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Research article

The impact of electricity consumption on CO_2 emission, carbon footprint, water footprint and ecological footprint: The role of hydropower in an emerging economy

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ABSTRACT

The primary objective of this paper is to investigate the isolated impacts of hydroelectricity consumption on the environment in Malaysia as an emerging economy. We use four different measures of environmental degradation including ecological footprint, carbon footprint, water footprint and CO_2 emission as target variables, while controlling for GDP, GDP square and urbanization for the period 1971 to 2016. A recently introduced unit root test with breaks is utilized to examine the stationarity of the series and the bounds testing approach to cointegration is used to probe the long run relationships between the variables. VECM Granger causality technique is employed to examine the long-run causal dynamics between the variables. Sensitivity analysis is conducted by further including fossil fuels in the equations. The results show evidence of an inverted U-shaped relationship between environmental degradation and real GDP. Hydroelectricity is found to significantly reduce environmental degradation while urbanization is also not particularly harmful on the environment apart from its effect on air pollution. The VECM Granger causality results show evidence of unidirectional causality running from hydroelectricity and fossil fuels consumption to all measures of environmental degradation and real GDP per capita. There is evidence of feedback hypothesis between real GDP to all environmental degradation indices. The inclusion of fossil fuel did not change the behavior of hydroelectricity on the environment but fossil fuels significantly increase water footprint.

1. Introduction

Global warming and climate change pose serious threats to the attainment of Sustainable Development Goals (SDGs) and therefore demand urgent global response (Stern, 2007). The United Nations laid down a 17-point agenda for the attainment of the SDGs by the year 2030, two of which are access to affordable and clean energy, and fight against climate change (United Nations Development Programme, 2015). The Malaysian government has, rightly so, keyed into this agenda as the 11th Malaysia Plan succinctly highlighted the pursuance of green growth for sustainability and resilience as one of the six strategic thrusts for achieving a high-income status by the year 2020. The country is committing to grow in a more sustainable pattern instead of pursuing 'grow first and clean up later' framework (Economic Planning Unit, Malaysia, 2015).

The increasing warming being experienced across the globe is a consequence of the gradual gathering of Greenhouse Gasses (GHGs) in the atmosphere and one of the main culprits is electricity generation as over one-third of human-induced GHGs emissions are due to fossil fuels in generating electricity (World Nuclear Association, 2014). This sets up dangerous consequences as global warming threatens to roll back decades of progress made on development. The general belief is that unless dramatic actions are undertaken to lessen pollution, the universe could encounter an environmental catastrophe (Stern, 2007).

Acknowledging electricity generation from fossil fuel as the chief cause of global warming with severe footprint on the nation's natural resources, the Malaysian government has over the years implemented several policies to diversify the country away from over dependence on fossil fuels in electricity generation. Such policies include the Four-Fuel Policy of 1981 which is also known as the diversification policy designed to prevent over-dependence on oil as the main energy resource. With this policy, hydropower

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became the fourth officially recognized key source of energy alongside oil, gas and coal. In 2001, the Four-Fuel policy was extended and became Five-Fuel policy to encourage the utilization of Renewable Energy (RE) resource such as biomass, solar, mini hydro in the energy supply mix. These policies were also followed by the launching, in 2009, of the National Green Technology and the National Renewable Energy (RE) Policy.

However, despite efforts by the government, the current situation remains worrying for the country. For instance, Malaysia was ranked ninth out of the 10 highest GHGs emitters between 1995 and 2000 by the World Resource Institute (2009). The Living Planet Report (2014) of the World-Wide Fund for Nature also noted that if every person in the world lived like a resident of Malaysia, humanity would need 1.7 earths to sustain our demand on nature. This statistic has also worsened as the Global Footprint Network (2016) puts Malaysia's ecological footprint at 4.2 global hectares which is 2.72 higher than the world average biocapacity of 1.7 global hectares. Malaysia is also ranked 53 out of 192 countries in terms of world ecological footprint.[1] The story is not different in terms of air pollution as CO_2 emissions increased from 7 million tonnes in 1965 to 246.9 million tonnes in 2015 representing an increase of over 3427% during that period (British Petroleum, 2016).

The severity of climate change has attracted the interest of environmental economists with significant attempts made to explain the causes of environmental degradation to generate policy options to manage same. The Environmental Kuznets Curve (EKC) hypothesis and the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model have been widely used in the literature to explain environmental degradation. The standard practice is to examine the effect(s) of economic growth on the environment but due to its serious effects on the environment, energy, in addition to some other variables such as financial development, urbanization, and trade openness have been incorporated into both the EKC and STIRPAT frameworks to broaden the horizon of understanding of the environment.

Majority of the previous studies rely solely on CO_2 emission as a measure of environmental decadence, while very few studies have employed ecological footprint as an indicator of environmental degradation including Al-Mulali et al. (2015). The use of CO_2 emission may be valid in some cases but not in all cases especially when it comes to resource stocks (Ulucak and Lin, 2017). Thus, emphasis should also be focused on resource stocks. Stern (2014) argued that while the volume of several pollutants per unit of output in specific processes have reduced in advanced nations over the years with innovations in technology and increasingly strict environmental policies, the effluent ratio has, however, moved from SO_x and N_2O to CO_2 and solid waste, leaving total waste to remain high and per capita waste unchanged. Therefore, it is important to augment specific indicators of degradation such as CO_2 emission with an aggregate indicator.

The objective of this paper is to examine the effects of an individual renewable electricity consumption (hydroelectricity) rather than aggregate electricity consumption on the environment in Malaysia as an emerging economy and we contribute to the literature in six areas. First, isolating the impacts of hydroelectricity as a renewable source of energy on the environment will give a more accurate policy decision as failure to assess the individual effects of the different component of energy source on the environment can conceal their distinctive influence and can, therefore, generate inaccurate policy inferences for each component. According to our knowledge, investigating the roles of hydroelectricity on the environment has gained little attention in the literature of energy and environmental economics (see section 2 on literature review. This is in spite of the fact that hydropower account for almost 75% of the global renewable sources used in the generation of electricity (US, Energy Information Administration (EIA), 2016). The 2012 International Energy Agency's Technology Roadmap for Hydropower reports that emerging economies possess the capacity to double hydroelectric production by 2050, thereby averting almost 3 billion tonnes of CO_2 yearly and nurturing economic and social development.[2] For Malaysia, it is the only established renewable energy source for generating electricity on a large scale (Shafie et al., 2011), thus representing the most plausible, fastest, and cheapest alternative to decarbonize the electric power sector in the country.

Secondly, in addition to CO_2 emissions, we employ ecological footprint as a measure of environmental degradation. We also include two sub-categories of ecological footprint namely carbon footprint and water footprint in the analysis. The inclusion of carbon footprint provides a solid platform to compare the results with CO_2 emissions while water footprint enables us to specifically examine the direct effect of hydroelectricity consumption on a water embodied natural resources. This is necessary because the effects of each explanatory variable may differ for different target variables thus requiring different policy approaches. Thirdly, we account for structural breaks in the estimation process by employing the unit root test of Narayan and Popp (2010) to examine the stationary properties of the series as disregarding the possibility of breaks in the estimation process may reduce the power to reject the null hypothesis (Narayan and Popp, 2010). This is particularly necessary in the case of Malaysia where several green energy policies have been rolled out in the 1980s and 2000s with the potential of creating breaks in the series.

Fourthly, we expand the basic STIRPAT model by incorporating the non-linear term of the Gross Domestic Product (GDP) which enables us to simultaneously test for the EKC hypothesis while controlling for urbanization. The addition of urbanization is important because its effects on the environment remain unresolved as it may either reduce or escalate environmental degradation. Urban areas typically have greater access to infrastructural amenities that enhance energy usage than rural areas thus inevitably generating more greenhouse gasses. However, population distribution in urban areas is denser when compared to that of the rural areas and as such the urban populace can garner the advantage of increasing returns to scale in the consumption of energy such as a unified heating system. Moreover, urban dwellers have higher propensity to adopt cleaner fuels which may enhance environmental quality. Thus, including urbanization will reduce the incident of omission of important variable bias in the estimation.

Fifth, we break the base data into sub-periods in order to examine how relationship between the variables changes from one period to another. This is important because presence of structural breaks due to changes in economic cycles can sometimes lead to change in the relationship among economic variables. Sixth, we conduct a sensitivity test by further including fossil fuels into the analysis. The interaction of fossil fuels with other controlled variables allows us to assess possible changes in our results when other possible factors are considered. The few papers that have focused on the effects of hydroelectricity consumption on the environment such as Lau et al. (2016) and Solarin et al. (2017) have ignored this sensitivity test.

The remaining parts of this paper are sectioned with section focusing on the review of existing literature while Section 3 is on

[1] See: http://www.footprintnetwork.org.

[2] https://www.iea.org/publications/freepublications/publication/2012_Hydropower_Roadmap.pdf.

methodology. Section 4 discusses the empirical results and section 5 concludes with policy implications.

2. Literature review

A considerable number of studies have been carried out to unravel the factors that impact the environment and how to mitigate the effects of climate change. Since a comprehensive survey of such studies can be found in works of Dinda (2004) and Al-Mulali et al. (2016a) among others, we, therefore, focus on studies that relate to Malaysia and other Asian countries for the purpose of putting the inferences into related context. Table 1 gives a summary of such studies.

With the exception of few studies such as Saboori and Sulaiman (2013a), Chandran and Tang (2013), Solarin and Lean (2016) and Solarin et al. (2017) who included more than one countries in their studies, majority of the works focusing on Asian countries have been single-country specific studies. While most of these studies including Saboori et al. (2012), Shahbaz et al. (2013), Saboori and Sulaiman (2013b), Lau et al. (2014), and Lau et al. (2016) for Malaysia; Jalil and Feridun (2011), Guangyue and Deyong (2011), and Du et al. (2012) for China; Tiwari et al. (2013) for India; Tan et al. (2014) for Singapore; Al-Mulali et al. (2015) for Vietnam; Ozturk and Al-Mulali (2015) for Cambodia, Chandran and Tang (2013) for 5 ASEAN countries; Solarin and Lean (2016), and Solarin et al. (2017) for India and China have been devoted to testing the validity of the EKC hypothesis, others such as Solarin (2014) for Malaysia; have employed the STIRPAT model to explain the driving forces behind the environment. Some other authors including Chang (2010) for China have simply tested for Granger Causality to

Table 1
Summary of literature review.

Author(s) and Year	Country	Period	Methodology/Framework	Variables	EKC Hypothesis	Causality test
Chang (2010)	China	1982–2004	VECM, GC	CO_2, GDP, EC	N/A	GDP ↔ CO_2; EC → CO_2
Jalil and Feridun (2011)	China	1953–2006	ARDL	CO_2, GDP Square, FD, GDP, EC,	Yes	N/A
Guangyue and Deyong (2011)	China	1990–2007	Johansen cointegration test and least squares estimation method	CO_2, GDP, GDP Square	Yes	N/A
Saboori et al. (2012)	Malaysia	1980–2009	EKC. ARDL, VECM, GC	CO_2, GDP, GDP Square	Yes	GDP → CO_2
Du et al. (2012)	China	1995–2009	FE and GMM	CO_2, GDP, GDP Square, URB, TO, EC, TP, IC, EC, TO	No	N/A
Shahbaz et al. (2013)	Malaysia	1971–2011	ARDL, VECM, GC	CO_2, GDP, EC, FD, FD Square FDI, TO	Yes (with FD)	GDP ↔ CO_2; EC ↔ CO_2
Tiwari et al. (2013)	India	1966–2011	ARDL, JJ, VECM, GC	CO_2, GDP, GDP Square Coal, TO	Yes	GDP ↔ CO_2 Coal ↔ CO_2
Saboori and Sulaiman (2013a)	ASEAN	1971–2009	ARDL, VECM, GC	CO_2, GDP, GDP Square, EC	Yes (Singapore and Thailand) No:(Indonesia, Malaysia and Philippines)	EC ↔ CO_2 (All cases)
Saboori and Sulaiman (2013b)	Malaysia	1980–2009	ARDL, JJML, GC	CO_2, GDP, GDP Square, EC	NO:(Aggregate EC) Yes: (Disaggregated EC).	GDP ↔ CO_2
Chandran and Tang (2013)	5 ASEAN countries	1971–2008	VECN, GC	CO_2, FDI, GDP, GDP Square, TRPEGC,	No	GDP ↔ CO_2 (Indonesia and Thailand); GDP → CO_2 (Malaysia); FDI &TRPEGC ↔ CO_2 (Thailand and Malaysia)
Solarin (2014)	Malaysia	1972–2010	STIRPAT, ARDL, VECM GC	CO_2, GDP, EC, FD, U, TUR	N/A	All Variables → CO_2; TUR ≠ GDP
Lau et al. (2014)	Malaysia	1970–2008	VECM, GC, ARDL	CO_2, FDI, TO, GDP, GDP Square	Yes	GDP → CO_2;
Tan et al. (2014)	Singapore	1975–2001	J-J cointegration test, VAR, GC	CO_2, GDP, GDP Square, EC	No	GDP → CO_2; EC ≠ CO_2
Al-Mulali et al. (2015)	Vietnam	1981–2011	ARDL, ECM	REC, NREC, CO_2, GDP, GDP Square, K, L, EX, IM	No	N/A
Ozturk and Al-Mulali (2015)	Cambodia	1996–2012	GMM, TSLS	GDP, GDP Square, URB, TO, GG	No	N/A
Lau et al. (2016)	Malaysia	1965–2010	Johansen cointegration VECM, GC	GDP, HC, CO2	N/A	HC → CO2; GDP → CO2; GDP → HC
Solarin and Lean (2016)	India and China	1965–2013	Hatemi-J, TYDL GC	CO_2, GDP, GDP Square, URB, NG,	No	NG → CO_2; GDP → CO_2; NC ↔ GDP
Solarin et al. (2017)	India and China	1965–2013	ARDL	CO_2, GDP, GDP Square URB, HD,	Yes	GDP ↔ CO_2 HD ↔ CO_2 Both countries

Notes: Definition of notations and abbreviations.
→ unidirectional causality; ↔ bidirectional causality; ≠ no causality; SR: Short run; LR: Long run; N/A: Not available; CO2: Carbon Dioxide; URB: Urbanization; NG: Natural Gas; GDP: Gross Domestic Product; POP: Population; TR: Trade; EX: Export; IM: Imports; K: Capital; L:Labour; IND: Industrialization; EMP: Employment; FD: Financial Development; TECH: Technology level; IS: Industrial Structure; EI: Energy Intensity; MR: Manufacture Ratio; TUR: Tourism; TP: Technical Progress; IC: Industrial Composition; ELC: Electricity Consumption; EC: Energy Consumption; REC: Renewable Energy Consumption; NREC: Non-Renewable Energy Consumption; TRPEGC: Transport Energy Consumption; EGR: Energy-GDP Ratio; TO: Trade Openness; FT: Foreign Trade: NEC: Nuclear Energy Consumption; Foreign Direct Investment; GG: Good Governance; HD: Hydroelectricity consumption ARDL: Autoregressive Distributed Lag; JJML: Johansen-Joselius maximum likelihood; VECM: Vector Error Correction Model; FE: Fixed Effects; TSLS: Two Stages Least Squares; GMM: General Methods of Moments; IRF: Impulse Response Function; GC: Granger Causality; DOLS: Dynamic Ordinary Least Squares; EKC: Environmental Kuznets Curve. TYDL: Toda and Yamamoto and Dolado and Lütkepohl.

examine the effects of selected explanatory variables on the environment.

These studies have adopted various econometrics techniques such as autoregressive distributed lag (ARDL) bounds testing approach to cointegration, the Johansen-Josselius cointegration method, vector error correction model (VECM), Granger Causality, fixed effect, general method of moment (GMM), Partial least square method, Johansen Fisher Panel cointegration and used various explanatory variables such as GDP, trade, energy consumption, financial development, technology progress, industrial composition, trade openness, urbanization, and population, and the results have also been diverse. For instance, while studies such as Jalil and Feridun (2011), Guangyue and Deyong (2011), Saboori et al. (2012), Shahbaz et al. (2013), Lau et al. (2014) and Solarin et al. (2017) have all validated the EKC hypothesis, others such as Du et al. (2012), Chandran and Tang (2013), Tan et al. (2014), Al-Mulali et al. (2015), Ozturk and Al-Mulali (2015), and Solarin and Lean (2016) have failed to validate the EKC hypothesis. In a panel study of 5 ASEAN countries, Saboori and Sulaiman (2013a) validated EKC for Singapore and Thailand but not for Indonesia, Malaysia and Philippines. The study, Saboori and Sulaiman (2013b) reported the existence of EKC hypothesis when aggregate energy consumption is used while failing to confirm same when energy consumption is disaggregated.

With respect to causality analysis, the results have also been mixed as some authors reported the existence of unidirectional causality running from CO_2 emission, to GDP (Ozturk and Al-Mulali, 2015). Others have reported a unidirectional causality running from the explanatory variables to CO_2 emission, such as Lau et al. (2014) for GDP; Chang (2010), for energy consumption; Solarin and Lean (2016) for natural gas; Lau et al. (2016) for hydroelectricity consumption in the short run; and energy consumption. Solarin (2014) reported unidirectional causality from GDP, trade openness, foreign direct investment and financial development, and tourism to CO_2 emission. Others such as Chang (2010), Saboori and Sulaiman (2013a, b), Shahbaz et al. (2013), Tiwari et al. (2013) and Solarin et al. (2017) have also reported bidirectional relationship between the explanatory variables and CO_2 emission.

What seems to be common with these studies is the adoption of CO_2 emission as the indicator for the environment which may not be valid in all cases especially when it comes to resource stocks (Ulucak and Lin, 2017). With regards to the explanatory variables, GDP is the de-facto choice as it is common with virtually all the studies. Given its effect on the environment, energy consumption is the most common explanatory after GDP. Energy and its variants such as renewable and non-renewable energy have been included in the analysis. The disaggregated component of energy such as oil, electricity and coal have also been added. Apart from Lau et al. (2016) for Malaysia and the more recent study on India and China by Solarin et al. (2017), hydroelectricity has received the least attention despite its reputation as one of the cleanest electricity sources with minimal negative impact on the environment.

3. Methodology

3.1. Model and data

In investigating the dynamic relationship between environment and hydroelectricity consumption in Malaysia, we expand the Dietz and Rosa (1997)'s Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model which allows for the inclusion of additional relevant variables that simultaneously fit into the EKC framework. This approach of expanding the basic STIRPAT model is consistent with Solarin (2014).

The basic STIRPAT model is specified as:

$$I_t = \beta_0 P_t^{\beta_1} A_t^{\beta_2} T_t^{\beta_3} \mu_t \quad (1)$$

where I is the index that captures environmental degradation, P, A, and T respectively represent population, affluence and technology. The β_s are the unbiased parameter estimates while μ is the random error term. Unlike the conventional use of CO_2 emission as the sole index of environmental degradation, we use three additional proxies of environmental degradation namely the Ecological Footprint of consumption, Carbon Footprint of consumption and Water Footprint of consumption. In addition to CO_2 emission, these additional proxies give a broader perspective to the analyses. Gross domestic product (GDP) is used to measure affluence-A. The T can be decomposed into different variables depending on the interest of the researcher. In our case, consistent with the study's objective, we decompose the T as hydroelectricity consumption which is a variant of renewable energy (electricity) consumption. We incorporate urbanization as a demographic variable and added the square of the GDP into the model to test the EKC hypothesis.

Thus, our expanded STRIPAT model is modified as follows:

$$I_t = \beta_0 P_t^{\beta_1} Y_t^{\beta_2} \left(Y^2\right)_t^{\beta_3} H_t^{\beta_4} UB_t{}^{\beta_5}{}_t \mu_t \quad (2)$$

Following Solarin et al. (2017), we divide both sides of equation (2) by population so that the model can be expressed in per capita form as:

$$i_t = \beta_1 y_t^{\beta_2} \left(y^2\right)_t^{\beta_3} h_t^{\beta_4} ub_t^{\beta_5} \mu_t \quad (3)$$

here, the lower-case letters represent the per capita form of the series. Real GDP per capita and its square are now being represented by y and y^2 while the added variables hydroelectricity consumption per capita and urbanization are respectively represented by h and ub. Taking the logs, the model is linearized as follows:

$$\ln i_t = \beta_0 + \beta_2 \ln y_t + \beta_3 \ln\left(y^2\right)_t + \beta_4 \ln h_t + \beta_5 \ln ub_t + \mu_t \quad (4)$$

In terms of our four different target variables, the following four equations are specified:

$$\ln ef_t = \alpha_0 + \alpha_2 \ln y_t + \alpha_3 \ln\left(y^2\right)_t + \alpha_4 \ln h_t + \alpha_5 \ln ub_t + \varepsilon_t \quad (5)$$

$$\ln cf_t = \phi_0 + \phi_2 \ln y_t + \phi_3 \ln\left(y^2\right)_t + \phi_4 \ln h_t + \phi_5 \ln ub_t + \nu_t \quad (6)$$

$$\ln wf_t = \varphi_0 + \varphi_2 \ln y_t + \varphi_3 \ln\left(y^2\right)_t + \varphi_4 \ln h_t + \varphi_5 \ln ub_t + \upsilon_t \quad (7)$$

$$\ln co_{2_t} = \delta_0 + \delta_2 \ln y_t + \delta_3 \ln\left(y^2\right)_t + \delta_4 \ln h_t + \delta_5 \ln ub_t + \xi_t \quad (8)$$

$\ln i_t$ is represented by the four measures of environmental degradation adopted in this study namely $\ln ef_t$, $\ln cf_t$, $\ln wf_t$, and $\ln co_{2_t}$ which are $\ln ef_t$, $\ln cf_t$ and $\ln wf_t$ are respectively the natural logs of per capita ecological, carbon, and water footprint of consumption. $\ln co_{2_t}$ is the natural log of CO_2 emission per capita. The ecological indices are measured in global hectares (gha) while CO_2 emission is measured in kilotons (kt). $\ln y_t$ and $\ln(y^2)_t$ are the natural logs of real GDP per capita and its square respectively and are obtained at constant 2010US$ to account for the impact of inflation. $\ln h_t$ is the natural log of hydroelectricity consumption per capita captured by the volume of electricity generated from hydropower expressed in terawatt hours (TWh) per capita while $\ln ub_t$ stands for urbanization measured as the proportion of urban population to total population. $\varepsilon_t, \nu_t, \upsilon_t$ and ξ_t are the different random error terms respectively for equations (5)–(8) with the desirable attributes of being distributed normally having mean of zero and constant variance. To validate the EKC hypothesis, we expect $\alpha_2, \phi_2, \varphi_2, \delta_2 > 0,$ and $\alpha_3, \phi_3, \varphi_3, \delta_3 < 0,$. The use of hydropower as a renewable form of electricity generation is expected to reduce environmental degradation so it is expected that $\alpha_4, \phi_4, \varphi_4, \delta_4 < 0,$. The impact of urbanization on the environment can be positive or negative depending how well environmental laws are enforced in the urbanization process so $\alpha_5, \phi_5, \varphi_5, \delta_5 < 0,$ can be $>$ 0 or <0.

Malaysia's annual time series data for the period 1971–2016 are used for the CO_2 emission per capita model while data for the ecological footprint per capita series cover the period 1971–2014.[3] The dataset for the GDP, urbanization, and CO_2 emission series have been extracted from the World Bank's World Development Indicators (WDI) while that of hydropower consumption and fossil fuel consumption have been retrieved from the British Petroleum's Statistical review of World Energy and Department of Statistics, Malaysia.[4] The annual data of ecological footprint of consumption, carbon footprint of consumption and water footprint of consumption are obtained from the National Footprint Accounts (NFA) of the Global Footprint Network (2018).[5]

3.2. Unit root tests

To obtain efficient and consistent parameter estimates, we begin by testing the stationarity properties of the variables included in our time-series model. The conventional unit root test can produce biased and spurious results due to their inability to account for structural breaks. To circumvent this, we employ the unit root test developed by Narayan and Popp (2010) to determine the integrating order of the variables. It is based on two regression equations namely M1 and M2 and incorporates two structural breaks are specified as follows:

$$y_t^{M1} = \rho y_{t-1} + \alpha_1 + \beta^* t + \theta_1 D\left(T_B'\right)_{1,t} + \theta_2 D\left(T_B'\right)_{2,t} + \delta_1 DU_{1,t-1}' + \delta_2 DU_{2,t-1}' + \sum_{j=1}^{k} \beta_j \Delta y_{t-j} + e_t \quad (9)$$

$$y_t^{M2} = \rho y_{t-1} + \alpha^* + \beta^* t + k_1 D\left(T_B'\right)_{1,t} + k_2 D\left(T_B'\right)_{2,t} + \delta_1^* DU_{1,t-1}' + \delta_2^* DU_{2,t-1}' + \gamma_1^* DT_{1,t-1}^* + \gamma_2^* DT_{2,t-1}^* + \sum_{j=1}^{k} \beta_j \Delta y_{t-j} + u_t \quad (10)$$

y_t^{M1} is the M1 model and provides for two changes in the intercept and y_t^{M2} represents the M2 model which allows for changes in both the intercept and the slope.

$DU_{i,t} = 1(t > T_{B,i})$ and $DT_{i,t} = 1(t > T_{B,i})(t - T_{B,i})$, $i = 1, 2,$ represent the dummy variables for breaks in the intercept and slope occurring at time T_{B1} and T_{B2} respectively. e_t and u_t are the independently and normally distributed error terms with a mean of zero and a constant variance i.e. $e_t, u_t \sim NIID(0, \sigma^2)$ respectively for equations (9) and (10). The null hypothesis of $\rho = 1$ is tested against alternative of $\rho < 1$ by using the $t - statistics$ of $\widehat{p}$.

3.3. ARDL bounds testing approach to cointegration

Consistent with Pesaran et al. (2001), the ARDL model for our empirical model in equations (5)–(8) are formulated as follows:

$$\Delta \ln ef_t = \alpha_0 + du_1 T_1 + du_2 T_2 + \alpha_1 \ln ef_{t-1} + \alpha_2 \ln y_{t-1} + \alpha_3 \ln\left(y^2\right)_{t-1} + \alpha_4 \ln ub_{t-1} + \alpha_5 \ln h_{t-1} + \sum_{k=1}^{l} \alpha_l \Delta \ln ef_{t-k} + \sum_{k=0}^{m} \alpha_m \Delta \ln y_{t-k} + \sum_{k=0}^{n} \alpha_n \Delta \ln\left(y^2\right)_{t-k} + \sum_{k=0}^{o} \alpha_o \Delta \ln ub_{t-k} + \sum_{k=0}^{p} \alpha_p \Delta \ln h_{t-k} + \varepsilon_t \quad (11)$$

$$\Delta \ln cf_t = \phi_0 + du_1 T_1 + du_2 T_2 + \phi_1 \ln cf_{t-1} + \phi_2 \ln y_{t-1} + \phi_3 \ln\left(y^2\right)_{t-1} + \phi_4 \ln ub_{t-1} + \phi_5 \ln h_{t-1} + \sum_{k=1}^{l} \phi_l \Delta \ln cf_{t-k} + \sum_{k=0}^{m} \phi_m \Delta \ln y_{t-k} + \sum_{k=0}^{n} \phi_n \Delta \ln\left(y^2\right)_{t-k} + \sum_{k=0}^{o} \phi_o \Delta \ln ub_{t-k} + \sum_{k=0}^{p} \phi_p \Delta \ln h_{t-k} + \nu_t \quad (12)$$

$$\Delta \ln wf_t = \varphi_0 + du_1 T_1 + du_2 T_2 + \varphi_1 \ln wf_{t-1} + \varphi_2 \ln y_{t-1} + \varphi_3 \ln\left(y^2\right)_{t-1} + \varphi_4 \ln ub_{t-1} + \varphi_5 \ln h_{t-1} + \sum_{k=1}^{l} \varphi_l \Delta \ln wf_{t-k} + \sum_{k=0}^{m} \varphi_m \Delta \ln y_{t-k} + \sum_{k=0}^{n} \varphi_n \Delta \ln\left(y^2\right)_{t-k} + \sum_{k=0}^{o} \varphi_o \Delta \ln ub_{t-k} + \sum_{k=0}^{p} \varphi_p \Delta \ln h_{t-k} + \upsilon_t \quad (13)$$

[3] Data for the footprint series are available up to year 2014.

[4] The fuel data included only those used in the generation of electricity to avoid over estimation.

[5] For more details on ecological footprint accounts, readers can refer to: https://www.footprintnetwork.org/content/documents/National_Footprint_Accounts_2016_Guidebook.pdf.

$$\Delta \ln co_{2_t} = \delta_0 + du_1 T_1 + du_2 T_2 + \delta_1 \ln co_{2t-1} + \delta_2 \ln y_{t-1} + \delta_3 \ln\left(y^2\right)_{t-1} + \delta_4 \ln ub_{t-1} + \delta_5 \ln h_{t-1} + \sum_{k=1}^{l} \delta_l \Delta \ln co_{2t-k} + \sum_{k=0}^{m} \delta_m \Delta \ln y_{t-k} + \sum_{k=0}^{n} \delta_n \Delta \ln\left(y^2\right)_{t-k} + \sum_{k=0}^{o} \delta_o \Delta \ln ub_{t-k} + \sum_{k=0}^{p} \delta_p \Delta \ln h_{t-k} + \xi_t \quad (14)$$

here, Δ is the difference operator, T_1 and T_2 are the structural break dates based on Narayan and Popp (2010) unit root tests on the dependent variables. l, m, n, o, and p are the optimal lag length. ε_t, ν_t, υ_t and ξ_t represent the standard normally distributed error terms. In each equation (11)–(14), the null hypotheses of no cointegration relationship:

$$\Delta \ln ef_t = \alpha_0 + du_1 T_1 + du_2 T_2 + \alpha_1 \ln ef_{t-1} + \sum_{k=1}^{l} \alpha_l \Delta \ln ef_{t-k} + \sum_{k=1}^{m} \alpha_m \Delta \ln y_{t-k} + \sum_{k=1}^{n} \alpha_n \Delta \ln\left(y^2\right)_{t-k} + \sum_{k=1}^{o} \alpha_o \Delta \ln ub_{t-k} + \sum_{k=1}^{p} \alpha_p \Delta \ln h_{t-k} + \varpi ect_{t-1} + \varepsilon_t \quad (15)$$

$$\Delta \ln cf_t = \phi_0 + du_1 T_1 + du_2 T_2 + \phi_1 \ln cf_{t-1} + \sum_{k=1}^{l} \phi_l \Delta \ln cf_{t-k} + \sum_{k=1}^{m} \phi_m \Delta \ln y_{t-k} + \sum_{k=1}^{n} \phi_n \Delta \ln\left(y^2\right)_{t-k} + \sum_{k=1}^{o} \phi_o \Delta \ln ub_{t-k} + \sum_{k=1}^{p} \phi_p \Delta \ln h_{t-k} + \sigma ect_{t-1} + \nu_t \quad (16)$$

$$\Delta \ln wf_t = \varphi_0 + du_1 T_1 + du_2 T_2 + \varphi_1 \ln wf_{t-1} + \sum_{k=1}^{l} \varphi_l \Delta \ln wf_{t-k} + \sum_{k=1}^{m} \varphi_m \Delta \ln y_{t-k} + \sum_{k=1}^{n} \varphi_n \Delta \ln\left(y^2\right)_{t-k} + \sum_{k=1}^{o} \varphi_o \Delta \ln ub_{t-k} + \sum_{k=1}^{p} \varphi_p \Delta \ln h_{t-k} + \omega ect_{t-1} + \upsilon_t \quad (17)$$

$$\Delta \ln co_{2t} = \delta_0 + du_1 T_1 + du_2 T_2 + \delta_1 \ln co_{2t-1} + + \sum_{k=1}^{l} \delta_l \Delta \ln co_{2t-k} + \sum_{k=1}^{m} \delta_m \Delta \ln y_{t-k} + \sum_{k=1}^{n} \delta_n \Delta \ln\left(y^2\right)_{t-k} + \sum_{k=1}^{o} \delta_o \Delta \ln ub_{t-k} + \sum_{k=1}^{p} \delta_p \Delta \ln h_{t-k} + \psi ect_{t-1} + \xi_t \quad (18)$$

$H_0 : \alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5 = \phi_1, \phi_2, \phi_3, \phi_4, \phi_5 = \varphi_1, \varphi_2, \varphi_3, \varphi_4, \varphi_5 = \delta_1, \delta_2, \delta_3, \delta_4, \delta_5 = 0$ is tested against the alternative hypotheses:

$H_1 : \alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5 \neq \phi_1, \phi_2, \phi_3, \phi_4, \phi_5 \neq \varphi_1, \varphi_2, \varphi_3, \varphi_4, \varphi_5 \neq \delta_1, \delta_2, \delta_3, \delta_4, \ \delta_5 \neq 0$ for the joint significance of the lagged level coefficients. In the presence of cointegration, the null hypothesis is rejected. The F-test statistics is applied to test the overall significance of the lagged terms of the explanatory variables in level. In this case, the normalized F-tests are expressed as $F_{\ln ef_{t-i}}(\ln ef_{t-1}/\ln y_{t-1}, \ln(y^2)_{t-1}, \ln ub_{t-1}, \ln h_{t-1})$, $F_{\ln cf_{t-i}}(\ln cf_{t-1}/\ln y_{t-1}, \ln(y^2)_{t-1}, \ln ub_{t-1}, \ln h_{t-1})$, $F_{\ln wf_{t-i}}(\ln wf_{t-1}/\ln y_{t-1}, \ln(y^2)_{t-1}, \ln ub_{t-1}, \ln h_{t-1})$, $F_{\ln co_{2t-i}}(\ln ef_{t-1}/\ln y_{t-1}, \ln(y^2)_{t-1}, \ln ub_{t-1}, \ln \ h_{t-1})$ for equations (11)–(14) respectively. There are two sets of critical values: one which is appropriate when all the series are $I(1)$ which is referred to as upper bound and the other is applicable when all the series are $I(0)$ which is the lower bound. The decision to determine the long run relationship is based on the comparison between the calculated F-statistics and the critical values. Lag selection criterion of Akaike information criteria (AIC) is employed to determine the lag orders of the variables in the estimation process. After establishing the long-run relationship, the vector error correction model (VECM) is then specified from which the error correction term (ect) can be estimated. For equations (5)–(8), the VECMs are specified as follows:

The VECM enables the examination of the causal relationship between the variables in order to infer policy implications. The suitability of the models is checked by carrying out some diagnostic tests such as the Breush-Godfrey Lagrange multiplier test of residual serial correlation, normality based on a test of Jarque-Bera statistics, and heteroscedasticity based on the ARCH and White tests. Furthermore, Cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) are conducted to test the stability of the models.

4. Empirical results and discussion

4.1. Unit root test results

The application of the ARDL bounds testing approach to cointegration demands that none of the variables have an integrating order of $I(2)$ or higher. Conventional unit root tests might be biased when there are structural breaks in the series. In order to ensure

Table 2
Unit root test with single break.

Level			First Difference		
Variables	Chosen break point	PUR test	Variables	Chosen break point	PUR test
ef	1990	−4.190	*Δef*	1987	−8.677***
cf	1989	−3.684	*Δcf*	1987	−7.658***
wf	2003	−3.356	*Δwf*	1991	−6.779***
co_2	1995	−2.460	Δco_2	1980	−6.632***
y	1992	−3.625	*Δy*	1980	−6.632***
y^2	1992	−3.588	Δy^2	1998	−6.750***
h	1995	−2.658	*Δh*	1984	−7.003***
ub	1991	−4.260	*Δub*	1991	−7.285***
ff	1994	−3.961	*Δff*	1988	−9.348***

Note: T-stat: −6.32. −5.59, −5.29 at 1%, 5%, and 10% respectively. The estimation includes intercept and trend. *** Denotes 1% significant level.

that none of the variables attain stationarity beyond $I(1)$, while providing for structural breaks, we apply the Perron (1997) unit root test that allows for a structural break and we summarized the results in Table 2. The results revealed that all variables are non-stationary at levels but attained stationarity at their first differences.

The Perron (1997) is designed to test for stationarity under the assumption of one break and may suffer power loss in the face of more than one breaks. To circumvent this weakness, the two breaks test of Narayan and Popp (2010) is employed. The results of the Narayan and Popp two breaks tests are provided in Table 3. For the M1 model, all variables are found to be nonstationary at levels but for the M2 model however, the null hypothesis of a unit root at levels is rejected for the variables y and y^2 suggesting that they (y and y^2) may be integrated of order $I(0)$. Since the M2 model enables changes in both the intercept and the gradient and its considered superior to the M1 model, we proceed with our analysis on the basis of the M2 model. In this circumstance, therefore, it will be inappropriate to adopt other approaches to cointegration such as the Johansen cointegration approach which requires the same integrating order for all variables. Hence, the appropriate method in this case is the ARDL approach to cointegration.

4.2. Cointegration and long-run equilibrium relationship results

We begin the cointegration procedure by conducting the bounds test for our models, the results of which are summarized in Table 4. The results show that the calculated F-statistics for the joint significance of all lagged level variables exceed the upper critical bounds $I(1)$ at 1% significance level for the *ef*, *cf*, and co_2 models and 5% for the *wf* models, hence, establishing cointegration and long run relationship between our measures of environmental degradation and the adopted explanatory variables across all models for the period 1971–2014 for the *ef*, *cf*, and *wf* models and 1971–2016 for the co_2 model.

The diagnostic tests results show that the Jarque-Bera (JB) test of normality cannot reject the null hypothesis of normality, hence confirming that the errors are normally distributed with zero mean and constant variances for all models. The Breusch-Godfrey LM test for serial correlation also accepted the null hypothesis of no serial correlation. In terms of homoscedasticity, all the three tests of Breusch-Pagan-Godfrey, ARCH and WHITE tests failed to reject the null hypothesis of no heteroscedasticity. The model stability is established with plots of CUSUM and the square of CUSUM.[6]

Having satisfied the necessary diagnostic tests, we then examined the long run equilibrium coefficients for our models as summarized in Table 5. For all models, the coefficients of real GDP per capita are positive while those of real GDP square per capita are negative and are found to be significant across all models with the exception of the ecological footprint per capita model where the coefficient of real GDP square per capita (α_3) is found to be insignificant. The coefficients of real GDP and real GDP square are 2.378 and −0.108 for ecological footprint model, 12.303 and −0.604 for the carbon footprint model, 6.580 and −0.299 for the water footprint model and 9.519 and −0.508 for the co_2 emissions model. This suggests that, all things being equal, a 1% increase in each of these terms is linked with a corresponding percentage increase in the respective dependent variables by the values of the associated parameter estimates. The respective positive and negative values of the coefficients of the real GDP and the real GDP square across the models is an evidence of an inverted U-shaped relationship between the four measures of environmental degradation adopted in this study and GDP per capita, hence validating the EKC hypothesis for Malaysia. The validation of the EKC hypothesis is congruous with some previous studies on Malaysia such as Saboori et al. (2012) but contrary to Saboori and Sulaiman (2013b). A cursory look at the coefficient of the nonlinear GDP series however reveals that the EKC hypothesis may not be automatic for Malaysia especially as the coefficient is insignificant in the case of the ecological footprint equation.

The coefficients of hydroelectricity consumption are found to be negative across all models suggesting that hydroelectricity reduces environmental degradation. On the average, the coefficient value of hydroelectricity ranges between 0.04 and 0.09 suggesting that, all else same, a 1% increase in hydroelectricity consumption corresponds to an approximate reduction of between 0.04 and 0.09 reduction in environmental degradation. This result is consistent the conclusion of Solarin et al. (2017) who also found a negative long-run relationship between hydroelectricity and CO_2 emission for China and India. The findings of a negative impacts of hydroelectricity consumption on environmental degradation is in conformity with the view that hydropower is a green energy source which can improve the quality of the environment. Interestingly, the coefficient of hydroelectricity consumption in the water footprint model is, though negative, insignificant despite the fact that hydropower is a water embodied energy source. This confirms the technical view that hydroelectric power plants do not 'use up' water resources to create electricity, they only require moving water to generate electricity. This finding is however in contrast with the result of Al-Mulali et al.

Table 3
Narayan and Popp (2010) structural breaks unit root test results.

Variable	Model-1(M1)			Model-2 (M2)		
	T-statistic	TB1	TB2	T-statistic	TB1	TB2
ef	−2.399	1997	2000	−3.676	1987	1997
cf	−3.347	1990	2000	−4.017	1989	1997
wf	−3.747	1992	1996	−4.188	1981	1998
co_2	−2.715	1990	1996	−0.025	1983	1997
y	−0.158	1984	1997	−5.284**	1984	1997
y^2	−0.290	1984	1997	−5.034*	1984	1997
h	−0.679	1983	1988	−2.503	1983	1998
ub	1.790	1991	2000	4.396	1991	2000
ff	−1.601	1997	2000	−0.495	1997	2001

Note: Model-1 assumes two breaks in level and Model-2 assumes two breaks in level and slope. **denotes 5% significant level; * denotes 10% significant level.

[6] We have not reported the plots due to space limitation but available upon request.

Table 4
The results of ARDL bounds testing cointegration test for base models.

Model	$F_{ef}(ef/y, y^2, h, ub)$	$F_{cf}(cf/y, y^2, h, ub)$	$F_{wf}(wf/y, y^2, h, ub)$	$F_{co_2}(co_2/y, y^2, h, ub)$
Optimal lag	(3,0,1,1,1)	(4,1,2,2,1)	(2,0,2,0,0)	(4,2,2,2,1)
Lower bounds: $I(0)$	3.29	3.29	2.56	3.29
Upper bounds: $I(1)$	4.37	4.37	3.49	4.37
F-Statistics	4.590***	8.904***	4.036**	9.010***
Significant level	1%	1%	5%	1%
R^2	0.81	0.81	0.45	0.84
Diagnostic tests				
Breusch-Godfrey LM Test:	1.440 (0.250)	2.120 (0.145)	1.171 (0.324)	0.164 (0.689)
Jarque-Bera	2.433 (0.296)	0.917 (0.632)	1.191 (0.551)	0.354 (0.837)
Breusch-Pagan-Godfrey:	0.697 (0.731)	0.388 (0.972)	1.608 (0.151)	0.865 (0.615)
ARCH	0.665 (0.621)	0.525 (0.718)	1.533 (0.229)	0.257 (0.904)
WHITE	0.810 (0.631)	0.582 (0.867)	1.694 (0.127)	0.983 (0.505)
CUSUM	STABLE	STABLE	STABLE	STABLE
CUSUM of Squares	STABLE	STABLE	STABLE	STABLE

Note: The figures in parenthesis are the probability values.
Optimal lag length is determined by AIC. $k = 4$, restricted intercept with no trend.
***denotes 1% significant level; ** denotes 5% significant level.

Table 5
Summary of the long-run relationship for base models.

Model	$F_{ef}(ef/y, y^2, h, ub)$		$F_{cf}(cf/y, y^2, h, ub)$		$F_{wf}(wf/y, y^2, h, ub)$		$F_{co_2}(co_2/y, y^2, h, ub)$	
Explanatory Variables	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat
y	2.378**	2.181	12.303***	9.741	6.580**	2.091	9.519***	7.861
y^2	−0.108	−1.364	−0.604***	−8.462	−0.299*	−1.652	−0.508***	−7.592
h	−0.085**	−2.213	−0.095**	−2.102	−0.041	−0.452	−0.044*	−1.681
ub	−0.549	−0.942	−0.528	0.753	−2.550	−1.543	0.780**	2.212
Constant	−12.323**	−2.551	−60.392***	−10.491	−26.092**	−2.012	−46.589***	−9.841

***denotes 1% significant level; ** denotes 5% significant level; * denotes 10% significant level.

(2016b) who found renewable electricity generation to increase water and land footprint in a panel study of 59 countries including Malaysia. The reason for this may be due to the fact that hydroelectricity is excluded from the renewable electricity sources used in the analysis. The relatively small values of the coefficients of hydroelectricity consumption across all models is a direct manifestation of the disproportionate share of hydroelectricity in the current electricity generation fuel mix for the country as fossil fuels accounted for over 90% of the electricity generation fuel mix in 2015 (World Bank, 2017).

The coefficients of urbanization are negative and insignificant for all models except the CO_2 emission model where it is positive and significant suggesting that urbanization reduces environmental degradation in case of ecological footprint per capita, carbon footprint and water footprint which are stock embodied measures while increasing CO_2 emission which basically captures air pollution. The coefficient values of −0.549, −0.528, −2.55 and 0.78 for the ecological footprint per capita, carbon footprint per capita, water footprint and CO_2 emission models respectively suggest that a 1% increase in urbanization rate is linked to a decrease in ecological footprint per capita, carbon footprint per capita, and water footprint while having a reverse effect on CO_2 emission per capita.

4.2.1. Sub-period analysis

The presence of structural breaks due to changes in economic cycles can sometimes lead to change in the relationship among economic variables. In other words, economic variables do not necessarily exhibit same pattern of relationship across different regimes. To account for this, we have estimated the relationship at different periods using the break periods determined by the Perron (1997) structural break unit root tests.[7] Based on the Perron (1997) one break unit root test, the ecological footprint per capita model has been estimated for two sub-periods: 1971–1990 which correspond to the period before the first break date and 1991–2014 which correspond to the period after the first break till the end of the sample period. The corresponding periods for carbon footprint, water footprint and CO_2 emission models are 1971–1989 and 1990–2014; 1971–2003 and 2004–2014; and 1971–1995 and 1996–2016 respectively. Table 6 shows cointegration is established across all periods for all models except for the water footprint model for the period 2004–2014.[8]

The summary of the long-run relationship for the sub-periods models is given in Table 7. We see that the parameters do change in terms of signs and significance at different periods. For instance, in the first periods for both the ecological footprint and carbon footprint per capital models the coefficients of real GDP are negative while that of its square are positive which is a violation of the EKC hypothesis. However, the reverse is the case in the second periods for the two models where the coefficients of real GDP are positive while that of its square are negative thus validating the EKC hypothesis. In the carbon footprint per and CO_2 emission models, EKC is validated for both periods however the parameters are not significant in the first period of the CO_2 emission model.

Importantly, hydroelectricity consumption is found to be negative and significant in all the first periods across all models

[7] Though our stationarity test decision was based on the Narayan and Popp (2010) unit root test, we have used the Peron (1997) one break test in order to have sufficient degree of freedom for the estimation of the sub-periods models.

[8] We could not estimate the water footprint model for the 2004–2014 period due to insufficient degree of freedom as a result of small sample size.

Table 6
The results of ARDL bounds testing cointegration tests for sub-period models.

Panel A:$F_{ef}(ef/y, y^2, h, ub)$	**1971–1990**	**1991–2014**
Optimal lag	(1,1,1,0,0)	(3,1,0,0,1)
$I(0)$- $I(1)$	3.29–4.37	2.2–3.09
F-Statistics	7.243***	3.17*
Significant level	1%	10%
R^2	0.897	0.826
Diagnostic test		
Breusch-Godfrey LM Test:	0.490 (0.500)	0.023 (0.882)
Jarque-Bera	0.641 (0.726)	2.176 (0.337)
Breusch-Pagan-Godfrey	1.161 (0.396)	0.733 (0.674)
ARCH	0.343 (0.566)	0.391 (0.839)
WHITE	1.166 (0.393)	0.720 (0.684)
CUSUM	STABLE	STABLE
CUSUM of Squares	STABLE	STABLE
Panel B:$F_{cf}(cf/y, y^2, h, ub)$	**1971–1989**	**1990–2014**
Optimal lag	(1,2,2,2,2)	(1,2,0,1,1)
$I(0)$- $I(1)$	3.29–4.37	3.29–4.37
F-Statistics	7.821***	6.971**
Significant level	1%	1%
R^2	0.951	0.834
Diagnostic test		
Breusch-Godfrey LM Test:	5.779 (0.282)	0.546 (0.583)
Jarque-Bera	0.422 (0.809)	41.652 (0.000)
Breusch-Pagan-Godfrey	0.863 (0.637)	0.263 (0.976)
ARCH	2.606 (0.115)	0.133 (0.876)
WHITE	0.820 (0.658)	0.272 (0.973)
CUSUM	STABLE	STABLE
CUSUM of Squares	STABLE	STABLE
Panel C:$F_{wf}(wf/y, y^2, h, ub)$	**1971–2003**	**2004–2014**
Optimal lag	(1,0,0,0,1)	N/A
$I(0)$- $I(1)$	3.29–4.37	N/A
F-Statistics	5.398	N/A
Significant level	1%	N/A
R^2	0.525	N/A
Diagnostic test		
Breusch-Godfrey LM Test:	1.661 (0.212)	N/A
Jarque-Bera	1.200 (0.549)	N/A
Breusch-Pagan-Godfrey	0.342 (0.908)	N/A
ARCH	1.656 (0.210)	N/A
WHITE	0.336 (0.911)	N/A
CUSUM	STABLE	STABLE
CUSUM of Squares	STABLE	STABLE
Panel D:$F_{co_2}(co_2/y, y^2, h, ub)$	**1971–1995**	**1996–2016**
Optimal lag	(3,0,0,2,1)	(1,0,0,0,0)
$I(0)$- $I(1)$	3.29–4.37	2.56–3.49
F-Statistics	7.88***	3.804**
Significant level	1%	5%
R^2	0.861	0.495
Diagnostic test		
Breusch-Godfrey LM Test:	2.706 (0.129)	2.469 (0.129)
Jarque-Bera	0.258 (0.879)	2.568 (0.277)
Breusch-Pagan-Godfrey	1.127 (0.421)	0.371 (0.860)
ARCH	0.324 (0.808)	0.152 (0.702)
WHITE	0.782 (0.647)	0.391 (0.846)
CUSUM	STABLE	STABLE
CUSUM of Squares	STABLE	STABLE

Note: the figures in parenthesis are the probability values; optimal lag length is determined by AIC.
$k = 4$, restricted intercept with no trend. *** denotes 1% significant level, ** denotes 5% significant level.
$I(0)$ denotes lower bound critical value, $I(1)$ denotes upper bound critical value.
***denotes 1% significant level; ** denotes 5% significant level; * denotes 10% significant level.

(except for the first period of the ecological footprint model where it is though negative but insignificant). Across the second period hydroelectricity is found to be insignificant. This may be an indication of the reduction in the contribution of hydroelectricity in the electricity generation mix in the country. The same scenario is applicable to urbanization as it is negative and significant in the first periods of the ecological footprint and carbon footprint per capital model but positive and significant in the same periods for the water footprint and CO_2 emission models.

Table 7
Summary of the long-run relationship for sub-period models.

Explanatory Variables	Coefficient	t-stat	Coefficient	t-stat
Panel A: $F_{ef}(ef/y, y^2, h, ub)$	**1971–1990**		**1991–2014**	
y	−3.121	−0.985	8.413	1.564
y^2	0.403	1.419	−0.423	−1.405
h	−0.052	−1.069	−0.049	−0.566
ub	−1.971***	−4.314	−0.893	−1.448
Constant	14.352	1.157	−37.059	−1.590
Panel B:$F_{cf}(cf/y, y^2, h, ub)$				
y	−56.838**	−2.502	20.420*	1.858
y^2	3.899***	2.753	−1.010*	−1.687
h	−0.353**	−2.003	−0.050	−0.373
ub	−4.665***	−3.326	−3.526*	−1.738
Constant	213.875**	2.491	−86.837**	−1.962
Panel C: $F_{wf}(wf/y, y^2, h, ub)$	**1971–2003**		**2004–2014**	
y	7.425***	2.804	N/A	N/A
y^2	−0.447***	−2.787	N/A	N/A
h	−0.266***	−3.904	N/A	N/A
ub	1.708***	2.305	N/A	N/A
Constant	−42.779***	−3.643	N/A	N/A
Panel D: $F_{co_2}(co_2/y, y^2, h, u)$	**1971–1995**		**1996–2016**	
y	3.210	0.419	44.565**	2.352
y^2	−0.181	−0.405	−2.450**	−2.340
h	−0.340**	−2.452	0.110	1.069
ub	3.805**	2.568	0.831	1.254
Constant	−32.669	−1.428	−202.551**	−2.447

***denotes 1% significant level. ** denotes 5% significant level. * denotes 10% significant level.

4.3. Sensitivity test result

We conducted sensitivity test by further controlling for fossil fuels in each of the equation. The bounds testing in Table 8 confirmed cointegration at 1% significant levels for the ecological footprint per capita, carbon footprint per capita and CO_2 emission per capita models, and at 5% for the water footprint per capita models and all diagnostic tests show satisfactory results. This establishes long run relationship with the addition of fossil fuels. The long run relationships are reported in Table 9. In terms of GDP, GDP square and urbanization, the results are basically the same as with the models without fossil fuels. Hydroelectricity still exhibits negative relationship with all the effluent measures except for the water footprint equation where the sign reverses. However, in both cases, the coefficients remain insignificant. The coefficient of fossil fuel is negative but insignificant for the carbon footprint and CO_2 emission models while positive for the ecological footprint (insignificant) and water footprint (significant) models. This means that Malaysia's electricity generation process is not completely environmentally unfriendly. This may be an indication of the dominance of liquefied natural gas which is considered less controversial in comparison with nuclear energy and more environmental-friendly relative to oil and coal (Solarin and Lean, 2016).

We also conducted the sensitivity analysis for the sub-period models. The bounds testing results in Table 10 show cointegration is established across all periods for all models except for the water footprint model for the period 2004–2014.[9] Just like the sub-period analysis with the base models, Table 11 also shows the fact that parameter estimates do differ in signs and level of significance with different periods. In general, hydroelectricity consumption seems

[9] We could not estimate the water footprint model for the 2004–2014 period due to insufficient degree of freedom as result of small sample size.

Table 8
The results of ARDL bounds testing cointegration for the base models with fossil fuels.

Model	$F_{ef}(ef/y,y^2,ub,h,ff)$	$F_{cf}(cf/y,y^2,ub,h,ff)$	$F_{wf}(wf/y,y^2,ub,h,ff)$	$F_{co_2}(co_2/y,y^2,ub,h,ff)$
Optimal lag	(3,0,1,0,1,0)	(2,2,1,0,2,0)	(2,0,0,0,0,2)	(4,2,1,1,1,0)
Lower bounds: $I(0)$	3.06	3.06	2.29	3.06
Upper bounds: $I(1)$	4.15	4.15	4.15	4.15
F-Statistics	5.580***	8.98***	3.40**	7.43***
Significant level	1%	1%	5%	1%
R^2	0.82	0.76	0.48	0.84
Diagnostic tests				
Breusch-Godfrey LM Test:	1.848 (0.153)	0.621 (0.546)	1.448 (0.252)	1.423 (0.245)
Jarque-Bera	4.557 (0.102)	0.543 (0.762)	1.770 (0.413)	0.341 (0.843)
Breusch-Pagan-Godfrey:	0.703 (0.735)	1.604 (0.142)	1.175 (0.345)	0.714 (0.756)
ARCH	0.473 (0.755)	0.129 (0.879)	1.336 (0.275)	0.010 (0.920)
WHITE	0.834 (0.617)	1.234 (0.309)	1.168 (0.349)	0.696 (0.772)
CUSUM	STABLE	STABLE	STABLE	STABLE
CUSUM of Squares	STABLE	STABLE	STABLE	STABLE

Note: The figures in parenthesis are the probability values.
Optimal lag length is determined by AIC. $k = 4$, restricted intercept with no trend.
***denotes 1% significant level; ** denotes 5% significant level.

Table 9
Summary of the long-run relationship for the base models with fossil fuels.

Model	$F_{ef}(ef/y,y^2,ub,h,ff)$		$F_{cf}(cf/y,y^2,ub,h,ff)$		$F_{wf}(wf/y,y^2,ub,h,ff)$		$F_{co_2}(co_2/y,y^2,ub,h,ff)$	
Explanatory Variables	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat
y	3.224**	2.451	12.419***	8.125	4.296***	1.827	8.815***	7.927
y^2	−0.137*	−1.912	−0.578**	−6.812	−0.278***	−2.150	−0.461***	−7.578
ub	−1.675**	−2.377	−2.324**	−3.082	−0.777**	−0.758	0.970**	2.548
h	−0.006	−0.088	−0.181**	−2.240	0.069	0.933	−0.070**	−2.218
ff	0.242	1.495	−0.007	−0.038	0.638***	3.075	−0.0081	−0.925
Constant	−6.668	−0.919	−57.650***	−6.650	−4.928	−0.390	−46.218***	−8.631

***denotes 1% significant level. ** denotes 5% significant level. * denotes 10% significant level.

to exert significant negative impact on the environment in the first period while the effects are reduced in the second period or in some cases like the CO_2 emission model exhibit a reverse in sign. It is also noticed that fossil fuel can have significant detrimental effect on the environment as evidenced by the positive significant coefficient in the second period for the CO_2 emission model.

4.4. The VECM Granger causality analysis

Cointegration between the variables in the models signifies the existence of at least one-way relationship but does not indicate the direction of causality. For policy inferences, it is instructive to examine the causal directional relationships between the variables in the models. We have applied the VECM granger causality framework to examine the causal relationship between the variables in the models. The results of the long-run VECM granger causality are presented in Table 12.

Beginning with the base models without the inclusion of fossil fuels, the upper part of Table 12 shows that the one period lagged error correction term (ect_{-1}) is statistically significant for all the environmental degradation variables as well as the real GDP per capita. Urbanization is only found to be significant at 5% in the case of the carbon footprint per capital model. The (ect_{-1}) for hydroelectricity consumption is found to be insignificant across all models. The same scenarios played out when fossil fuels are controlled for as the lower part of Table 12 shows that significant (ect_{-1}) when ecological footprint per capita, carbon footprint per capita, water footprint and CO_2 emission and real GDP are used as dependent variables. However, the sensitivity model found that in addition to the carbon footprint model, the one period lagged (ect_{-1}) for urbanization is also significant in the ecological footprint model. The (ect_{-1}) for both hydroelectricity consumption and fossil fuel consumption are found to be insignificant.

These results indicate that, in general, there is one-way causality running from hydroelectricity consumption and fossil fuels consumption to ecological footprint per capita, carbon footprint per capita, water footprint per capita, CO_2 emission and real GDP per capita. There is evidence of bidirectional granger causality between real GDP and all measures of environmental degradation as well as between urbanization and ecological footprint per capita; and between urbanization and carbon footprint per capita.

5. Conclusion and policy implications

This paper assesses the isolated impacts of hydroelectricity as a green energy source on the environment. Using four different measures of environmental degradation including ecological footprint, carbon footprint, water footprint and CO_2 emission as target variables, we augment the basic STIRPAT model with the inclusion of GDP square to simultaneously test for the EKC hypothesis while controlling for urbanization as a demographic variable in the case of Malaysia using annual time series data spanning 1971 to 2016 and 1971 to 2014 for the ecological series. We have employed the Narayan and Popp structural breaks unit root test to examine the stationarity of the series and ARDL bounds testing approach to cointegration to probe the long run relationships between the variables as well as the Granger causality test based on the VECM to explore the direction of the long-run causal relationship between the variables. Sensitivity analysis is conducted by further including fossil fuels in the equations. The sample periods are also broken into sub-periods to compare the relationships between the variables for different periods.

The results establish long run relationship between our measures of environmental degradation and the controlled variables.

Table 10
The results of ARDL bounds testing cointegration tests for sub-period models with fossil fuels.

Panel A:$F_{ef}(ef/y,y^2,ub,h,ff)$	**1971–1990**	**1991–2014**
Optimal lag	(1,1,1,0,0,0)	(4,1,1,0,1,1)
$I(0)$- $I(1)$	3.06–4.15	3.06–4.15
F-Statistics	5.645***	4.30***
Significant level	1%	5%
R^2	0.897	0.907
Diagnostic test		
Breusch-Godfrey LM Test:	0.813 (0.391)	2.653 (0.137)
Jarque-Bera	0.784 (0.676)	0.475 (0.789)
Breusch-Pagan-Godfrey	0.381 (0.908)	0.540 (0.852)
ARCH	2.084 (0.168)	0.819 (0.533)
WHITE	0.400 (0.896)	0.512 (0.872)
CUSUM	STABLE	STABLE
CUSUM of Squares	STABLE	STABLE
Panel B:$F_{cf}(cf/y,y^2,ub,h,ff)$	**1971–1989**	**1989–2014**
Optimal lag	(3,1,1,0,1,1)	(1,0,0,0,1,0)
$I(0)$- $I(1)$	3.06–4.15	2.56–3.49
F-Statistics	18.58***	4.30***
Significant level	1%	5%
R^2	0.99	0.55
Diagnostic test		
Breusch-Godfrey LM Test:	5.689 (0.284)	1.939 (0.178)
Jarque-Bera	0.469 (0.791)	16.683 (0.00)
Breusch-Pagan-Godfrey	2.167 (0.286)	0.555 (0.781)
ARCH	0.965 (0.451)	0.121 (0.946)
WHITE	2.621 (0.232)	0.549 (0.787)
CUSUM	STABLE	STABLE
CUSUM of Squares	STABLE	STABLE
Panel C:$F_{wf}(wf/y,y^2,ub,h,ff)$	**1971–2003**	**2004–2014**
Optimal lag	(2,1,0,0,0,3)	N/A
$I(0)$- $I(1)$	3.06–4.15	N/A
F-Statistics	5.229***	N/A
Significant level	1%	N/A
R^2	0.723	N/A
Diagnostic test		
Breusch-Godfrey LM Test:	1.890 (0.164)	N/A
Jarque-Bera	0.221 (0.895)	N/A
Breusch-Pagan-Godfrey	0.782 (0.655)	N/A
ARCH	1.329 (0.289)	N/A
WHITE	0.857 (0.592)	N/A
CUSUM	STABLE	STABLE
CUSUM of Squares	STABLE	STABLE
Panel D:$F_{co_2}(co_2/y,y^2,ub,h,ff)$	**1971–1995**	**1996–2016**
Optimal lag	(2,1,0,1,1,1)	(1,0,1,1,1,1)
$I(0)$- $I(1)$	3.06–4.15	2.08–3.00
F-Statistics	7.196***	3.27*
Significant level	1%	10%
R^2	0.537	0.922
Diagnostic test		
Breusch-Godfrey LM Test:	0.724 (0.408)	1.020 (0.416)
Jarque-Bera	1.271 (0.530)	0.884 (0.643)
Breusch-Pagan-Godfrey	0.957 (0.482)	1.593 (0.261)
ARCH	0.206 (0.654)	0.058 (0.813)
WHITE	0.813 (0.813)	1.617 (0.257)
CUSUM	STABLE	STABLE
CUSUM of Squares	STABLE	STABLE

Note: the figures in parenthesis are the probability values; optimal lag length is determined by AIC.
$k = 5$, restricted intercept with no trend. *** denotes 1% significant level, ** denotes 5% significant level.
I (0) denotes lower bound critical value, I (1) denotes upper bound critical value.
***denotes 1% significant level. ** denotes 5% significant level. * denotes 10% significant level.

The results also show evidence of an inverted U-shaped relationship between environmental degradation and real GDP. Hydroelectricity is found to significantly reduce environmental degradation while urbanization increases only CO_2 emissions. The inclusion of fossil fuel did not change the behavior of hydroelectricity on the environment but fossil fuels is found to significantly increase water footprint. The sub-period analysis shows that

Table 11
Summary of the long-run relationship for the sub-period models with fossil fuels.

Explanatory Variables	Coefficient	t-stat	Coefficient	t-stat
Panel A:$F_{ef}(ef/y,y^2,h,ub,ff)$	**1971–1990**		**1991–2014**	
y	3.621	1.034	6.159	0.922
y^2	−0.101	−0.478	−0.344	−0.979
h	−0.139***	−3.207	−0.075	−0.800
ub	−1.788***	−5.166	−1.488**	−2.056
ff	−0.411***	−2.758	0.824	1.573
Constant	−23.196	−1.364	−10.648	−0.288
Panel B:$F_{cf}(cf/y,y^2,h,ub,ff)$	**1971–1989**		**1990–2014**	
y	−14.806	−0.708	14.528**	2.325
y^2	1.270	0.945	−0.721**	−2.072
h	−0.993**	−2.452	−0.050	−0.484
ub	1.604	1.113	−1.250*	−1.715
ff	−2.596**	−2.381	−0.028	−0.131
Constant	−22.574	−0.342	−67.445**	−2.231
Panel C:$F_{wf}(wf/y,y^2,h,ub,ff)$	**1971–2003**		**2004–2014**	
y	6.158**	3.371	N/A	N/A
y^2	−0.401***	−3.391	N/A	N/A
h	0.009	0.194	N/A	N/A
ub	0.179	0.431	N/A	N/A
ff	0.595***	3.713	N/A	N/A
Constant	−16.928**	−2.268	N/A	N/A
Panel D: $F_{co_2}(co_2/y,y^2,h,ub,ff)$	**1971–1995**		**1996–2016**	
y	17.071***	3.450	37.932*	1.727
y^2	−0.851***	−3.136	−2.100*	−1.725
h	−0.553**	−2.233	0.140	1.071
ub	2.036	1.096	−3.606	−1.452
ff	−1.210***	−2.635	0.827*	1.835
Constant	−115.159***	−4.276	−140.986	−1.528

***denotes 1% significant level. ** denotes 5% significant level. * denotes 10% significant level.

relationship between the variables can sometimes vary from one period to another. Except for the ecological footprint per capita model, hydroelectricity if found to significant in the first periods across the other three models. The Granger causality test results show evidence of one-way unidirectional causality running from hydroelectricity consumption per capita and fossil fuels consumption per capita to all measures of environmental degradation and real GDP per capita. There is evidence of bidirectional causal relationship between real GDP and all environmental indices as well as between urbanization and water footprint and carbon footprint per capita.

The empirical findings are laced with a number of important policy implications. First, the insignificance of the coefficient of the GDP square per capita with respect to ecological footprint couple with the fact that the coefficients of the GDP are substantially larger than that of the GDP square suggest that the validation of the EKC hypothesis is not categorical for Malaysia. Moreover, the feedback hypothesis between real GDP per capita and the environmental indices also points to the fact that while environmental degradation can Granger cause economic growth, economic growth can also Granger cause environmental degradation. Therefore, Malaysia must exercise caution in the pursuant of her economic growth objective as without appropriate policy intervention the EKC may not happen or may take longer than hypothesized. Thus, to guarantee the empirical prediction of the EKC hypothesis, Malaysia will have to implement appropriate policies to reduce environmental degradation.

Insights on relevant policies to mitigate environmental degradation while promoting economic growth can be inferred from the results of the VECM. The one-way unidirectional causality running from hydroelectricity consumption per capita to real GDP per capita

Table 12
Summary of long-run VECM Granger causality results.

Model	Long-run causality	Dependent variable				
$F_{ef}(ef/y, y^2, h, ub)$	ect_{-1}	Δef	$\Delta y(\Delta y^2)$	Δh	Δub	Δff
		0.001***	−0.031*	−0.001	−0.001	N/A
		(-2.987)	(-1.970)	(-0.066)	(2.667)	N/A
$F_{ef}(ef/y, y^2, h, ub)$	ect_{-1}	Δcf	$\Delta y(\Delta y^2)$	Δh	Δub	Δff
		−0.002**	−0.192***	−0.002	0.00002**	N/A
		(-2.361)	(-3.089)	(-1.275)	(1.999)	N/A
$F_{wf}(wf/y, y^2, h, ub)$	ect_{-1}	Δwf	$\Delta y(\Delta y^2)$	Δh	Δub	Δff
		−0.453***	−53.033***	0.139	−0.003	N/A
		(-2.573)	(-4.167)	(0.295)	(-0.856)	N/A
$F_{co_2}(co_2/y, y^2, h, ub)$	ect_{-1}	Δco_2	$\Delta y(\Delta y^2)$	Δh	Δub	Δff
		−0.121**	−20.660***	−0.175	−0.001	N/A
		(-2.218)	(-2.979)	(-1.157)	(0.389)	N/A
$F_{ef}(ef/y, y^2, h, ub, ff)$	ect_{-1}	Δef	$\Delta y(\Delta y^2)$	Δh	Δub	Δff
		−0.584***	−41.16*	−0.306	0.010**	−0.334
		(-2.670)	(-1.746)	(-0.581)	(2.442)	(-1.293)
$F_{ef}(ef/y, y^2, h, ub, ff)$	ect_{-1}	Δcf	$\Delta y(\Delta y^2)$	Δh	$\Delta ub \Delta u$	Δff
		−0.515***	−22.306***	−0.010	0.003*	−0.169
		(-3.755)	(-2.634)	(-0.049)	(1.668)	(-1.881)
$F_{wf}(wf/y, y^2, h, ub, ff)$	ect_{-1}	Δwf	$\Delta y(\Delta y^2)$	Δh	Δub	Δff
		−0.996***	−75.298***	0.019	−0.006	−0.072
		(-4.587)	(-3.994)	(0.027)	(-1.263)	(-0.020)
$F_{co_2}(co_2/y, y^2, h, ub, ff)$	ect_{-1}	Δco_2	$\Delta y(\Delta y^2)$	Δh	Δub	Δff
		−0.004***	−0.395*	0.007	0.001	0.001
		(-2.963)	(-1.832)	(1.508)	(0.686)	(0.370)

Figures in parenthesis are the t-statistic. *** denotes 1% significant level; ** denotes 5% significant level.
*denotes 10% significant level.

and to environmental degradation suggests that policies that promote the consumption of more hydroelectricity can help Malaysia mitigate the negative effects of environmental degradations while promoting economic growth. Such policies could include the implementation of hydroelectricity production tax rebates and or subsidies and rebates or tax grants for the installation of hydropower energy systems.

Second, the negative and significant relationship between hydroelectricity consumption per capita and all measures of environmental degradation confirms its reputation as a green source of electricity generation with the capacity to promote a green environment thus reducing the rate of environmental degradation. Although, there is a caveat as the inclusion of fossil fuels in the sensitivity test shows that hydroelectricity may increase water footprint. The good news however is that this relationship is found to be insignificant. This implies that hydroelectricity being a water-based electricity generating fuels may have some unwanted impacts on the water footprint but these effects are not likely to significantly erode the overall advantages associated with the use of hydropower to generate electricity in Malaysia.

Third, though negative and significant, the magnitude of the impacts of hydroelectricity on the environment is relatively small. Thus, to have an improved hydroelectricity impact on the environment its share in the fuel share mix has to be increased. Increasing the share of hydroelectricity in the fuel mix will also reduce the impact of tariff hike as it is not affected by the fluctuations in global market price like the fossil fuels. The implementation of policy programs such as the Feed-in Tariff (FiT) has increased the contribution Renewable Energy (RE) in power generation in the country as, for instance, under the FiT mechanism, the cumulative installed capacity Megawatt (MW) of commissioned RE installations between 2012 and 2017 is 533.94MW generating a total of 2,804,161.32MW within the same period (Sustainable Energy Development (SEDA), 2017). This is a remarkable improvement considering the fact that only 12MW of RE was generated between 2001 and 2005 under the Small Renewable Energy Power (SREP) program launched in 2001. By the end of the SREP program in 2010, only 64.95MW was generated (Wong et al., 2015). These programs should however be complimented with carbon tax to discourage the use of fossil fuels. The more the use of fossil fuel is forgone the more likelihood the adoption of more renewable energy sources including hydroelectricity.

Fourth, hydropower plants are not limited to generating electricity as they could be applied to other uses such as flood control, water supply, irrigation, draught management and recreational facilities for the benefit of the country. Hydrological extremes such a floods and droughts with severe environmental consequences can better be managed with the constructions of hydropower dams which can serve as reservoirs thus enhances an even distribution of water by conserving and releasing water during floods and droughts respectively. As this is likely to impose some engineering challenges, there is need to invest in researches that focus on advanced engineering and international safety standards particularly for modern dam constructions. In addition, private sector participation in the investment of hydro power projects should also be encouraged through loans and research grants.

Fifth, while the empirical evidence reveals that Malaysia's electricity generation process may not be completely environmentally unfriendly as the fossil fuels also have negative effect on all target variables bar water footprint, these 'favourable' effects are however not significant. The only significant effect of fossil fuels is on water footprint and it is positive which implies a detrimental effect. Thus, despite the dominance of fossil fuel in the electricity generation fuel mix for Malaysia its positive effects are non-significant while its detrimental effects are highly significant. The implication of this is that the most plausible, fastest, and effective method to prevent environmental deterioration while generating the needed electricity to keep the economy alive is to decarbonize the electric power sector by investing more in renewable of which hydropower is well established for Malaysia.

However, it has to be said that there are inherent limitations in the ability of the government to effectively mobilise hydroelectricity consumption per capita to reduce environmental degradation as, though Malaysia has substantial hydropower resources, time is required before they can be fully harnessed to meet the country's electricity needs. Necessary distinction has to be made between potentials and installed capacities. While the projection of the hydropower potential of the country is up to 20,000MW the installed capacity is about 4,738MW which is a just about 25% of the potential. The capital-intensive nature of hydropower plants with considerable gestation period means that it may take some time before the full potential of hydroelectricity is optimized.

Lastly, the relationship between urbanization and the components of ecological footprint suggests that Malaysia has pursued urbanization responsibly. It is however unsurprising that urbanization constitute a strain to the environment in terms of air pollution as urbanization rate has grown more than double between 1971 and 2015 (World Bank, 2017). Therefore, there is need for policies to address environmental issues emanating from urbanization. Since transportation is one sector where urbanization negatively impacts the environment through the emission emanating from fuel combustion from vehicles, policies that promote the use of electric vehicles, mass transit and rail transportation should be considered.

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References

Al-Mulali, U., Saboori, B., Ozturk, I., 2015. Investigating the environmental Kuznets curve hypothesis in Vietnam. Energy Policy 76, 123–131.
Al-Mulali, U., Ozturk, I., Solarin, S.A., 2016a. Investigating the environmental Kuznets curve hypothesis in seven regions: the role of renewable energy. Ecol. Indic. 67, 267–282.
Al-Mulali, U., Solarin, S.A., Sheau-Ting, L., Ozturk, I., 2016b. Does moving towards renewable energy causes water and land inefficiency? An empirical investigation. Energy Policy 93, 303–314.
Chandran, V.G.R., Tang, C.F., 2013. The impacts of transport energy consumption, foreign direct investment and income on CO 2 emissions in ASEAN-5 economies. Renew. Sustain. Energy Rev. 24, 445–453.
Chang, C.C., 2010. A multivariate causality test of carbon dioxide emissions, energy consumption and economic growth in China. Appl. Energy 87 (11), 3533–3537.
Dietz, T., Rosa, E.A., 1997. Effects of population and affluence on CO2 emissions. Proc. Natl. Acad. Sci. 94 (1), 175–179.
Dinda, S., 2004. Environmental Kuznets curve hypothesis: a survey. Ecol. Econ. 49 (4), 431–455.
Du, L., Wei, C., Cai, S., 2012. Economic development and carbon dioxide emissions in China: provincial panel data analysis. China Econ. Rev. 23 (2), 371–384.
Economic Planning Unit, 2015. The Eleventh Malaysian Plan (2016-2020). Malaysia.
Guangyue, X., Deyong, S., 2011. An empirical study on the environmental kuznets curve for China's carbon emissions: based on provincial panel data. Chin. J. Popul. Resour. Environ. 9 (3), 66–76.
International Energy Agency (IEA), 2012. Technology Roadmap, Hydropower. https://www.iea.org/publications/freepublications/publication/2012_Hydropower_Roadmap.pdf.
Jalil, A., Feridun, M., 2011. The impact of growth, energy and financial development on the environment in China: a cointegration analysis. Energy Econ. 33 (2), 284–291.
Lau, L.S., Choong, C.K., Eng, Y.K., 2014. Investigation of the environmental Kuznets curve for carbon emissions in Malaysia: do foreign direct investment and trade matter? Energy Policy 68, 490–497.
Lau, E., Tan, C.C., Tang, C.F., 2016. Dynamic linkages among hydroelectricity consumption, economic growth, and carbon dioxide emission in Malaysia. Energy Sources Part B Econ. Plan. Policy 11 (11), 1042–1049.
Narayan, P.K., Popp, S., 2010. A new unit root test with two structural breaks in level and slope at unknown time. J. Appl. Stat. 37 (9), 1425–1438.
National Footprint Accounts, 2016. Working Guidebook to the National Footprint Accounts: 2016. Available: at: http://www.footprintnetwork.org/content/documents/National_Footprint_Accounts_2016_Guidebook.pdf.
Network, G.F., 2018. Global Footprint Network. Advancing the Science of Sustainability. Available at: www.footprintnetwork.org.
Ozturk, I., Al-Mulali, U., 2015. Investigating the validity of the environmental Kuznets curve hypothesis in Cambodia. Ecol. Indic. 57, 324–330.
Perron, P., 1997. Further evidence on breaking trend functions in macroeconomic variables. J. Econ. 80 (2), 355–385.
Pesaran, M.H., Shin, Y., Smith, R.J., 2001. Bounds testing approaches to the analysis of level relationships. J. Appl. Econ. 16 (3), 289–326.
Petroleum, B., 2016. BP Statistical Review of World Energy.
Saboori, B., Sulaiman, J., 2013a. CO2 emissions, energy consumption and economic growth in Association of Southeast Asian Nations (ASEAN) countries: a cointegration approach. Energy 55, 813–822.
Saboori, B., Sulaiman, J., 2013b. Environmental degradation, economic growth and energy consumption: evidence of the environmental Kuznets curve in Malaysia. Energy Policy 60, 892–905.
Saboori, B., Sulaiman, J., Mohd, S., 2012. Economic growth and CO2 emissions in Malaysia: a cointegration analysis of the environmental Kuznets curve. Energy Policy 51, 184–191.
Malaysia, SEDA, 2017. The Sustainable Energy Development Authority of Malaysia. http://seda.gov.my/. (Accessed 19 December 2017).
Shafie, S.M., Mahlia, T.M.I., Masjuki, H.H., Andriyana, A., 2011. Current energy usage and sustainable energy in Malaysia: a review. Renew. Sustain. Energy Rev. 15 (9), 4370–4377.
Shahbaz, M., Solarin, S.A., Mahmood, H., Arouri, M., 2013. Does financial development reduce CO2 emissions in Malaysian economy? A time series analysis. Econ. Model. 35, 145–152.
Solarin, S.A., 2014. Tourist arrivals and macroeconomic determinants of CO2 emissions in Malaysia. Anatolia 25 (2), 228–241.
Solarin, S.A., Lean, H.H., 2016. Natural gas consumption, income, urbanization, and CO2 emissions in China and India. Environ. Sci. Pollut. Res. 23 (18), 18753–18765.
Solarin, S.A., Al-Mulali, U., Ozturk, I., 2017. Validating the environmental Kuznets curve hypothesis in India and China: the role of hydroelectricity consumption. Renew. Sustain. Energy Rev. 80, 1578–1587.
Stern, N.H., 2007. The Economics of Climate Change: the Stern Review. Cambridge University Press.
Stern, D.I., 2014. The Environmental Kuznets Curve: a Primer. Centre for Climate Economics and Policy. Crawford School of Public Policy, ANU.
Tan, F., Lean, H.H., Khan, H., 2014. Growth and environmental quality in Singapore: is there any trade-off? Ecol. Indic. 47, 149–155.
Tiwari, A.K., Shahbaz, M., Hye, Q.M.A., 2013. The environmental Kuznets curve and the role of coal consumption in India: cointegration and causality analysis in an open economy. Renew. Sustain. Energy Rev. 18, 519–527.
Ulucak, R., Lin, D., 2017. Persistence of policy shocks to ecological footprint of the USA. Ecol. Indic. 80, 337–343.
United Nations Development Programme, 2015. 2030 Agenda for Sustainable Development.
U.S. Energy Information Administration (EIA), Washington DC, 2016. International Energy Outlook.
Wong, S.L., Ngadi, N., Abdullah, T.A.T., Inuwa, I.M., 2015. Recent advances of feed-in tariff in Malaysia. Renew. Sustain. Energy Rev. 41, 42–52.
World Bank Group, 2017. World Development Indicators 2017. World Bank Publications.
World Nuclear Association, 2014. Climate Change-the Science.
World Resources Institute, 2009. Climate Analysis Indicators Tool (CAIT). World Resources Institute, Washington, DC, 7.0.
World Wide Fund for Nature (WWF), 2014. Living Planet report.: Species and Spaces, People and Places.