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Modeling Residential Electricity Consumption Function in Malaysia: Time Series Approach

L. L. Ivy-Yap, H. A. Bekhet

***Abstract*—**As the Malaysian residential electricity consumption continued to increase rapidly, effective energy policies, which address factors affecting residential electricity consumption, is urgently needed. This study attempts to investigate the relationship between residential electricity consumption (EC), real disposable income (Y), price of electricity (Pe) and population (Po) in Malaysia for 1978-2011 period. Unlike previous studies on Malaysia, the current study focuses on the residential sector, a sector that is important for the contemplation of energy policy. The Phillips-Perron (P-P) unit root test is employed to infer the stationarity of each variable while the bound test is executed to determine the existence of co-integration relationship among the variables, modelled in an Autoregressive Distributed Lag (ARDL) framework. The CUSUM and CUSUM of squares tests are applied to ensure the stability of the model. The results suggest the existence of long-run equilibrium relationship and bidirectional Granger causality between EC and the macroeconomic variables. The empirical findings will help policy makers of Malaysia in developing new monitoring standards of energy consumption. As it is the major contributing factor in economic growth and CO_2 emission, there is a need for more proper planning in Malaysia to attain future targets in order to cut emissions.

***Keywords*—**Co-integration, Elasticity, Granger causality, Malaysia, Residential electricity consumption.

I. Introduction

LITERATURE on energy and economic development discussed in length the relationship between the two variables because energy is an essential input for economic development [1]. Since the pioneering work of [2], the relationship between energy consumption and economic growth becomes a key and hot topic and it is studied by many researchers using various methodologies for different time period and geographical locations. In particular, electricity is more frequently studied compared to other forms of energy because energy consumption is switching away from traditional fuels to cleaner and safer energy sources such as electricity [3], [4]. Although numerous studies considered total electricity consumption, electricity consumption by sector is gaining attention due to the different properties of each sector. In particular, the residential sector is more frequently studied compared to other sectors. Among the empirical works on residential sector are those by [5]–[15]. This is because the residential sector is one of the most electricity consuming sector in an economy and its consumption is anticipated to continue to rise [7], [9]. Also, the determinants of residential electricity consumption are more amenable to theorization and quantification [9]. Due to these reasons, the residential sector is important for the contemplation of energy policy in an economy [8]. Despite all the existing studies, residential electricity consumption (RELC) in Malaysia continued to increase rapidly (see Fig. 1).

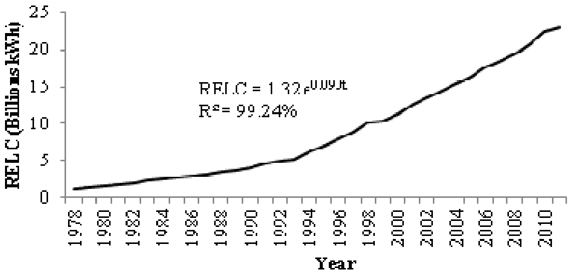

Fig. 1 Residential Electricity Consumption Growth in Malaysia [16]

From Fig. 1, the average growth rate for residential electricity consumption is 9.0% for 1978-2011 period. The growing electricity consumption warrants attention since formulation of wrong policies would adversely affect economic growth [17]. Therefore, one of the most urgent tasks for the authorities is to develop effective, long-term energy policies [18]. In order to do so, firm evidence on the elasticity and Granger causality of residential electricity consumption is inevitable as it is the key to effective energy policies [19]. However, the inconsistent findings in the literature result in insufficient evidences on the elasticity and Granger causality of residential electricity consumption. For example, many economists believed that resource scarcity, signaled by price increase will stimulate technological progress. However, heavy electricity subsidy in developing countries like Malaysia distorts electricity markets and promotes overconsumption [20]. Motivated by the urgency of the problem facing Malaysian residential electricity consumption and the inconsistent findings of the literature, the goal of this study is to reinvestigate the elasticity and Granger causality of residential electricity consumption in Malaysia. To the best of our knowledge, no study is dedicated to residential electricity consumption in Malaysia. Therefore, it is essential for us to attempt this study to provide more evidences on the elasticity and Granger causality of residential electricity consumption especially in the Malaysian scenario.

The rest of this paper is organized as follows. A concise review of the electricity consumption in Malaysia is presented in the next section while Section III discusses the past empirical studies on electricity consumption. The variables definition and data sources; methodologies; and empirical

L. L. Ivy-Yap is with Universiti Tenaga Nasional, Malaysia (e-mail: iv_yap@ yahoo.com).
H. A. Bekhet is with Universiti Tenaga Nasional, Malaysia (e-mail: profhussain@uniten.edu.my; drbekhet1953@hotmail.com).

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results are discussed in Sections IV, V and VI respectively. Finally, Section VII presents the conclusions and limitations.

II. Overview of Electricity Consumption in Malaysia

Energy plays a key role in enabling growth. Although technology advancement allowed less energy to be used per unit output, energy remains important to economic growth [21]. Fig. 2 shows the growth rate of real gross domestic product (RGDP) and electricity consumption (ELC) in Malaysia for 1978-2011 period.

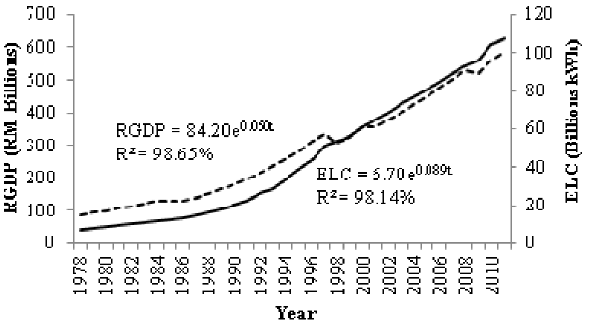

Fig. 2 Real GDP and Electricity Consumption in Malaysia [16], [22]

The real GDP recorded RM85.44 billion in 1978 and continued to increase by 6.0% per year for the 1978-2011 period. Meanwhile, the electricity consumption recorded an average annual growth rate of 8.9% for the 1978-2011 period, reaching 107.40 billion kWh in 2011. One of the main reason for the high growth rate of electricity consumption was due to the development of transport sector such as the railway system, particularly the light rail transit in Klang Valley and inter-city commuter train service which recorded almost 200% increase in electricity consumption, from 58.15 million kWh in 2005 to 164.18 million kWh in 2006 and subsequently to 214.45 million kWh in 2010 [23]. Similarly, the electricity consumption in the residential sector is also increasing significantly within the same period as shown in Fig. 1. From 1978 to 2011, the average annual growth rate for residential electricity consumption (RELC) is 9.0%, slightly higher than the total electricity consumption growth rate (8.9%).

In order to encourage energy efficiency and conservation practices, the government had implemented various policies [24]. For the residential sector, the government announced rebate for household with monthly electricity bills equal or less than RM20 in October 2008 [25]. The mechanism of the rebate is such that if the electricity bills is RM20 or below, they are exempted from paying the bills. However, if the electricity bills are above RM20, they are required to pay the bills in full, not just the additional difference. Through this program, it is envisaged that consumers will use electricity more prudently. On average, about one million households manage to keep their monthly electricity bills below RM20. Besides offering electricity bills exemption, the government also launched the Sustainability Achieved Via Energy Efficiency (SAVE) Rebate Program on 7 July 2011 [26]. Under this program, each household is entitled for a rebate of RM200 and RM100 for the purchase of highly energy efficient refrigerators and air-conditioner respectively. The aim of this program was to instigate households to choose energy efficient appliances over the less efficient ones. The rebate is given for the purchase of refrigerators and air-conditioners because they are the main electricity consuming appliances in a typical Malaysian household [27].

III. Literature Review

There is a vast literature on energy consumption and economic growth because the relationship between them has important policy implications. In each study, an electricity consumption function consisting of various macroeconomic variables was developed. Real disposable income, price of electricity, price of alternative energy, population, weather and urbanization were the most frequently included variables in the electricity consumption function. These macroeconomic variables were studied in terms of elasticity and Granger causality with electricity consumption. Understanding the elasticity and direction of Granger causality is very important for policymakers to formulate appropriate policies for sustainable development. Unfortunately, the literature does not provide consistent results on the elasticity and Granger causality of electricity consumption.

Generally, the findings of the literature are only consistent in terms of the type of relationship that existed i.e. positive or negative relationships but the findings on the elasticity and Granger causality were inconsistent. For example, [8]–[11], [13]–[15], [28]–[35] found that electricity consumption is inelastic to real disposable income but [36], [37] found electricity consumption to be elastic to real disposable income.

Similarly, there is no clear evidence on the direction of Granger causality as some studies found unidirectional Granger causality from electricity consumption to real disposable income [17], [38]–[43], but some others found the opposite, whereby unidirectional Granger causality exist from real disposable income to electricity consumption [44], [45]. There are still some other studies that found bidirectional Granger causality between electricity consumption and real disposable income [46]–[53].

These diverse results on the elasticity and Granger causality of electricity consumption arise due to the different data set, alternative econometric methodologies and different countries' characteristics [54], [55]. For example, bi-variate models are prone to suffer from omitted variable bias problem resulting in the estimates of the elasticity and causal relationship between the two variables of interest to be unreliable.

IV. Variables Definition and Data Sources

There are several factors that affected electricity consumption in the residential sector. In order to keep the consumption function of residential electricity (EC) parsimonious, relevant to the Malaysian context and to avoid unnecessary over-parameterization, only the most important and significant variables are included. Taking note of the different countries' characteristics, not all the macroeconomic variables frequently used in the literature are suitable in explaining residential electricity consumption in Malaysia. For example, Malaysia experiences constant weather all year round, unlike some countries which experience significant seasonal weather differences. Therefore, any variation in electricity consumption could not be due to weather because it stays constant all the time. Similarly, urbanization often implies greater access to electricity since urban household can be more easily connected to the grid compared to rural households due to the difficulty in construction of rural power supply networks. However, Malaysia is fully electrified and almost every household, whether in the urban or rural areas, has access to electricity. The literature also agreed that urbanization is not a significant factor in countries that have pursued policies aimed at electrifying rural areas [12]. The literature also considered cross elasticity of other energies i.e. natural gas, diesel, oil, etc. which were believed to be substitutes to electricity. However, most of the studies found the cross elasticity of these so-called substitutes to be either very inelastic or insignificant, suggesting that electricity is not perfectly substitutable by other form of energies especially in the residential sector [56]. Due to these reasons, this study excludes weather, urbanization and price of other energies from the consumption function of residential electricity. Hence, EC is given as a function of real disposable income (Y); price of electricity (Pe); and population (Po). All the variables are transformed to natural logarithm, a transformation that is very popular in econometric [57]. The residential electricity consumption model is given as in (1).

$$lec_t = \alpha_0 + \alpha_1 ly_t + \alpha_2 lpe_t + \alpha_3 lpo_t + \varepsilon_t \quad (1)$$

The data are collected from various sources i.e. relevant government agencies in Malaysia and international organizations. Proxy variables are used in cases whereby the data are unavailable. Real gross domestic product (GDP) is widely used in the literature as a proxy to real disposable income [4], [28], [54]. Hence, this study also uses real GDP at constant price (2000=100) to represent the real disposable income. The data on price of electricity in Malaysia is unavailable and it is suggested that the price index is used as a proxy [17], [29]. Following this suggestion, the price index for utilities i.e. gross rent, fuel and power is used as a proxy for price of electricity. Specifically, annual data on residential electricity consumption is collected from the Malaysia Energy Commission while annual data on real GDP is collected from the World Bank. Meanwhile, annual data on price index and population are collected from the Department of Statistic Malaysia. All the data are collected for the same period i.e. from 1978 to 2011.

V. Methodologies

Firstly, the diagnostic tests are executed to check the suitability of the selected variables and data to ensure the validity of the regression results and subsequent analyses on the model. Next, the variables are tested for stationarity. The most common tool to test for stationarity is the unit root test. There are a few unit roots tests and the results from each test usually agree with one another. However, the Phillips-Perron (P-P) test is employed in this study because it is robust to serial correlation and heteroskedasticity [58]. Only a constant is included because it is more appropriate with economic practice [59]. If a series at level is not stationary but is stationary at first difference, the series is integrated of order one, denoted by *I(1)*. Similarly, if the series has to be differenced twice before it becomes stationary, the series is integrated of order two or *I(2)*. In general, if a series needs to be differenced *d* times to become stationary, it is integrated of order *d* or *I(d)*. Usually, macroeconomics data will be stationary at first or second difference [29]. The P-P test reveals that all the variables are stationary at level or first difference.

Subsequently, the Auto Regressive Distributed Lag (ARDL) bounds testing approach is executed to examine the presence of long-run equilibrium relationship. This approach is chosen due to its advantages over other conventional methods [60]. Firstly, this method can be used even if the variables in the model are integrated of different order, i.e. *I(0)* and *I(1)*. Secondly, it is more efficient in small samples. Thirdly, the ARDL application allows the variables to have different optimal lags, which is impossible with conventional co-integration procedures and finally, the ARDL model has become increasingly popular in recent years. The model to infer co-integration is as in (2).

$$\begin{aligned}\Delta lec_t = {} & \beta_0 + \beta_1 lec_{t-1} + \beta_2 ly_{t-1} + \beta_3 lpe_{t-1} + \beta_4 lpo_{t-1} + \sum_{i=1}^{j} \delta_{(EC)i} \Delta lec_{t-i} \\ & + \sum_{i=0}^{k} \delta_{(Y)i} \Delta ly_{t-i} + \sum_{i=0}^{l} \delta_{(Pe)i} \Delta lpe_{t-i} + \sum_{i=0}^{m} \delta_{(Po)i} \Delta lpo_{t-i} + \mu_t\end{aligned} \quad (2)$$

where Δ is the first difference operator, β's are the long-run parameters, δ's are the short-run parameters and μ_t is the error term. *j, k, l* and *m* are the optimal lag orders determined by Akaike Information Criterion (AIC). Reference [61] argued that AIC is superior in small sample. Usually, the lag length for annual series is one or two [9]. However, in order to obtain more robust results, the maximum lag length tested in this study is four. The *F*-test on level lagged explanatory variables (lec_{t-1}, ly_{t-1}, lpe_{t-1}, lpo_{t-1}) are performed to ascertain the presence of co-integration relationship. However, the computed *F*-statistic has non-standard distribution. Reference [62] computed the upper and lower bound critical values for large sample size (>500). However, [63] argued that these critical values are inappropriate for a small sample size and computed the critical values for samples ranging from 30 to 80 observations. If the computed *F*-statistic is greater than the upper bound critical value, the null hypothesis is rejected and co-integration relationship exists among the variables. On the other hand, if the computed *F*-statistic is less than the lower bound critical value, the null hypothesis cannot be rejected, implying no co-integration relationship. However, if the computed *F*-statistic falls between the upper and lower bound critical value, inference is inconclusive. If the variables are co-integrated, there is long-run relationship among the variables and they can be modeled in an error correction model given as in (3).

$$\begin{bmatrix} \Delta EC_t \\ \Delta Y_t \\ \Delta Pe_t \\ \Delta Po_t \end{bmatrix} = \begin{bmatrix} \theta_{EC} \\ \theta_Y \\ \theta_{Pe} \\ \theta_{Po} \end{bmatrix} + \sum_{i=0}^{p} \begin{bmatrix} \phi_{11i} & \phi_{12i} & \phi_{13i} & \phi_{14i} \\ \phi_{21i} & \phi_{22i} & \phi_{23i} & \phi_{24i} \\ \phi_{31i} & \phi_{32i} & \phi_{33i} & \phi_{34i} \\ \phi_{41i} & \phi_{42i} & \phi_{43i} & \phi_{44i} \end{bmatrix} \begin{bmatrix} \Delta ec_{t-i} \\ \Delta y_{t-i} \\ \Delta pe_{t-i} \\ \Delta po_{t-i} \end{bmatrix} + \begin{bmatrix} \gamma_{EC} \\ \gamma_Y \\ \gamma_{Pe} \\ \gamma_{Po} \end{bmatrix} \left[ecT_{t-1} \right] + \begin{bmatrix} \mu_{ECt} \\ \mu_{Yt} \\ \mu_{Pet} \\ \mu_{Pot} \end{bmatrix} \quad (3)$$

where ecT_{t-1} is the lagged error correction term derived from the long-run relationship, γ's are the speeds of adjustment, p is the optimal lag orders determined by Akaike Information Criterion (AIC), θ's are the constant terms and ϕ's are the short-run dynamics. The Granger causality among the variables is then examined via the F-test on the first differenced lagged explanatory variables.

VI. Result Analysis

Table I provides a summary of descriptive statistics of the variables under investigation. The skewness, kurtosis and Jarque-Bera statistics show that all the variables are spherically distributed.

TABLE I
SUMMARY OF DESCRIPTIVE STATISTICS FOR EACH VARIABLE

Statistics	lec	ly	lpe	lpo
Mean	1.8452	5.4836	4.4346	3.0030
Median	1.8930	5.5952	4.4531	3.0160
Maximum	3.1316	6.3736	4.7423	3.3657
Minimum	0.2463	4.4478	3.8523	2.5802
Std. Dev.	0.8943	0.6018	0.2372	0.2462
Skewness	-0.1503	-0.1621	-0.7288	-0.1483
Kurtosis	1.7108	1.6514	2.8195	1.7279
Jarque-Bera	2.4827	2.7252	3.0559	2.4170
Probability	0.2890	0.2560	0.2170	0.2987
Sum	62.7363	186.4426	150.7777	102.1023
Sum Sq. Dev.	26.3951	11.9521	1.8566	1.9998
Observations	34	34	34	34

The results on unit root test are presented in Table II. The null hypothesis, H_0 that the series contains unit root is tested against the alternative hypothesis, H_1 that the series is stationary. If the computed statistic is smaller than the critical value, H_0 is rejected. On the other hand, if the computed statistic is larger than the critical value, H_0 cannot be rejected and the series has to be differenced until H_0 is rejected. The unit root test results show that lec and ly are stationary at first difference but lpe and lpo are stationary at level.

TABLE II
UNIT ROOT TESTS ON EACH VARIABLE

Variable	P-P
lec	-2.7611 [0.0749]*
ly	-1.2837 [0.6253]
lpe	-3.3164 [0.0221]**
lpo	-3.0029 [0.0450]**
Δlec	-4.7005 [0.0007]***
Δly	-4.6215 [0.0008]***
Δlpe	NA
Δlpo	NA

Notes: ***, **, * denotes statistical significance at 1%, 5% and 10% respectively.

Since there is a mixture of I(0) and I(1) variables, the ARDL bounds testing is performed to infer the existence of long-run relationship and the results are tabulated in Table III. The calculated F-statistic is larger than the 1% upper bound, indicating existence of strong co-integrating relationship.

TABLE III
ARDL CO-INTEGRATION TEST

Calculated F-statistic for bounds test		
F_{EC}(EC|Y, Pe, Pop)	7.8696***	
Optimal lag	[1,1,3,2]	
Significance level	Lower I(0)	Upper I(1)
1%	5.198	6.845
5%	3.615	4.913
10%	2.958	4.100
Conclusion	Co-integrated	

Notes:
(1) ***, **, * denotes statistical significance at 1%, 5% and 10% respectively.
(2) Critical values obtained from [63] for unrestricted intercept and no trend (k=3, T=35).

In order to ensure that the model is stable, the CUSUM and CUSUM of squares are performed. Figs. 3 and 4 show that both CUSUM and CUSUM of squares fluctuate within the 5% critical bounds. Therefore, the estimated coefficients are stable over the sample period from 1978 to 2011.

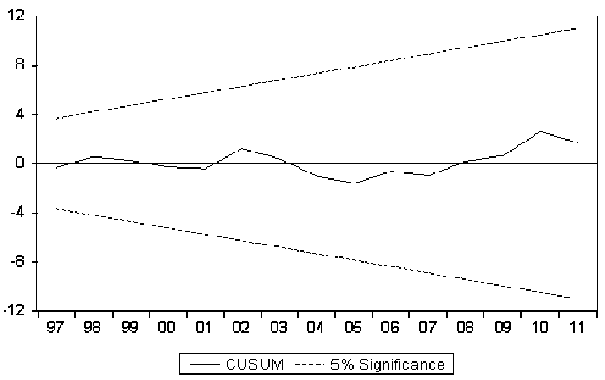

Fig. 3 CUSUM statistics plot

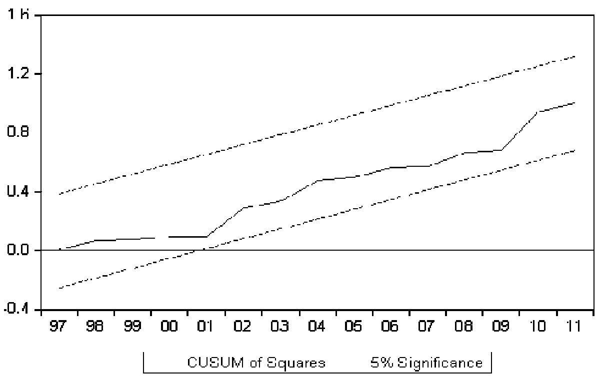

Fig. 4 CUSUM of squares statistics plots

Since all the variables are co-integrated, they can be modeled in an error correction model. An error correction term, *ecT*, is included into the error correction model to tie the short-run behaviors to the long run relationship given in Table IV.

TABLE IV
LONG-RUN RELATIONSHIP

Explanatory variable	Coefficient	Standard Error	*t*-statistic
Constant	-7.1531	1.2904	-5.5434***
ly_t	0.8435	0.3000	2.8122**
lpe_t	-0.1350	0.4092	-0.3298
lpo_t	1.6660	0.6629	2.5131**

Notes: ***, **, * denotes statistical significance at 1%, 5% and 10% respectively.

The significance of the lagged error correction term, ecT_{t-1}, in the error correction model indicates the existence of long-run Granger causality while its coefficient signifies the rate of convergence to the long-run equilibrium. In testing the short-run Granger causality, we apply the *F*-test on the first differenced lagged explanatory variables. If the null hypothesis is rejected, the explanatory variable is said to Granger cause the dependent variable. Table V shows the results on long and short-run Granger causality.

TABLE V
GRANGER CAUSALITY

Dependent variable	*F*-statisitc				ecT_{t-1}
	Δlec_t	Δly_t	Δlpe_t	Δlpo_t	
Δlec_t	-	10.54***	5.03***	3.26**	-6.19***
Δly_t	3.19**	-	0.25	2.57*	-2.74**
Δlpe_t	3.74**	9.20***	-	4.93**	3.27***
Δlpo_t	2.77*	12.97***	1.79	-	2.97**

Notes:
(1) The optimal lag order is determined by the Akaike Information Criterion (AIC).
(2) The selected lag lengths for Δlec_t = [1,1,4,4], Δly_t = [4,2,1,4], Δlpe_t = [4,3,4,2], Δlpo_t = [4,1,4,3].
(3) ***, **, * denotes statistical significance at 1%, 5% and 10% respectively.

The error correction term is significant in all equations, which further confirm the existence of long-run relationship. The results show that there is long and short-run bidirectional Granger causality between residential electricity consumption and all the macroeconomic variables.

VII. CONCLUSIONS AND LIMITATIONS

Unlike previous studies on energy consumption in Malaysia, this is the first study that considers the electricity consumption in the residential sector instead of the total electricity consumption. Examining electricity consumption by sector will enable the special characteristics of the residential sector to be taken into consideration and thus resulting in a more accurate model. The results show that residential electricity consumption has positive long-run relationship with real disposable income and population but negative long-run relationship with price of electricity, in line with economic theories. All the variables are co-integrated and there is bidirectional Granger causality between residential electricity consumption and all the macroeconomic variables both in the long and short-run.

Since energy consumption is a major contributing factor in economic growth and CO_2 emission, policy makers should be careful in formulating future energy policies and targets to ensure that energy is used efficiently without affecting economic growth and the environment. In fact, emission reduction policies and investment in pollution abatement will not hurt economic growth and could be a feasible policy tool for Malaysia to achieve its sustainable development in the long-run [64]. Although the results are consistent with economic theories and the literature, this model can be further improved by including the role of complements i.e. price of electrical appliance as a new variable. This is because electricity cannot be consumed without electrical appliances. Hence, the role of complements is highly justifiable in the consumption of electricity. Further studies should include this important variable in the model to give a better explanation on the residential electricity consumption and to capture the role of this variable.

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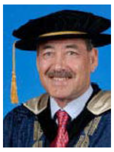
L.L. Ivy-Yap (Ivy Yap Lee Lian) is an Administrative and Diplomatic Officer at the Energy Sector, Ministry of Energy, Green Technology and Water, Malaysia. She is currently pursuing a PhD in Business Management specializing in Energy and Environment studies at Universiti Tenaga Nasional (UNITEN) under the Kursi Biasiswa Ekonomi Tenaga post graduate scholarship program.



H.A. Bekhet (Hussain Ali Bekhet) is a professor in Quantitative analysis in applied economics. He is currently professor at the Graduate Business School (GBS), COGS of Universiti Tenaga Nasional (UNITEN), Malaysia. He earned his PhD in Input-Output Methods from the University of Keele, England, UK, in 1991. He taught at Baghdad University from April 1991 to May 2003, Al-Zyatoonh University, Jordan from September 2003 to December 2007 and joined UNITEN in July 2008 up to date.

He has already published more than 70 papers in peer-reviewed articles and five text books in mathematical economics, econometrics, quantitative analysis for business and modeling & data analysis by SPSS. His teaching and research interests include the Mathematical Economics Models, Econometrics, and Input-Output Analysis. Other research interests include the Cost Benefit Analysis, Development Models, Time Series Analysis, and Energy Economics. His three published research articles are as below:

[1] H.A. Bekhet, "Assessing Structural Changes in the Malaysian Economy: I-O Approach", Economic Modeling, vol. 30, pp. 126-135, 2013.

[2] H.A. Bekhet, "Assessing Development Efficiency in Malaysian Economy: Input-Output Approach", International Journal of Economics & Business Research (IJEBR), vol.4, pp. 297-325, 2012.

[3] H.A. Bekhet and A. Matar, "Co-integration and Causality Analysis between Stock Market Prices and Their Determinates in Jordan", Economic Modeling, vol. 35, pp. 508-514, 2013.

Prof. Hussain is the Editor-in-Chief of Journal of Advanced Social Research (JASR). He is the Member of Input-Output Association, IIOA, Vienna, Austria.