIC statistics, P-values of Breusch-Godfrey Lagrange multiplier test statistics at prescribed lag orders 1 and 4, *F*-statistic, and *t*-ratio were estimated. All statistics, except the AIC statistics, for the cases of *p* = 0 to 2 were evaluated using the data sets spanning the periods 1972-2007, 1973-2007, and 1974-2007, respectively. In estimating the AIC statistics for all values of *p*, the data set spanning the period 1974-2007 was used, which was a necessity to aid comparison among the AIC values estimated.

The results, tabulated in Table 3, show that the AIC statistic is at its minimum at *p* = 0. The corresponding P-values of the Breusch-Godfrey Lagrange multiplier test statistics are large enough to not reject the null hypothesis of no residual serial correlation even at 10% level of significance. The corresponding *F*-statistic listed in Table 3 falls on the right-hand side of the respective upper bound critical value (listed in Table 2) resulting in the rejection of the null of no cointegration even at 1% level of significance. The *t*-ratio given in Table 3 reveals that the null of $\beta_y = 0$ in Eq. (1) is also rejected at 1% level of significance. It is therefore the existence of cointegration among the variables *E* and *G* for Sri Lanka is strongly established.

Table 3 Statistics for testing the existence of a cointegrating relationship between *E* and *G* in Eq. (1) with *E* as the dependent variable and *G* as the explanatory variable.

Maximum lag length	$p = 0$	$p = 1$	$p = 2$
AIC	-4.407	-4.404	-4.300
Probability $\chi^2_{SC}(1)$	0.058	0.634	0.381
Probability $\chi^2_{SC}(4)$	0.189	0.571	0.298
F_{III}	10.21	7.66	5.09
t_{III}	-4.42	-3.91	-3.17

Note: Probability $\chi^2_{SC}(1)$ and Probability $\chi^2_{SC}(4)$ denote the P-values of the Breusch-Godfrey Lagrange multiplier test statistics for the null of no residual serial correlation at pre-specified lag orders 1 and 4, respectively.

4.2 Long-run equilibrium relationship

Since cointegration between *E* and *G* was firmly established, as the next step, the long-run equilibrium relationship between *E* and *G* was estimated. First the AIC and SC statistics were estimated for different combinations of the lag orders *m* and *n* in the *ARDL*(*m,n*) model, given by Eq. (2). Limiting the maximum lag length to 5, I carried out 36 (= $[5+1]^2$) regressions. Of which, the minimum AIC and SC values were found to correspond to the *ARDL*(*1,0*) model. The coefficients of the levels relationship given by the *ARDL*(*1,0*) model was estimated using the OLS procedure, and the corresponding standard errors and *t*-statistics were estimated using the Delta method. The resulting long-run equilibrium relationship between *E* and *G* is expressed as follows:

ARDL(*1,0*): $$E(t) = -\underset{[-19.6]}{2.0642} + \underset{[98.5]}{1.4522}\,G(t) + ECT(t) \quad (7)$$

where the numerical values given within the brackets are the *t*-statistics of the corresponding coefficients, the high values of which suggest the coefficients are highly significant, and *ECT(t)* are the serially uncorrelated residuals. Moreover, the long-run income elasticity is estimated to be 1.45.

4.3 Granger causality

The existence of a long-run relationship between *E* and *G* paved the way for the Granger causality tests to be carried out with Eqs. (3) and (4). The optimum lag length selected using both the AIC and SC is unity in both cases. The test statistics are given in Table 4. The short-run Granger causality test results are such that the null hypotheses are not rejected in both cases at 5% level of significance, or even at 10% level of significance. It is therefore evident that neither *E* Granger causes *G* nor *G* Granger causes *E* in the short-run. The highly significant, negative coefficient of *ECT* of Eq. (3), given as -0.7374 in Table 4, and the insignificant near zero coefficient of *ECT* of Eq. (4), given as -0.0195 in Table 4, reveal that any disequilibrium in the long-run relationship cause changes in electricity consumption, and do not cause any change in GDP.

Table 4 Results of short and long run Granger causality tests.

Equation considered	Short-run Granger causality test	Long-run Granger causality test	
	χ^2 statistic of the *F*-test	coefficient of the *ECT*	*t*-statistic of the coefficient of *ECT*
Eq. (3): GDP-led electricity consumption with *m* = *n* = 1	0.5489 [0.4332]	-0.7374	-3.0028 [0.0053]
Eq. (4): Electricity consumption-led GDP *q* = *r* = 1	0.0123 [0.9062]	-0.0195	-0.1392 [0.8902]

Note: Given within the square brackets are the probability values.

Owing to the crucial nature of the results of causality to energy policy implications in Sri Lanka, the Granger causality is also tested with Eqs. (5) and (6), and the results are given in Table 5. The null hypotheses is rejected in case of Eq. (5) resulting in GDP Granger causing electricity consumption. The null hypotheses is not rejected in case of Eq. (6) consolidating the results stated in the preceding paragraph that electricity consumption, or for that matter electricity production in Sri Lanka do not Granger cause GDP.

Table 5 Results Granger causality tests with *I*(1) data .

Equation considered	χ^2 statistic of the *F*-test
Eq. (5): GDP-led electricity consumption with *m* = *n* = 1	12.492 [0.0007]
Eq. (6): Electricity consumption-led GDP *q* = 1 and *r* = 2	0.0401 [0.9558]

Note: Given within the square brackets are the probability values.

4.4 Short-run dynamic equation

The short-run dynamic equation estimated from the conditional ECM corresponding to *ARDL*(*1,0*), using the OLS procedure, is given in Table 6 along with the estimated essential statistics. Tabulated P-values show that the respective coefficients are statistically significant at 1% level. The null hypotheses of no residual serial correlation, no heteroskedasticity among the residuals, and normally distributed residuals were tested using the Breusch-Godfrey Lagrange multiplier test, Jarque-Bera normality test, and ARCH heteroskedasticity test, respectively. P-values corresponding to the chi-squared statistics of the residual tests, tabulated in Table 5, show that all of the test statistics were insignificant at 5% level of significance. I therefore concluded that the parameter estimates of the short-run dynamic equation are statistically significant. P-values corresponding to the Ramsey regression specification error test (RESET) ruled out any model misspecification. The stability was further verified using the cumulative sum of recursive residuals (CUSUM) test. Figure 2 reveals that CUSUM confines itself within the 5% critical lines. It is therefore I concluded that the estimated coefficients have remained nearly constants from one sample period to the other providing further verification for the stability of the short-run dynamic equation considered.

Table 6 Equilibrium correction form of the *ARDL(1,0)* model of Eq. (3).

Explanatory variable	Coefficient	Standard Error	t-Statistic	P-value
$ECT(t-1)$	-0.72405	0.129314	-5.59918	0
$\Delta G(t)$	0.858455	0.123333	6.960471	0
adjusted R^2 = 44.9%; Durbin-Watson statistic = 1.40				
$\chi^2_{SC}(4)$ = 1.25 [0.27]; $\chi^2_N(2)$ = 1.12 [0.57]; $\chi^2_H(1)$ = 0.04 [0.85]; $\chi^2_{FF}(1)$ = 1.37 [0.23]				

Note: The equilibrium correction term $\hat{v}(t-1)$ is the residual of Eq. (3). $\chi^2_{SC}(4)$, $\chi^2_N(2)$, $\chi^2_H(1)$ and $\chi^2_{FF}(1)$ denote chi-squared statistics of Breusch-Godfrey serial correlation LM test, Jarque-Bera normality test, ARCH heteroskedasticity test, and RESET, respectively. The corresponding P-values are given within the brackets.

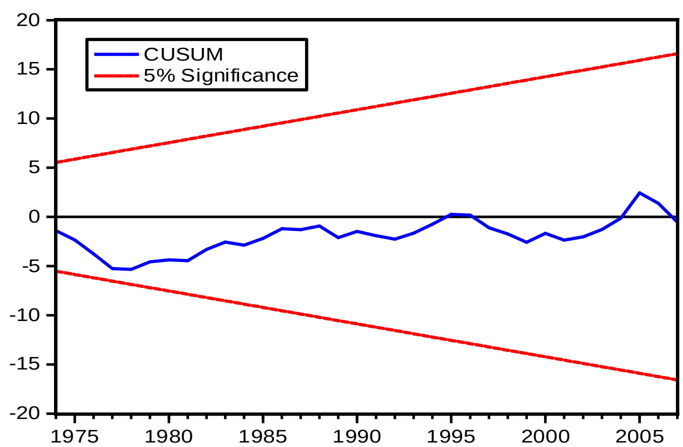

Figure 2 Cumulative sum of recursive residuals (CUSUM) of the conditional ECM.

4.5 Electricity demand forecast – business as usual scenario

The forecast equation is derived by substituting the *ECT* of Eq. (7) in the corresponding short-run dynamic equation given in Table 6 as follows:

$$\Delta E(t) = -0.7241[E(t\text{-}1)\text{-}1.4522G(t-1) + 2.0642] + 0.8585\Delta G(t) \qquad (8)$$

Figure 3 shows the electricity consumption obtained by dynamically simulating Eq. (8) along with the actual electricity consumption values used for developing the model. Dynamical simulation of Eq. (8) is carried out with the actual values of GDP per capita from 1971 to 2007 and with electricity consumption at 1971 as the initial value. The match between the model predictions and the actual emissions seen in Figure 3 is commendable. Eq. (8) could therefore be used for reliably forecasting Sri Lanka's future electricity consumption under the business-as-usual scenario.

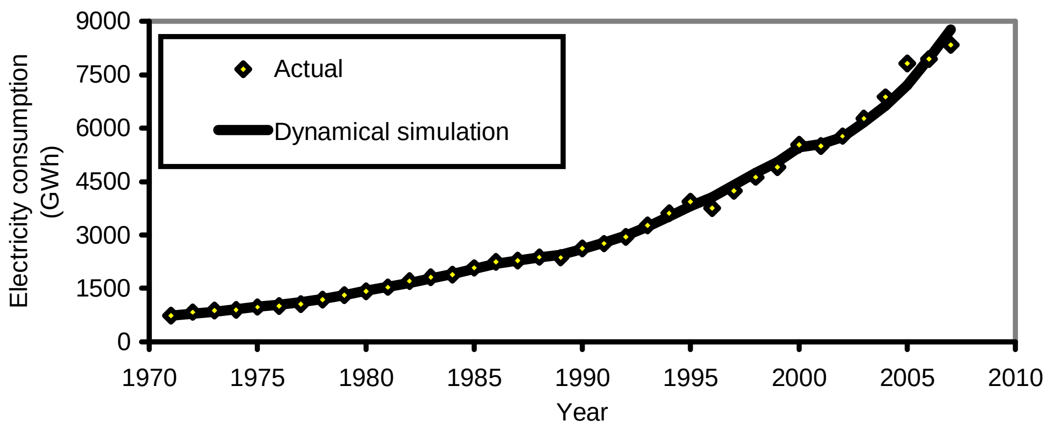

Figure 3 Dynamically simulated CO_2 emissions per capita using the forecast equation, Eq. (5), compared with the actual values used for model development.

In forecasting electricity consumption after 2007, which is the end year of the data set used, I used the actual value of GDP for 2008 (which is 2365.5 const billion 2002 LKR) and the GDP projected by the Central Bank of Sri Lanka for 2009 to 2012, with annual growth rates of 2.5%, 5.0%, 6.0% and 6.5%, respectively. Beyond 2012, in line with the study carried by the consultants to the World Bank Group (ECA, RMA, ERM, 2009), annual GDP growth rates of 6% from 2013 to 2017, 5% from 2018 to 2022 and 4.5% since 2022 are used.

Forecasts of electricity consumption for the business-as-usual scenario discussed above are 16422, 24242, 33972 and 46769 GWh for 2015, 2020, 2025 and 2030, respectively. These are 97%. 190%, 307% and 461% increase over the Sri Lankan total electricity consumption in 2007, respectively. It should be borne in mind that such high forecasted increases in electricity consumption is essential only if the economic development and electricity consumption paths pursued by Sri Lanka since 1971 undergo no appreciable policy changes in the future.

5 Conclusion

Sri Lanka has planned to increase the total coal-fired power plant capacity to 3,155 MW by 2022, which is 88.25% of the estimated additional electricity generation capacity to be installed during 2009 to 2022. In the statistical estimates of the future electricity consumption, it is routine to use GDP as the explanatory variable, with the implicit assumption that there exists a causal relationship between Sri Lanka's electricity generation in Sri Lanka and her GDP.

The empirical results obtained in this study, using annual data covering the period 1971 to 2007, have firmly established uni-directional Granger causality running from GDP to electricity consumption in Sri Lanka. Such findings indeed justify the estimation of future electricity consumption using GDP as an explanatory variable. Nevertheless, unidirectional causality running from GDP to electricity consumption also discloses the crucial fact that economic growth in Sri Lanka, proxied by GDP, is independent of her electricity consumption, and hence electricity generation. Therefore, Sri Lanka is in an advantage position to take on a less electricity intensive economical development path by adopting electricity conservation policies, promoting green buildings, and investing on less electricity intensive production technologies and lifestyles.

In devoid of such initiatives, with the continuation of the business-as-usual policies, the results of this study show that 1% increase in Sri Lanka's GDP causes 1.45% increase in her electricity consumption in the long-run. The long-run equilibrium relationship between electricity consumption and GDP is so strong that 72% of any deviation from the long-run equilibrium is corrected within a year. Forecasts of electricity consumption made for Sri Lanka with the model developed in this study for the business-as-usual scenario lead to 97%. 190%, 307% and 461% increase over the Sri Lankan total electricity consumption in 2007 for 2015, 2020, 2025 and 2030, respectively. It is therefore indispensable that the Sri Lankan government takes proactive actions to weaken the strong cointegrating relationship existing between electricity consumption and economic growth, particularly because the economic growth in Sri Lanka is not electricity dependent.

Acknowledgement: Financial support for this work from the University of Peradeniya of Sri Lanka under the grant No. RG/2008/31/E is gratefully acknowledged.

References

Amarawickrama HA, Hunt LC. Electricity demand for Sri Lanka: a time-series analysis. Energy, 2008;33:724-39.

CEB. Long-term Generation Expansion Plan 1999-2013. CEB, Colombo, Sri Lanka, 1999.

CEB. Long-term Generation Expansion Plan 2009 -2022. CEB, Colombo, Sri Lanka, 2008.

Dickey DA, Fuller WA. Distribution of the estimators for autoregressive time series with a unit root. Journal of the American Statistical Association, 1979;74:427-31.

ECA, RMA, ERM. Sri Lanka: Environmental Issues in the Power Sector (Draft Report). Economic Consulting Associates Limited, 41 Lonsdale Road, London NW6 6RA, UK, 2009.

Elliott G, Rothenberg TJ, Stock JH. Efficient tests for an autoregressive unit root. Econometrica, 1996;64:813-36.

Engle RF, Granger CWJ. Co-integration and error correction: representation, estimation and testing. Econometrica, 1987;55:251-76.

Ferguson R, Wilkinson W, Hill R. Electricity use and economic development. Energy Policy, 2000;28:923-34.

Ghosh S. Electricity consumption and economic growth in India. Energy Policy, 2002;30: 125-9.

Granger CWJ, Newbold P. Spurious regressions in econometrics. Journal of Econometrics, 1974;2:111–20.

Morimoto R, Hope C. The impact of electricity supply on economic growth in Sri Lanka. Energy Economics, 2004;26:77-85.

Narayan PK. The saving and investment nexus for China: evidence from cointegration tests. Applied Economics, 2005;37:1979-90.

Narayan PK, Singh B. The electricity consumption and GDP nexus for the Fiji islands. Energy Economics, 2007;29:1141-50.

Pesaran MH, Shin Y. An autoregressive distributed lag modeling approach to cointegration analysis. In: Strom S, editor. Econometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium. Cambridge: Cambridge University Press, 1999.

Pesaran MH, Shin Y, Smith R. Bounds testing approaches to the analysis of level relationships. Journal of Applied Econometrics, 2001;16:289–326.

Phillips PCB, Perron P. 'Testing for a unit root in time series regression. Biometrika, 1988;75:335-46.

World Bank Group. World Development Indicators & Global Development Finance. Obtained through the Internet: http://databank.worldbank.org [accessed May 08, 2010], 2010.

Yang H-Y. A note on the causal relationship between energy and GDP in Taiwan. Energy Economics, 2000;22:309-17.

Author's Vitae

Rajaratnam Shanthini is the Professor of Chemical & Process Engineering at University of Peradeniya, Sri Lanka. She has received her Bachelor's degree in Chemical Engineering from University of Moratuwa, Sri Lanka, her M.Sc. from University of Alberta, Canada, and her PhD from Luleå University of Technology, Sweden. She has authored a text book on Thermodynamics and a popular book on Household Composting. Her concerns for the well-being of the people and other living things led her to carryout research on economic development with environmental protection, carbon dioxide emissions modelling, emissions emancipated human development, and sustainable development. Her other interests include Counselling, Literary Writing, Photography and Hiking.