Dynamics of Technological Innovation, Energy Consumption, Energy Price and Economic Growth in Denmark

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This study investigates the dynamic relationships between technological innovation, consumption of energy, energy price, and economic growth in Denmark during the period from 1970 until 2012, using multivariate setting to examine time-series data. The analysis employs the autoregressive distributed lag (ARDL) approach to co-integration to examine both the short and long run dynamics among the variables. Furthermore, the study uses the Granger procedure within the VAR framework to identify causality among the variables. The model used in this study is found to be sound, a diagnosis of the reliability of the model reached by testing normality, functional form, serial correlation, and heteroscedasticity, with stability of the model tested using a cumulative sum and cumulative sum square test, based on recursive regression residuals. The ARDL approach to co-integration reveals that real GDP growth positively influences energy consumption as well as significantly in both the short run and long run, while energy prices and technological innovation influence energy consumption negatively and significantly. The results ascertain that energy consumption and economic growth are independent of each other, and thus they support a neutral hypothesis for Denmark. Besides, both the technological innovation and energy prices are found to be Granger cause energy consumption. Therefore, the study suggests that Denmark should adopt conservative energy policy using technological innovation and energy prices as instruments to achieve energy security and protect the environment from pollution. Environ Prog, 38: 22–29, 2019

Keywords: Technological innovation, energy price, energy consumption, economic growth, Denmark

INTRODUCTION

Energy consumption and economic growth are variables which are usually considered to be highly correlated. Energy is considered a basic input in the production, which in turn contributes to economic growth. A continuous energy supply is required to maintain and improve the current levels of production, and any shortfall in energy will negatively affect economic growth. But high energy consumption is responsible for the emissions of greenhouse gas (GHG), with subsequent effects on global warming as part of climate change. Protection from global warming and climate change requires protective measures to isolate carbon emission from energy consumption by replacing energy extracted from fossil fuels with energy drawn from renewable sources. Since developed countries are most responsible for carbon emissions, they need to comply with Kyoto protocol in energy consumption. A few developed countries including Denmark have taken initiatives to reduce dependency on fossil fuel energy consumption as it is primarily responsible for carbon emission. Some emerging economies such as Hungary, Russia, and South Africa are voluntarily adopting similar strategies to reduce their dependency on fossil fuels. If the causality of economic growth is seen as coming from energy consumption, a reduction in energy consumption may cause an energy crisis with a spillover effect on production and employment. Yet if causality is seen running the opposite way, it may be possible to implement a conservative policy to reduce energy consumption without causing economic harm. It follows that an informed policy requires a determination of how energy consumption relates to economic growth.

Following the pioneering contribution by Kraft and Kraft [1], plentiful studies have been conducted focusing on both the developing and the developed countries to examine the nexus between energy consumption and economic growth. The results from those studies could be broadly categorized in four groups, however on closer inspection, they are mixed. One group of studies [2–6] examined the causal relationship between energy consumption and economic growth. These studies determine that a dependency on energy for economic growth, indicating the sensitivity of economic growth on a crisis in energy supply. They also argue that energy serves as a key ingredient in production and thus affects economic growth, both directly and indirectly. Therefore, the claim by the hypothesis of energy-growth is that a conservative energy policy may be detrimental to energy consumption as well as economic growth. A second grouping of studies [7–14] found an unidirectional causality [15] relationship between economic growth and energy consumption, which supported the conservative hypothesis. This hypothesis is contrasting to the growth hypothesis, which implies that conservative energy policy does not harm economic growth. Subsequently, a third group of studies [16–21] reported indications of a bidirectional Granger causality between energy consumption and economic growth, which supports the hypothesis of feedback. Those who support this hypothesis contend that energy consumption and economic growth are interlinked, which leads to an argument that energy policy should aim at increasing the efficiency of energy use instead of conservation, so that production is not deteriorated. The fourth group of studies [9,22] suggested that energy consumption affects neither income nor economic growth, meaning these studies found no causality from the consumption of energy to the growth of the economy, which they considered as independently functioning variables, a hypothesis which affirms energy neutrality. Those who support this hypothesis assert that since the consumption of energy has minor influence on the growth of the economy, governments are free to enact energy policies which are ecologically-friendly, aiming to reduce environmental pollution. For example, imposition of carbon tax on output and introduction of subsidy on energy consumption are two recommended policies which can motivate the use of environmentally-friendly technology in industrial production to keep pollution at minimal levels. Obviously, the previous hypotheses indicate that an in-depth understanding of the nexus between energy consumption and economic growth is necessary for the careful formation of energy policy.

As reflected above the recent literature provides contradictory empirical results of the nexus between energy consumption and economic growth. One study by Toman and Jemelkova [23] demonstrated a divergent relationship between climate and dynamics of the pattern of energy consumption in the countries under study. Also, Ewing *et al.* [24] indicated that one reason for divergence was the heterogeneous financial structure of those countries being studied. They argue that since the growth of each country's economy is unique, their enslavement on energy-consuming technology may also differ. Also, Ozturk [25] points out methodological flaws, and how conflicting results from omission of variable bias; while Smyth [26] highlights how different data are used depending on what span of time is considered. Smyth [26] argues the major limitation imposed by the use of aggregated data is the difficult of identifying links between particular types of energy consumption and economic growth. He asserts that as each country uses different energy sources for production, different factors influence energy consumption as well as economic growth. Therefore, the nexus between energy consumption and economic growth should be investigated using a multivariate setting instead of a bi-variate setting, with some other influential variables added that may cause economic growth as well as energy consumption. Karanfil [27] argues that those making policy should consider the use of varied sets of data and methodology, unless the results are robust and consistent.

Nonetheless, the above contradictory empirical results encourage us to reinvestigate the nexus between economic growth and energy consumption, given the multivariate setting for Denmark, considering technological innovation as an additional exploratory variable. We believe that due to the mixed nature of the results, that technological innovation influences energy consumption both directly and indirectly, and that enhanced technological innovation reduces energy consumption through developing green and energy saving technologies and energy efficiency. We also believe that technological innovation increases energy supplies and energy security through developing alternative renewable energy sources, and that better technological innovation can make it possible to achieve both sustainable economic growth and environment security at the same time, by reducing dependency on fossil fuel. But, no previous studies have so far investigated whether or not technological innovation causes energy consumption in the case of any countries, whether developed or developing. In this study, we include energy price in the multivariate model because of its effect on both energy consumption and economic growth. Evidence suggests that energy price reinforces energy consumption more or less which ultimately affects the energy production process. Higher energy price may cause energy crisis in industrial production, which is evident from two energy crises during 1970s [28]. Conversely, low energy price may increase energy waste and energy inefficiency. In addition, energy price may become one of the reasons for creating energy scarcity in the industrialization and production process.

In selecting sample/data on an appropriate country, however, the study considers Denmark for some valid reasons. First, Denmark is recognized as one of the world's most energy-efficient countries. As a member of the International Energy Agency (IEA), Denmark is highly concerned about its economic development, energy security, and environment protection[1] as a condition of the agency for which technological innovation is vital. Second, Denmark is considered as a pioneer and leader among the IEA[2] member countries in terms of policy formulation for energy in energy efficiency, climate change, and renewable energy[3]. Third, it is Denmark that articulates Energy Strategy 2050 for the first time to replace fossil fuel (especially oil, coal and gas) with increasing energy efficiency and renewable green energy (especially wind and biomass) completely by 2050[4]. So, it is a big challenge for the country to replace a stable energy system with only wind and biomass energy. In this case, it is important to know how technological innovation can play a role in bringing energy efficiency and innovating new technology supportive in building a carbon free society. To the best of our knowledge, no previous studies have examined the debate on energy consumption and economic growth for Denmark, except a few cross country studies, such as [28,29].

This study is expected to contribute to the energy consumption and economic growth literature in contextually and empirically. It investigates relationship dynamics of technological innovation, energy price, economic growth, and energy consumption of Denmark using annual time series data from 1970 to 2012. The investigation process uses an autoregressive distributed lag (ARDL) approach to assess the long-term relationship dynamics between the key variables, for a valid reason which we will discuss in the section on methodology. Furthermore, the study examines causality among the variables using Granger procedure within the VAR. The study includes the results of some diagnostics checking the model's reliability including tests of functional form, normality, serial correlation, and heteroscedasticity. In addition, the study employs a stability test including cumulative sum and cumulative sum square, based on residuals from recursive regression. The structure of the paper: Section "Methodology" reviews data and methodology, following an analysis of findings in section "Empirical Results And Analysis". Section "Conclusions" offers some concluding remarks as well as reviewing some policy implications.

[1]http://www.iea.org
[2]It is noted that all the IEA countries are also the member of OECD, which stands for Organization for Economic Cooperation and Development.
[3]http://www.iea.org/countries/membercountries/denmark/
[4]http://denmark.dk/en/green-living/strategies-and-policies/independent-from-fossil-fuels-by-2050/

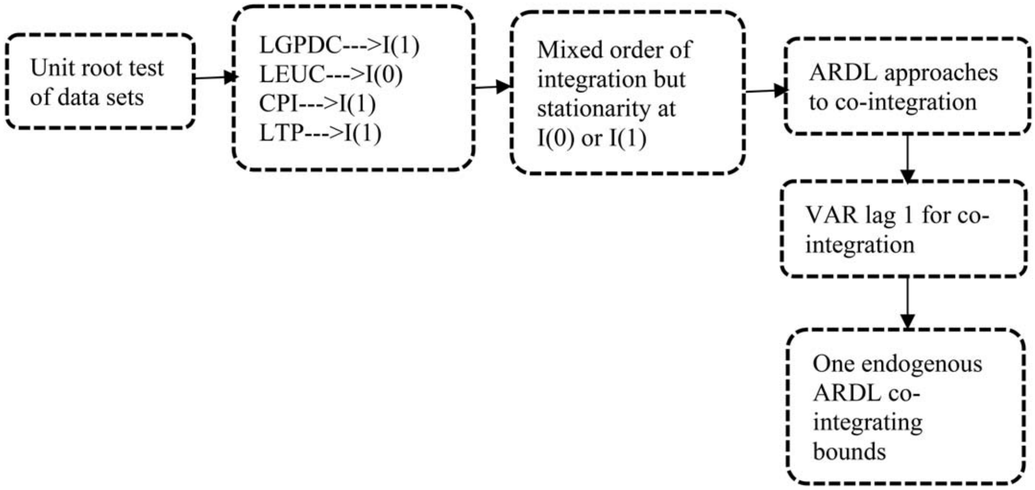

Figure 1. Flow chart of the investigative procedures used in the study.

METHODOLOGY

Data and Variables

The study investigates the relationship dynamics between economic growth, the price of energy, technological innovation, and energy consumption, over the short as well as the long term. For an empirical test, this study considers Denmark, which is recognized as a very high energy efficient country. The study uses data collected annually between 1970 and 2012. Data was taken from the dataset World Development Indicator (WDI) 2013. Variables of interest include energy consumption (kg of oil equivalent per capita) (EUC) as a dependent variable, and gross domestic product per capita (considered constant at the 2005 price) (GDPC) as a proxy for economic growth, total number of energy-efficient patent application (TP), and consumer price index (CPI) as explanatory variables. The CPI is used as a proxy for energy prices, and number of energy-efficient patent application (TP) is considered as an indication of technological innovation. Except for CPI, other data series were converted into natural logarithms. The relationships among the variables for the linear model were considered in functional form as follows:

$$\text{EUC} = f\,(\text{GDPC, TP, CPI}) \tag{1.0}$$

Specification of Econometric Models

This study was done employing the ARDL technique as developed by Pesaran *et al.* [30] for assessment of the long-term relationship dynamics (i.e., relationships with a tendency to change) between the key variables. This methodology has some key characteristics, such as (i) the co-integration relationship, which is estimated using ordinary least squares (OLS), after choosing the respective lag order of the model used; (ii) the approach by Johansen and Juselius, a technique which remains statistically significant regardless whether the variables are I(0) or (I(1) or mutually co-integrated, which typically explains the position that it might not be necessary for a unit root test; (iii) additionally, it should be stated that the ARDL method is necessary and valid for small and finite data set [31]; (iv) this approach provides unbiased estimates over the long-term provided some of the model regressors are endogenous [10,32]; and (v) in addition, this method simultaneously assesses the short term and long term effects of each variable upon another, and generates separate results for short term and long-term effects [33].

While doing estimation, the ARDL bounds testing approach distinguishes variables between being dependent and explanatory. To implement the procedure for bounds testing following Ang and McKibbin [34], and Khan and Qayyum [35], the ARDL version of the vector error correction model (VECM) from Equation (1) can be transformed as follows:

$$\Delta\ln \text{EUC}_t = \beta_0 + \beta_1 \ln \text{EUC}_{t-1} + \beta_2 \ln\text{GDPC}_{t-1} + \beta_3\, TP_{t-1} + \beta_4\, CPI_{t-1} + \sum_{i=1}^{q} \gamma_i \Delta\ln \text{EUC}_{t-i} + \sum_{j=1}^{q} \delta_j \Delta\ln\text{GDPC}_{t-j} + \sum_{l=1}^{q} \varphi_l \Delta\ln\text{TP}_{t-l} + \sum_{m=1}^{q} \eta_m \Delta\ln\text{CPI}_{t-m} + \varepsilon_t \tag{1.1}$$

where the first difference is denoted by Δ, β_0 is the component of drift, the time trend is denoted by t, the maximum lag length is q, while the usual white noise residuals are represented by ε_t.

Estimation Procedure

The investigative procedures used in the study are given in Figure 1. First, we have estimated Equation (1.1) using an OLS approach, after which we conducted a Wald test and an *F*-test to find joint significance for the coefficients of lagged variables for examining the existence of long-term relationship dynamics between the variables. The null hypothesis that a long-term relationship does not exist is denoted by (F_{LEUC}(LEUC|LGDPC, CPI, LTP). Hence, the null hypothesis assumes that the variables have no cointegration, i.e., (H_0): $\gamma_i = \delta_j = \varphi_l = \eta_m = 0$, while the alternative hypothesis (H_1) is: $\gamma_i \neq \delta_j \neq \varphi_l \neq \eta_m \neq 0$. The F statistics is then compared with the critical value (upper and lower bound) given by Pesaran *et al.* [30]. Second, after establishing the co-integration relationship among the variables, the ARDL model's long-term coefficient can be estimated as below:

$$\ln \text{EU}_t = \beta_0 + \sum_{i=1}^{q} \gamma_i \ln \text{EUC}_{t-i} + \sum_{j=1}^{q} \delta_j \ln\text{GDPC}_{t-j} + \sum_{l=1}^{q} \varphi_l \ln\text{TP}_{t-l} + \sum_{m=1}^{q} \eta_m\, CPI_{t-m} + \varepsilon_t \tag{1.2}$$

For this process, we used Schwarz-Bayesian criteria (SBC) criteria to select the appropriate lag length used in the ARDL

Table 1. DF-GLS unit-root test results.

Levels (Z_t)			1st difference (Z_t)			
Variable	SIC Lag	DFGLS stat	Variable	SIC Lag	DFGLS stat	I(d)
LGPDC	0	0.102	ΔLGDPC	0	−4.075*	I(1)
LEUC	0	2.174**	ΔLEUC	1	−4.960*	I(0)
CPI	0	−0.158	ΔCPI	0	−2.232**	I(1)
LTP	0	−1.041	ΔLTP	2	−4.289*	I(1)

*Indicates significant at level of 1%.
**Indicates significant at level 5%.

Table 2. VAR Lag order selection criteria for co-integration results.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−64.99919	NA	0.000370	3.449959	3.618847	3.511024
1	148.2118	373.1193	1.94 e −08	−6.410592	−5.566152*	−6.105269*
2	166.9850	29.09848*	1.74 e −08	−6.549252	−5.029261	−5.999671
3	186.2329	25.98465	1.58 e −08*	−6.711647*	−4.516103	−5.917808

*Indicates lag order selected by the criterion.
AIC, Akaike Information Criterion; FPE, final prediction error; HQ, Hannan-Quinn Information criterion; LR, sequential modified LR test statistic (each test at 5% level); SC, Schwarz information criterion.

model. Finally, as shown below, we estimate the short-term relationship dynamics with the error correction model (ECM) as below (Equation 1.3):

$$\Delta \ln \mathrm{EU}_t = \beta_0 + \sum_{i=1}^{q} \gamma_i \Delta \ln \mathrm{EUC}_{t-i} + \sum_{j=1}^{q} \delta_j \Delta \ln \mathrm{GDPC}_{t-j} + \sum_{l=1}^{q} \varphi_l \Delta \ln \mathrm{TP}_{t-l} + \sum_{m=1}^{q} \eta_m \Delta\, \mathrm{CPI}_{t-m} + \vartheta \mathrm{ECM}_{t-1} + \varepsilon_t \tag{1.3}$$

Diagnostic and Stability Test of the Model

For checking the reliability of the model, several diagnostic tests were conducted, as implied by Pesaran and Pesaran [36]. These diagnostic tests included testing for normality, serial correlation, heteroscedasticity, and functional form. In addition, we also conducted the stability tests used by Brown *et al.* [37], known as the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) tests, which are based on the recursive regression residuals.

EMPIRICAL RESULTS AND ANALYSIS

Unit Root Analysis

For co-integration, analysis starts with determination of which properties of the time series are univariate. For co-integration, the concept requires that the set of variables to be integrated are of the same order with stationary linear combinations. If the data series do not follow the same order of integration, then no meaningful relationship can be shown. Whereas if the series to be integrated are of the same order, one can proceed to the test of co-integration.

Unit root tests for stationarity are performed at the levels and first differences for all variables. Although ADF tests (Table 1) confirm that unit roots exist, and therefore the non-stationarity for the levels of only one variable, the rest of the variables show stationarity at the first differencing level. The Dicky Fuller generalized least square test (DF-GLS) result of is shown in Table 1. In 1996, the Dickey-Fuller test statistic was modified by Elliott, Rothenberg and Stock [38] and they then proposed an efficient test using a generalized least squares (GLS) rationale. They prove that this modified test has the best overall performance in terms of small-sample size and power, conclusively dominating the ordinary Dickey-Fuller test. In particular, they find that their DF-GLS test has significantly improved power when an unknown mean or trend is present. However, the variables on which the DF-GLS test has been conducted include energy consumption per capita (EUC), GDPC, total number of energy-efficient patent application (TP), and CPI.

This paper also notes that there is no need to check the order of integration of the respective variables to conduct an ARDL bound test using the methodology of Pesaran *et al.* [30]. We conducted the unit root test to ensure no variable surpasses the order of integration I(1). This is because an *F*-test would be spurious when variables are stationary at 2nd difference [39]. This technique is followed precisely to show the appropriateness of applying the ARDL approach, as opposed to other standard approaches for co-integration. The unit root test showed a mixed order of integration and all variables were found to be stationarity at I(0) or I(1), which supports our decision to employ the ARDL bounds test instead of the approaches used by Johansen, or Engle and Granger. Figure 1 shows the step-by-step investigative procedures that have been used in the study.

Cointegration Analysis

This study used the ARDL bounds tests approach to test for the existence of co-integration. To determine the appropriate lag length for the series and to compute the F-statistics for co-integration, we considered lag 1, based on the significant minimum lag values of LR, FPE, AIC, SC, and HQ criterion (Table 2).

The F-statistics under the Wald Test measures the joint effect of all regressors, where the output shows there is only one

Table 3. ARDL Bounds test results.

Dep. Var.	SIC Lag	F-stat.	Probability	Outcome
F_{LEUC}(LEUC|LGDPC, CPI, LTP)	1	3.618**	0.015	Co-integration
F_{LGDPC}(LGDPC|LEUC,CPI, LTP)	1	2.702	0.048	Inconclusive
F_{CPI}(CPI|LGDPC, LEUC,LTP)	1	0.977	0.434	No Co-integration
F_{LTP}(LTP|LGPC, LEUC, CPI)	1	1.571	0.206	No Co-integration
Critical Value	I(0)	I(1)	Notation	Method
1% significance level	3.29	4.37	***	Pesaran *et al.* [30]
5% significance level	2.56	3.49	**	
10% significance level	2.20	3.09	*	
1% significance level	3.892	5.173	***	Narayan [10]
5% significance level	2.850	3.905	**	
10% significance level	2.402	3.345	*	

Table 4. Estimated long run coefficients using the ARDL approach.

Regressor	Coefficient	Standard error	T-Ratio[Prob]
LGDPC	0.727*	0.288	2.520[0.016]
CPI	−0.006**	0.002	−3.323[0.002]
LTP	−0.058†	0.032	−1.807[0.079]
C	1.470	2.972	0.494[0.624]

*Indicate significant at 5% level.
**Indicate significant at 1% level.
†Indicates significant at 10% level.
Approach ARDL (1,1,0,0), which is selected based on Schwarz Bayesian Criterion (SBC): LEUC is dependent variable.

Table 5. Error correction representation using the ARDL approach.

Regressor	Coefficient	Standard error	T-Ratio[Prob]
ΔLGDPC	1.117*	0.320	3.487[0.001]
ΔCPI	−0.004**	0.001	−2.662[0.012]
ΔLTP	−0.036†	0.019	−1.893[0.066]
ΔC	0.904	1.826	0.494[0.624]
ECM(–1)	−0.614*	0.148	−4.154[0.000]

*Indicate significant at 1% level.
**Indicate significant at 5% level.
†Indicates significant at 10% level.
Approach ARDL (1,1,0,0), which is selected based on Schwarz Bayesian Criterion (SBC): LEUC is Dependent Variable.

co-integration among the variables. The calculated *F*-statistics (F_{LEUC}(LEUC|LGDPC, CPI, LTP) is 3.618, which is higher than the Pesaran critical value of 3.49. This indicates that the null hypothesis of no co-integration is rejected at a significance level of 5% (Table 3). We further compared the calculated *F*-statistics value with the critical value of Narayan [40], which is considered as better than Pesaran critical value, as it was developed through applying stochastic simulations specific to the sample size based on 40,000 replications. Considering the critical value supported by Narayan [40], there is only one co-integration at 10% level.

Assessment of Long Run and Short Run Scenarios

Table 4 reports the long run elasticity of the respective variables on energy consumption (EUC). Here, we selected the optimal lag length utilizing the SBC, because Pesaran and Shin [41] argue that the SBC-based ARDL model performs better than the AIC-based model. Real GDP per capita shows a positive and statistically significant influence on energy consumption (EUC) over the long-term. This finding is conforming to the one obtained recently by Menegaki [42], who provided evidence that the long run elasticity of GDP growth with respect to energy consumption is not independent of the method employed for cointegration. In fact, the impossibility of determining a general rule governing the directionality between energy and growth cannot question the very fact that growth requires energy and that the efficiency gains induced by technological advances have not alleviated this strong link [43]. However, the price level (CPI) and technological innovation (TP) have statistically significantly negative influence on energy consumption (EUC) in the long run. Assuming all other factors remain constant, a 1% increase in technological innovation will reduce energy consumption by 0.058% in the long run. A recent study [44] does conform to our empirical finding in that investments in renewables technology would slowdown the accumulation of capital outside the energy sector, GDP growth, the rate of energy resource depletion, and environmental degradation.

Just like long-term scenario, Table 5 depicts the short-term elasticity of the respective variables on the energy consumption (EUC). Real GDP per capita is found to have a positive and statistically significant influence on EUC in the short-term. Several previous studies [2–5,45] also found similar findings on the relationship dynamics of economic growth and energy consumption. Also, as like as the long run scenario, both the price level (CPI) and technological innovation (TP) have statistically significantly negative influence on EUC in the short run. Assuming all other factors remain constant, in the short run, a 1% increase in technological innovation will reduce energy consumption by 0.036%. Obviously, both the long run and short run relationship dynamics, as discussed above, are compatible in the case of Denmark.

It is now most important, to ensure the convergence of the dynamics to long-run equilibrium, that the sign of the lagged error correction term (ECM_{t-1}) must be negative and statistically significant. Here, we found negative sign of the coefficient of the lag error correction term (ECM_{t-1}) which indicates the disequilibrium of the long-term equilibrium and short-term. The estimated ECM coefficient is −0.614, which indicates that any deviation from the long-term equilibrium between variables will be corrected by about 61.4% each year, and that after about 1.628 yr, long-term levels will return to equilibrium.

Causality Analysis

Causal links between the series were examined through application of the Granger procedure within the VAR [46]. The existence of co-integration implies that a causal link exists in at least one direction. The results for the Granger causality test in Table 6 show short-term bi-directional link from energy consumption (EUC) to price level (CPI) and from technological innovation (TP) to energy consumption (EUC) at 5% significance level. These indicate that higher energy consumption leads to an increase the price level, and that higher technological innovation leads to less energy consumption in Denmark. As presented above our empirical findings of the causality between energy consumption and price level as well as technological innovation and energy consumption do conform to the ones obtained previously [16–21].

Diagnostic and Structural Stability Tests

The models passed through several diagnostic tests (Table 7). These diagnostic tests confirm that the models show no serial correlation problem, no functional error, no problem with abnormality, and no problem with heteroscedasticity. The value of R^2 is above 61%. Thus, no problem was found with the diagnostic test and the structural stability test, and the moderate value of R^2 indicates that the model has a good fit.

Since the stability of the energy consumption (EUC) function is vital for any economic and environmental policy to be sound, an important part of our empirical analysis is testing whether the estimated models have shifted over time. Figure 2 shows that the plots of the CUSUM and CUSUMSQ statistics are within critical bounds, which indicates that the parameters of the energy consumption (EUC) function are stable during the sample period.

CONCLUSIONS

The study investigates the relationship dynamics of technological innovation, energy price, economic growth, and energy consumption of Denmark. The ARDL approach reveals that real GDP growth influences energy consumption positively and significantly both in the short run and long run while energy prices and technological innovation influence energy consumption negatively and significantly also both in the short run and long run. The result of bound test implies that higher economic growth for Denmark requires continuous energy supply and technological innovation, and hence proper energy pricing may play a significant role in managing energy supply. Conversely, findings of causality test show that energy consumption and economic growth are independent, and validate neutral hypothesis for Denmark. The findings also indicate that Denmark is not an energy dependent country, and it will not face a big challenge to reduce the dependency of fossil fuel and keep reliance on renewable energy sources. Also, Granger causality test reveals that both technological innovation and energy price Granger cause energy consumption. This implies that technological innovation and energy price place significant role in bringing energy efficiency and carbon free society.

Considering the above circumstances, we think Denmark should adopt an eco-friendly conservative energy policy and reduce reliance on fossil fuel energy by 2050. Though 80

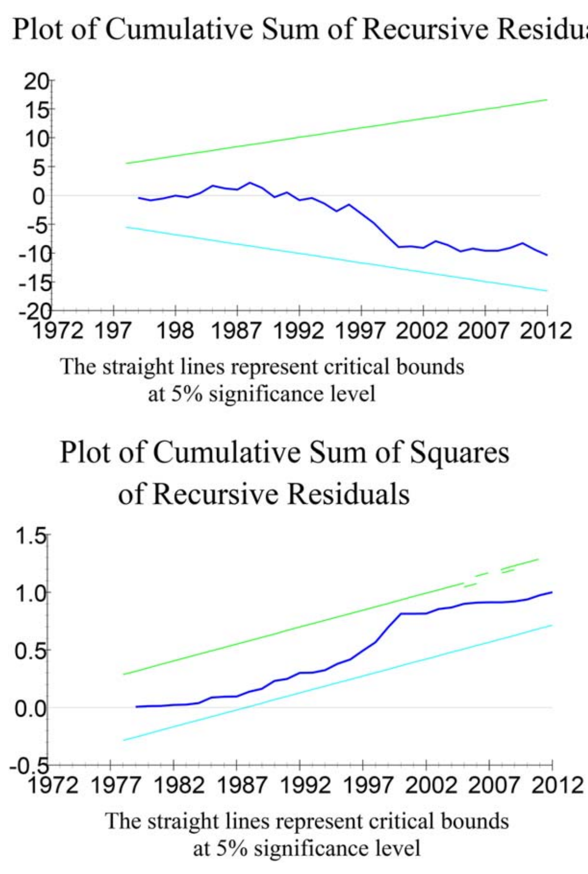

Figure 2. CUSUM and CUSUM Square tests. [Color figure can be viewed at **wileyonlinelibrary.com**]

Table 6. Results of Granger causality tests.

Direction of Causality	χ^2 test	*P*-value
LEUC→LGDPC	1.407	0.495
LEUC→CPI	8.543*	0.014
LEUC→LTP	0.781	0.677
LGDPC→LEUC	2.783	0.249
LGDPC→CPI	3.957	0.138
LGDPC→LTP	1.157	0.561
CPI→ LEUC	1.639	0.441
CPI→LGDPC	0.458	0.795
CPI→LTP	2.531	0.282
LTP→LEUC	7.193*	0.027
LTP→LGDPC	1.606	0.448
LTP→CPI	1.343	0.511

*Indicate significant at 5% level.

Table 7. Results of ARDL-VECM diagnostic tests.

Type of tests	Test-statistic	*P*-value	Type of tests	Test-statistic	*P*-value
R^2	0.61		Adjusted R^2	0.55	
Serial Correlation $\chi^2(1)$	1.811	0.178	Normality $\chi^2(2)$	2.315	0.315
Functional Form $\chi^2(1)$	0.528	0.467	Heteroscedasticity $\chi^2(1)$	0.006	0.936

percent of its current energy comes from fossil fuel, energy consumption of the country does not affect its GDP growth. But from a business point of view, greater energy efficiency is of importance as it has direct economic benefits such as increased competitiveness and higher productivity [47], [48]. Moreover, to reduce energy consumption and costs it is essential to integrate enhanced management concepts and systems considering energy efficiency as a strategic factor alongside with technological measures [49]. In conjunction with this, energy price and technological innovation can be used in formulating a conservative energy policy. Currently, fossil fuel is cheaper than renewable energy in Denmark. Therefore, Denmark can impose a carbon tax to discourage the Danish people from using fossil fuels, and use the revenue generated to subsidize the construction of alternative energy plants based on renewable sources including windmill, solar plant, and biomass plant. Policy settings including putting a price on carbon emissions and redirecting investments to infrastructure, production systems and technologies that allow products and services to be delivered at a much lower environmental cost (lower material and energy intensity), are technically achievable and economically viable options [50]. Thus, renewable energy can become more cost-effective as well as attractive to Danish energy users. Persistent technological innovation within the country can also help to modernize and upgrade their renewable energy plants. This will in turn enable the country to increase the efficiency of energy use, keep sources of renewable energy attractive, and keep carbon emission to minimal levels.

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