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Mehmet Balcilar, Zeynel Abidin Ozdemir, Huseyin Ozdemir, Muhammad Shahbaz

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Mehmet Balcilar[a, b, c]
[a] Eastern Mediterranean University, Northern Cyprus, via Mersin 10, Turkey
[b] Montpellier Business School, Montpellier, France
[c] University of Pretoria, Pretoria, South Africa
e-mail: mehmet@mbalcilar.net

Zeynel Abidin Ozdemir[d,e, *]
[d] Gazi University, Ankara, Turkey
[e] Economic Research Form, Cairo, Egypt
e-mail: zabidin@gazi.edu.tr

Huseyin Ozdemir[e]
[e] Gazi University, Ankara, Turkey
e-mail: huseyinozdemir83@gmail.com

Muhammad Shahbaz[b]
[b] Montpellier Business School, Montpellier, France
e-mail: shahbazmohd@live.com

Abstract

This paper investigates the relationship between carbon dioxide emissions, energy consumption and economic growth in the G-7 countries from a historical perspective. To this end, taking time varying interaction and business cycle into account, we use the historical decomposition method for the first time in the literature. Our results provide evidence that Canada, Italy, Japan and partly the United States need to sacrifice economic growth if they aim to reduce CO2 emissions by decreasing the fossil-based energy use. This situation is not valid since the early 1990s for France, throughout the analysis period for Germany and a few exceptions in all periods for the UK. Furthermore, empirical results provide evidence contrary to the EKC hypothesis for Canada, Germany, Japan, the UK and the US. We found BC-shaped and N-shaped curve for France and Italy, respectively. Although the EKC hypothesis is not valid for Germany and the UK, economic growth has no damaging effect on environmental quality. Also, this effect seems to be cyclical for the US. While the energy conservation theory is fully supported for Canada, it is strongly supported for France, Italy, Japan and the US with the exception of some periods. In addition to these findings, we find strong evidence to support the growth theory for all the G-7 countries.

Keywords: CO2 emissions; Energy consumption; Economic growth; Historical Decomposition; G-7 Countries.
JEL Codes: C22, Q42, Q48

[*] Corresponding author

I Introduction

The United Nations (UN) member states set 17 Sustainable Development Goals (SDGs) and adopted the 2030 Agenda for Sustainable Development under the United Nations umbrella in 2015. The second annual report named as *Sustainable Development Goals Report 2017* was published in 2017 to follow the progress in these 17 goals [74]. Three of the 17 goals mentioned in the report are related with energy, economic growth and climate change. According to the report, global carbon dioxide (CO2) emissions have already exceeded the level of CO2 emissions in 1990. Furthermore, the level of emissions from 2000 to 2010 increased more rapidly compared to the previous three decades. Also, the level of CO2 emissions has risen roughly by 50 percent since 1990. If the current greenhouse gas emissions continue on a global scale, the temperature at the end of this century is expected to be 1.5°C higher than the global temperature between 1850 and 1900. A crucial point emphasized in the report is that energy consumption is responsible for 60% of the total global greenhouse gas emissions. The report further stated that it is possible to prevent this worst-case scenario with major institutional and technological changes particularly in the field of energy. It is also emphasized that economic growth is the main driver of sustainable economic growth, which is defined as the economic progression that does not harm the environment. Economic growth, social inclusion and environmental protection should be harmonized by countries to accomplish sustainable development. To address the climate change problem, the United Nations has historically taken serious steps. The most comprehensive step taken by the UN is Paris Agreement, which has been ratified by 175 of the 197 parties so far. It entered into force in 2016 and the main aim of the agreement is to keep global warming at well below 2°C. Among the G-7 countries, the US announced its withdrawal from the Paris Agreement in January 2017 despite all domestic policy objections.

If a country fosters economic growth using carbon based fossil energy sources, it massively emits different amounts of heat-trapping gases, especially CO2, into the atmosphere. In the light of this reality, the interaction between environmental degradation, energy consumption and economic growth has been a highly debatable issue within the energy economics literature over the past few decades. In order to draw different policy implications, researchers have focused on three research strands using various econometric models for different countries and regions around the world.

The first strand emphasizes the relationship between economic growth and energy consumption without taking into account environmental quality of economic development. Following the seminal study of Kraft and Kraft [45], researchers have attempted to find the nexus between output growth and energy consumption by utilizing mostly the Granger causality test procedure and its variations to determine the direction of the causal linkage. Akarca and Long [3], Eden and Hwang [33], Apergis and Payne [11,12] and more recent studies such as Mutascu [49], Fang and Chang [36], Tang et al. [72], Bayramoglu and Yildirim [21], Saidi et al. [64], Destek and Aslan [30], Rodríguez-Caballero and Ventosa-Santaulària [61], Menagaki and Tugcu [48], Narayan and Doytch [51], Rafindadi and Ozturk [60], Shahbaz et al. [68], Ouyang and Li [53], Kourtzidis et al. [44], Bakirtas and Akpolat [16], and Wu and Yan [76] examine the inter-linkages between energy consumption and economic growth to determine four types of energy-growth nexus: (i) the *growth hypothesis* i.e. if there is unidirectional causality from energy consumption to economic growth, the rise in energy consumption contributes to economic growth, (ii) the *conservation hypothesis* is valid when economic growth drives the total energy consumption, (iii) the *feedback hypothesis* proposes a bi-directional causality between energy consumption and economic growth in economy, and (iv) the *neutrality hypothesis* proposes no dynamic links between these two variables.

The second strand of empirical studies attempt to explore the relationship between energy consumption and income growth, which is known as the *Environmental Kuznets Curve* (EKC) hypothesis in the literature. The EKC hypothesis, suggested by Grossman and Krueger [38, 39], asserts that there is a U-shaped relationship between the level of per capita CO2 emissions and per capita output growth. The EKC hypothesis also maintains that environmental degradation increases as income per capita surges, but it begins to decline upon reaching a certain threshold by means of raising public awareness and technological progress. Some pioneering papers such as Grossman and Krueger [38], Shafik and Bandyopadhyay [67], Shafik [66], Selden and Song [65], Cole et al. [27], and De Bruyn et al. [29] investigate whether the EKC hypothesis is verified in the analyzed countries or not. Furthermore, Dogan and Turkekul [31], Bilgili et al. [24], Jebli et al. [41], Al-Mulali and Ozturk [8], Narayan et al. [50], Ozatac et al. [54], Wang et al. [75], Ozokcu and Ozdemir [55], Apergis et al. [13], Dogan and Ozturk [32], Pablo-Romero et al. [56], Saidi and Mbarek [63], Zoundi [80] , Al-mulali and Sab [7], Appiah [14], Aslan et al. [15], Katircioglu et al. [42] and Olale et al. [52]

have recently investigated the existence of the EKC hypothesis in various economies. Contrary to these findings, some researchers find particular empirical evidence supporting N-shaped EKC hypothesis, which proposes that income growth first increases environmental degradation, and then prevents it, but eventually increases it again after reaching a certain income level [5, 20]. Besides the inverted-U shape and N-shaped curve, researchers also find U-shaped, inverted N-shaped, M-shaped, and a monotonic increasing or decreasing relationship between various greenhouse gas (GHG) emissions and output growth. For instance, Bekhet and Othman [22] find evidence to support the inverted N-shaped EKC hypothesis for Malaysia between 1971 and 2015. Furthermore, a monotonically increasing relationship is found between CO2 and income by Akbostanci et al. [6] for 58 provinces in Turkey using the panel data model. In addition to these findings, Yang et al. [77] analyze the EKC hypothesis for 67 countries from 1971 to 2010 and find evidence supporting the inverted-N, M, inverted-U and monotonically increasing shape varying depending on different regions or economic development.

The third and last strand of studies combines these two approaches to investigate three-way linkages among CO2 emissions, energy consumption and output growth in the literature. Ang [9] examined for the first time the dynamic relationship between pollutant emissions, energy consumption, and economic development for France over the 1960–2000 period. According to Ang [9], if these three variables are intensely inter-related, omitting one may cause serious problems in empirical analysis. Tiba and Omri [73] review the literature regarding the nexus between energy, environment and economic growth at both country-specific and multi-countries level. Following Ang [9], various researchers investigate the three-way nexus for different countries: Soytas et al. [70] (the US), Zhang and Cheng [79] (China), Halicioglu [40] (Turkey), Acaravci and Ozturk [1] (nineteen European countries), Pao and Tsai [57] (BRICS countries), Alam et al. [4] (India), and Saboori et al. [62] (27 OECD countries). The three-way linkages are also examined in more recent studies such as Chen et al. [25], Ahmad et al. [2], Zaman and Abd-el Moemen [78] and Antonakakis et al. [10]. By utilizing Markov Switching-Vector Autoregressive (MS-VAR) and MS-Granger Causality methods, Bildirici and Gokmenoglu [23] found different results regarding the nexus between environmental pollution, economic growth and hydropower energy consumption in different regimes of the business cycles of the G7 countries.

The empirical studies carried out so far use various econometric techniques, data span and individual or multi-country level analysis. In the energy-environment-growth nexus literature, the most frequently used methods for country-specific and multi-country level analyses are the Granger/Sims causality tests, Engle-Granger/Johansen-Juselius cointegration, ARDL bounds test and error-correction models and the panel version of these methods. These methods can be defined as full-sample methods which produce one statistically significant conclusion over the analysis period. Furthermore, to the best our knowledge, few available studies take into account the business cycle effect on energy-environment-growth relationship as well as structural break and regime shift in the whole analysis period. As stated by Balcilar et al. [19] and Balcilar and Ozdemir [17, 18], the empirical studies analyzing the causal relationships among variables but ignoring structural break and regime shifts may produce misleading results because the dynamic interaction among these variables is not stable in sub-periods. Fortunately, the historical decomposition (HD) method allows one to overcome this problem because considers time varying effect of a variable on the other, taking into consideration structural break and regime shifts occurring in time. Also, the traditional causality methods do not give information about the magnitude and sign of the relationship between variables; however, the HD method demonstrates the variation in a related variable which is driven by a sequence of shocks of different magnitude and signs. This allows one to analyze the political inference in depth.

We use annual time series of CO2 emissions per capita, energy consumption per capita and real GDP per capita, covering the period from 1960 to 2014 for the G-7 countries with the exception of one country. The exception is Germany, with the data covering the period between 1970 and 2014. In this study, the historical decomposition method is used to investigate the dynamic linkages between CO2 emissions per capita, energy consumption per capita and real GDP per capita. The three major policy implications are evaluated together for the G7 countries in time varying manner as follows. The HD analyzes indicates that Canada, Italy, Japan and partly the US must forgo economic growth if they aim to decrease fossil fuel-based energy consumption to protect the environment. This situation is not valid for France after the 1990s, for Germany throughout the whole period, and for the United Kingdom over the period except for a few trivial sub-periods. As regards the EKC hypothesis, we find strong evidence to support N-shaped EKC hypothesis for Italy. The EKC hypothesis is not valid for Canada, Germany and the United Kingdom over the whole period. Besides, in France, the influence of output growth on environment oscillates up to the 2000s, and then it continuously improves the environment. Moreover, it is seen that the effect of economic growth on environment is cyclical over the time period in the US. The conservation theory is strongly supported for Canada; periodically supported for France, Italy, Japan and the US; but not supported for Germany and the UK. In brief, the historical decomposition method will bring a new breath to solve the vicious conflicts experienced in the environmental economics literature. The reason for selecting the G7 countries (Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States) is that these countries consume 35.45% of the world's total energy consumption, and they account for 55.3% of the world's total GDP and consequently cause 33% of the world's total CO2 emissions in average terms over the 1991–2014 period (WDI, World Development Indicators 2018).

The rest of the paper is organized as follows: Section II presents the econometric model employed. Section III describes the data and evaluates the empirical results. Section IV discusses the empirical findings. The final section summarizes and concludes the paper.

II Econometric Methodology

Vector autoregression (VAR) is a stochastic process model which is widely used in the literature to analyze the dynamic behavior of economic and financial time series for structural inference and policy analysis. Let $y_t = (\Delta \log CO_2, \Delta \log EN, \Delta \log RGDP)'$ represent the (3x1) vector of time series and CO_{2t} EN_t and $RGDP_t$ denote CO2 emissions per capita, energy consumption per capita and real GDP per capita for the G-7 countries. The basic VAR(p) model has the following form

$$y_t = c + \Pi_1 y_{t-1} + \Pi_2 y_{t-2} + \cdots + \Pi_p y_{t-p} + \varepsilon_t \tag{1}$$

where Π_i are (3x3) coefficient matrices, c is (3x1) vector of constants and ε_t is a (3×1) zero mean white noise (innovation) vector process with time invariant and uncorrelated covariance matrix. The historical decomposition used in this study can be computed from the moving average representation (MA) as follows (see [47]);

$$y_t = \mu + \left(I - \Pi_1 L^1 - \Pi_2 L^2 - \cdots - \Pi_p L^p\right)^{-1} \varepsilon_t = \sum_{i=0}^{\infty} \Phi_i \varepsilon_{t-i} \tag{2}$$

where $\phi(L) = (I - \Pi_1 L - \cdots - \Pi_p L)^{-1}$ is a lag polynomial with (3×3) coefficient matrices Φ_i and L is the lag operator. Furthermore, any positive definite matrix M can be written as QQ', where Q is the lower triangular matrix. Based on this approach, we can write the expression in equation (2) as follows:

$$y_t = \mu + \sum_{i=0}^{\infty} \Phi_i Q Q^{-1} \varepsilon_{t-i} = \mu + \sum_{i=0}^{\infty} \Theta_i \eta_{t-i} \quad (3)$$

,

where $\Theta_i = \Phi_i Q$ and $\eta_t = Q^{-1}\varepsilon_t$. Provided that we divide the expression in equation (3) into two parts before and after the observation date t, we can decompose the shocks on any variable as historical and base projection (i.e. forecast).

$$y_t = \mu + \sum_{i=0}^{t-1} \Theta_i \eta_{t-i} + \sum_{i=t}^{\infty} \Theta_i \eta_{t-i} \quad (4)$$

,

If the disappearance of MA coefficients phenomenon is taken into account, the effect of second term on y_t diminishes as t increases. Therefore, we can drop the second term of the expression in equation (4), and y_t approximately equals to the first term (e.g. $\hat{y}_t \cong \sum_{i=0}^{t-1} \Theta_i \eta_{t-i}$). In brief, the derivation of the historical decomposition of each shock on any variable can be explained in three stages. First, we compute the MA coefficient matrices as explained in (2). Second, we calculate each structural shock as shown in (3). Lastly, we derive each structural shock on a specific variable at each time and graph.

To find the confidence interval for the historical decomposition analysis, we utilize the bootstrap method as described in [34]. We can establish the bootstrap procedure in a stepwise manner as follows:

1) (3x1) innovations, $\hat{\varepsilon}_t = y_t - \hat{c} - \hat{\Pi}_1 y_{t-1} - \hat{\Pi}_2 y_{t-2} - \cdots - \hat{\Pi}_p y_{t-p}$, are obtained from the estimated VAR(p) model using the ordinary least squares.
2) Each innovation is redrawn 5000 times with previous centering on the mean and it is obtained as $\hat{\varepsilon}^*_{k,N}$, where k denotes the number of series used in the VAR model and $N = 1,2,\ldots,5000$.
3) New pseudo time series used in model are calculated using new innovations which are computed in step (2).

4) Finally, we re-estimate the VAR(p) model 5000 times using pseudo time series and we obtain the historical decomposition results to find the upper and lower bounds of the confidence interval (e.g. $y_t^* \cong \sum_{i=0}^{t-1} \Theta_i^* \eta_{t-i}^*$).

III Data and Empirical Analysis

In the empirical analysis, we examine the dynamic relationship between CO2 emissions, energy consumption and economic growth of the G-7 countries, that is, Canada, France, Germany, Italy, Japan, UK and USA, using annual data CO2 emissions per capita (hereafter CO2 emissions), energy consumption per capita (hereafter energy consumption) and reel GDP per capita (hereafter output or economic growth) over the 1960-2014 period except for Germany due to data unavailability. The annual data of Germany is confined to the period from 1970 to 2014. The CO2 emissions, energy consumption and output data are obtained from the World Development Indicators (WDI) of 2017 except for the data pertaining to CO2 emissions for Germany. As the data on CO2 emissions for Germany is too limited to analyze, we calculate it dividing the total annual CO2 emissions data (obtained from BP Statistical Review of World Energy 2017) into annual population data (obtained from WDI 2017) for Germany[1]. The CO2 emissions are measured in metric tons per capita, and the energy consumption is in kg of oil equivalent; whereas, the output is in real dollar currency units at the base year of 2010 prices. All series are converted into logarithms.

To evaluate the stationary properties of the variables employed in this study, we used the familiar Z_α test of Phillips [58] and Phillips and Perron [59], which utilizes a statistics combining $T(\hat{\beta}-1)$ with a semi-parametric adjustment to overcome the serial correlation problem. T denotes the sample size of observations, while $\hat{\beta}$ represents the Ordinary Least Squares (OLS) estimation of the first order autoregressive parameter. We use Barlett Kernel as the spectral estimation method for the PP test. Also, Newey-West method is utilized to select the bandwidth. The results of Z_α test are displayed in Table 1. Column 1 of Table 1 shows the name of the countries for each variable. Column 2 of Table 1 shows the Z_α test results regarding CO2 emissions, energy consumption and output with a constant and a linear

[1] Although there seems to be a difference between our calculation and World Bank data regarding CO2 emissions per capita, both data moved together exactly after 1991, which is the beginning year of the World Bank data. It is clear that this small detail is of no significance considering the 30-year data gain for Germany.

trend in the test equation. Moreover, Column 3 of Table 1 displays the Z_α test results regarding the first difference of the CO2 emissions, energy consumption and output with only a constant in the test equation, respectively.

In Panel A of Table 1, the Z_α test results point to the conclusion that at the level, the CO2 emissions series for all the G-7 countries except for Japan fail to reject the null hypothesis of a unit root. Rejection of the null hypothesis implies that the series are stationary. The CO2 emissions of Japan reject the null hypothesis of a unit root at the 10 % significance level. When we take the first difference of CO2 emissions, the estimates confirm that all CO2 emission series for the G-7 countries reject the null hypothesis of a unit root at 1 % level of significance except for Italy. The CO2 emission series for Italy reject the null hypothesis of a unit root at 5 % level of significance as well. The Z_α test results in Panel B and Panel C of Table 1 illustrate that energy consumption and output series for all the G-7 countries fail to reject the null hypothesis of a unit root at the level, whereas the first difference of all the energy consumption and output series of the G-7 countries reject the null hypothesis of a unit root at 1 % level of significance. We use the first difference of all series for the G-7 countries to remove the deterministic components in the actual data to reach more accurate historical decomposition results from the VAR models in this study. Meanwhile, CO2 emissions, energy consumption and output become stationary and can be interpreted as growth after taking the first difference.

Table 1

Z_α unit root test results of CO2 emissions, energy consumption and real GDP for G-7 Countries

(1) Country	(2) Level[a]	(3) First Difference[b]
Panel A: CO2 emissions		
Canada	-2.116	-5.980***
France	-2.509	-7.043***
Germany	-3.084	-3.592**
Italy	-2.217	-3.02**
Japan	-3.391*	-5.128***
United Kingdom	-1.029	-8.754***
United States	-1.801	-4.810***
Panel B: Energy Consumption		
Canada	-2.336	-4.309***
France	-1.276	-5.815***

Germany	-2.721	-7.030***
Italy	-2.730	-4.028***
Japan	-2.467	-4.306***
United Kingdom	-0.099	-7.110***
United States	-1.999	-4.510***
Panel C: Output		
Canada	-2.096	-5.068***
France	-1.567	-3.663***
Germany	-1.895	-5.545***
Italy	0.728	-4.330***
Japan	-2.595	-4.083***
United Kingdom	-0.776	-4.929***
United States	-1.199	-5.227***

Notes: *, **, and *** indicate 10%, 5%, and 1% level of significance, respectively.

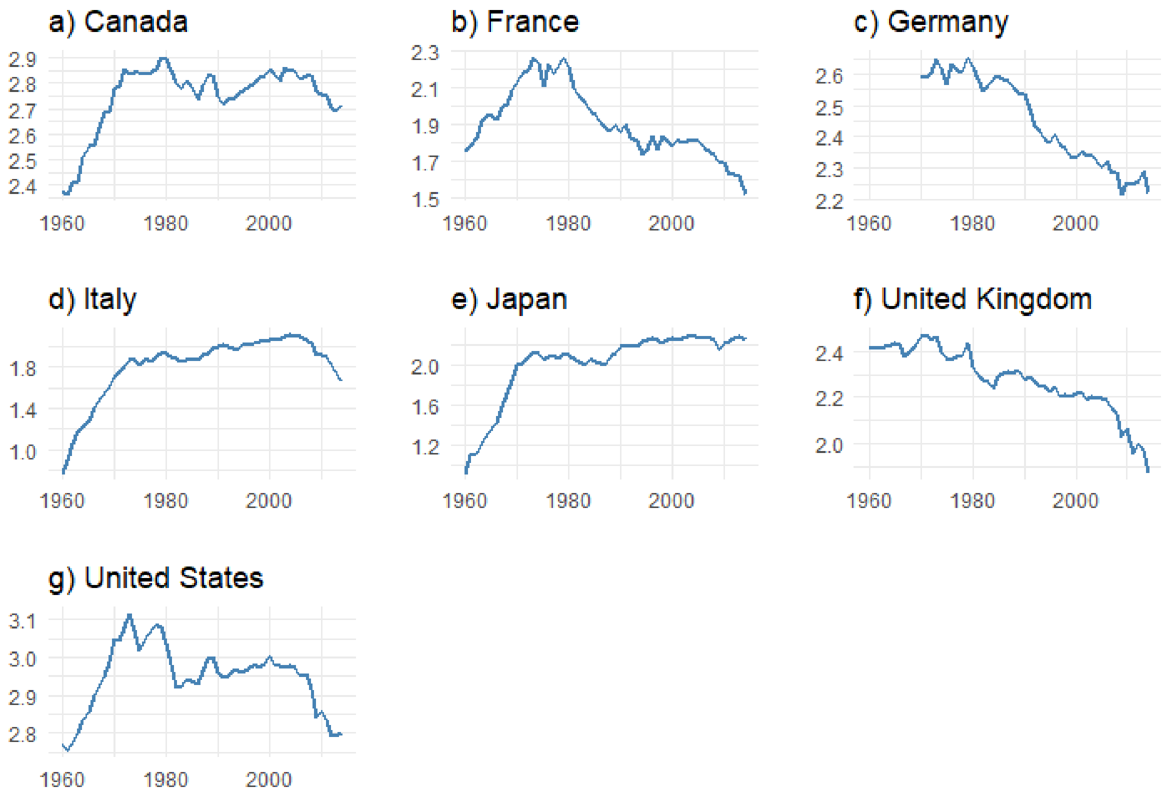
[a] A constant and a linear trend are included in the test equation; one-sided test of the null hypothesis that a unit root exists; 1%, 5%, and 10% critical values equal --4.13, -3.49 and -3.17 respectively for all countries, with the exception. The exception is Germany, where 1%, 5%, and 10% critical values equal to -4.18, -3.51 and -3.18 respectively.

[b] A constant is included in the test equation; one-sided test of the null hypothesis that a unit root exists; 1%, 5%, and 10% critical values equal -3.56, -2.91 and -2.59 respectively for all countries, with the exception. The exception is Germany, where 1%, 5%, and 10% critical values equal to -3.59, -2.93 and -2.60 respectively.

As discussed in detail in Kilian and Lütkepohl [43], sometimes one would like to decompose the VAR variables into structural shocks historically at each observation time, unlike the structural forecast error variance decompositions and the structural impulse responses analysis. Thus, we must use stationary variables in the HD analysis. As this analysis is based on stationary MA representation, whether the series are integrated or co-integrated is of no significance. In our study, we make analysis to explore the relationship between CO2 emissions per capita, energy consumption per capita and real GDP per capita as growth variables. As the Z_α test results in Table 1 reveal, all the time series for the G-7 countries are non-stationary and they contain unit roots. Although we lose some information in this approach due to transforming level of data into growth, computing the cumulative shock of any variable on other variables at each observation is highly preferable for us. In addition, we have utilized the AIC model selection criterion and the sequential likelihood ratio (LR) test statistics to determine the lag length of the VAR models for each country. The maximum lag length of each VAR model is set to ten, and then, the model is tested downwards. While the optimum lag order of the VAR model for Germany is determined as 3, the lag length is proposed as 1 for other countries.

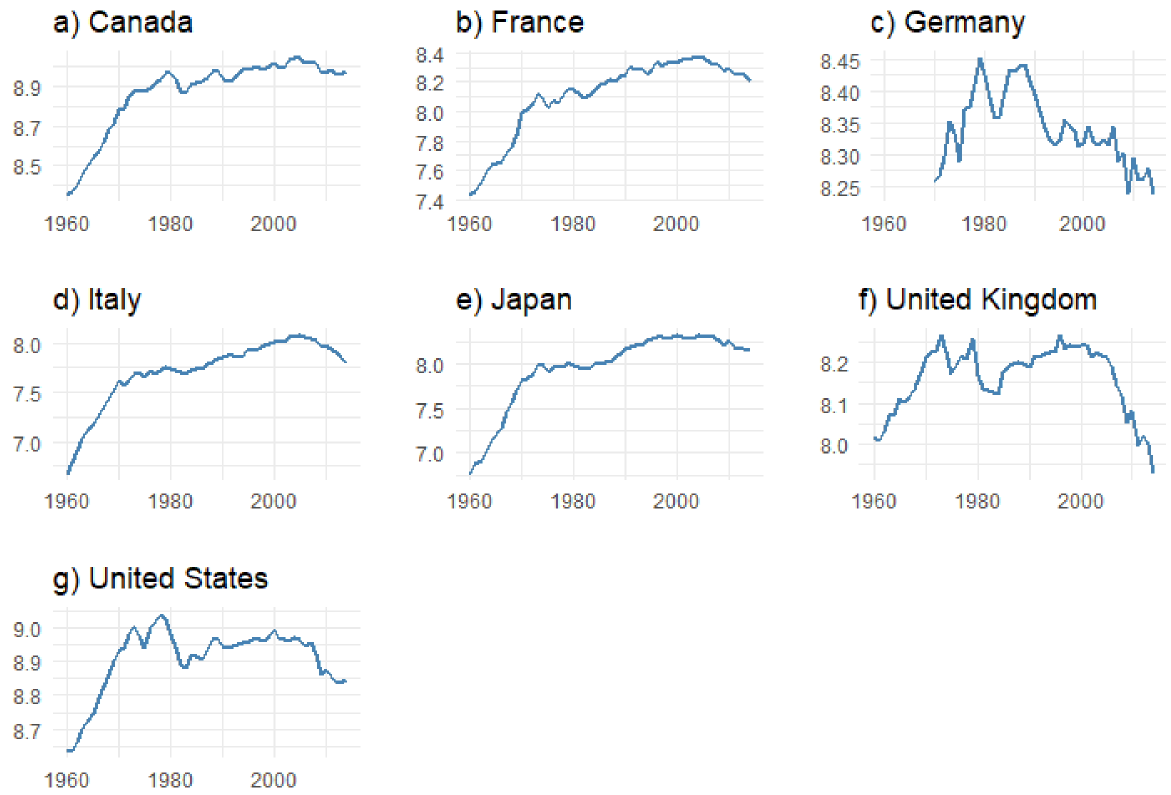
Figure 1 depicts the overall picture of the development of carbon dioxide emissions for the G-7 Countries. The level of per capita CO2 emissions significantly increased from the early 1960s to the early 1970s for Canada, France, Italy, Japan and the US. While the CO2 emissions declined dramatically in France and in the US after the early 1970s, they remained virtually flat over the remaining period for Canada, Italy and Japan. In Germany and the United Kingdom, the level of carbon dioxide emission was quite different from that of other countries. In Germany, the level of CO2 emissions also decreased between 1970 and 2014, whereas it decreased smoothly after flattening out until the early 1980s in the UK.

Figure 1 The Log of CO2 Emissions for G-7 Countries



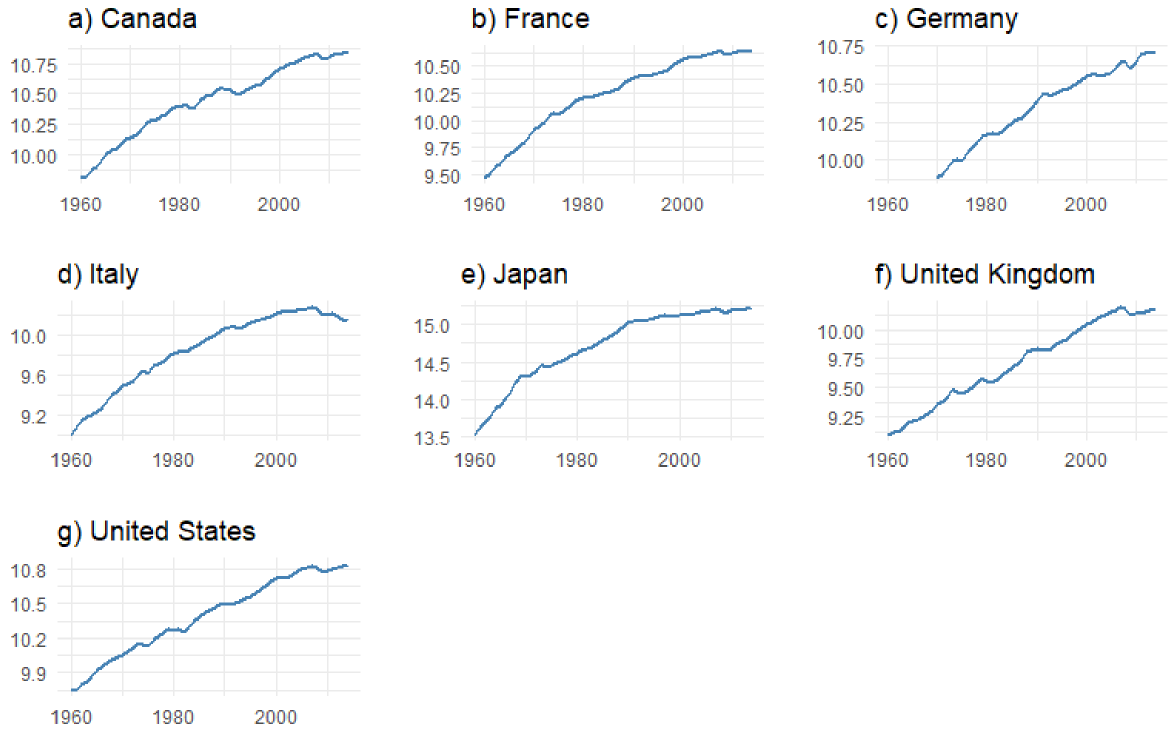
The log of per capita energy consumptions for the G-7 countries is displayed in Figure 2. Energy consumption rose sharply until the early 1970s in Canada, France, Italy and Japan, and it continued to increase up to mid-2000s. Then, it began to decline from the mid-2000s. In Germany, energy consumption showed a smooth increase in the early 1970s and reached a peak in the early 1980s. It then showed a downward trend after fluctuating from 1980 to 1990. The log of energy consumption level increased initially but declined dramatically after the early 1980s after oscillating about 30 years after the mid-1970s. On the one hand, before following a virtually straight path after a sharp decline, the energy consumption series for the US increased up to the late-1970s.

Figure 2 The Log of Energy Consumption per capita for G-7 Countries



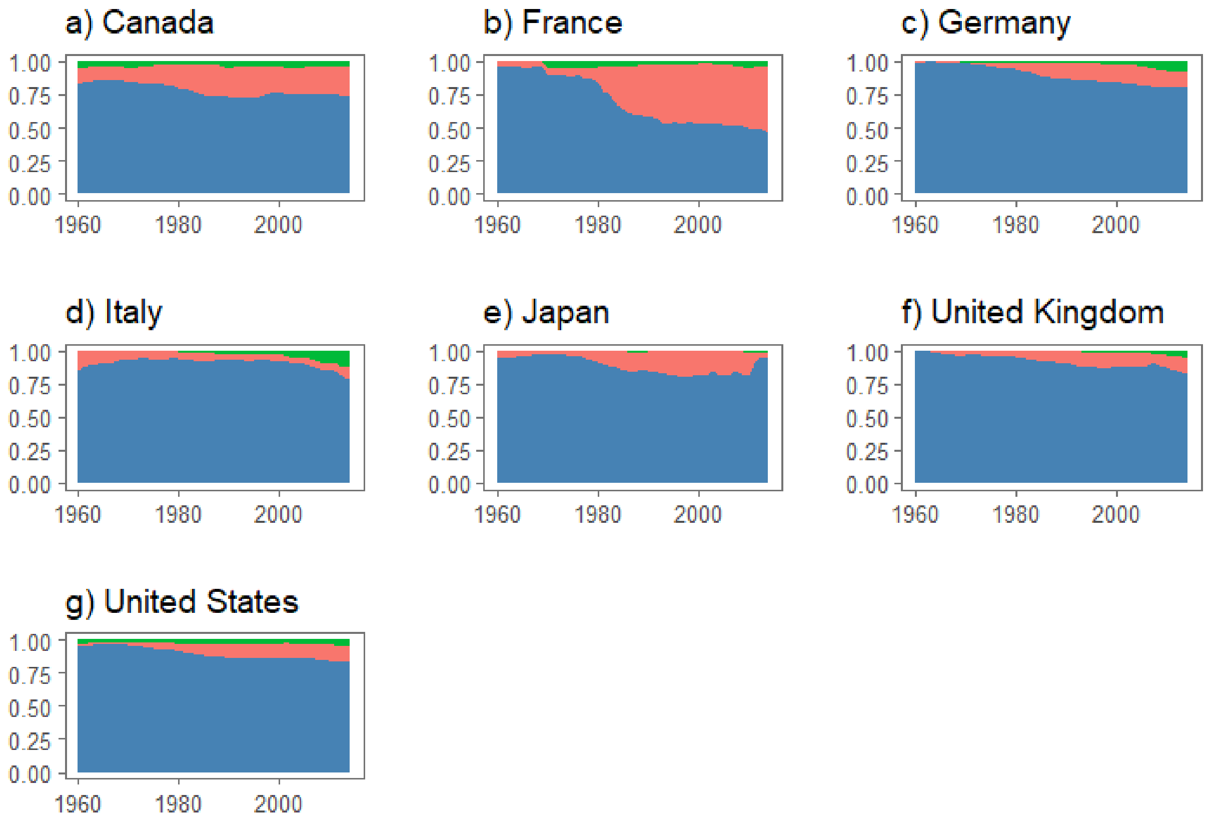
In Figure 3, the log of GDP per capita for the G-7 countries is illustrated. The GDP growth per capita showed a smooth increase over the period in Canada, Germany, the UK and the US, whereas a slightly different pattern is observed for other countries. The economic growth series pursued a decreasingly growing trend in France, Italy and Japan. The most prominent result for Italy was obtained after the late 2000s unlike the other G-7 countries, since economic growth per capita tended to decline steadily.

Figure 3 The Log of GDP per capita for G-7 Countries



In addition to the aforementioned figures, it would be appropriate to give information on how energy consumptions in the G7 countries historically converted from fossil fuels towards alternative energy sources. In Figure 4, the blue color shows the percentage of fossil fuel use, the red color indicates the percentage of alternative and nuclear energy use and the green color shows the percentile of other sources in total energy use, respectively. Fossil fuel energy consumption (% of total) and alternative and nuclear energy (% of total) data are obtained from the World Bank Indicators from 1960 to 2015. The types of energy called *others* are obtained by subtracting 100 of the sum of these two series. “1” on the vertical axis in the figure represents 100%. The fossil fuels include coal, oil, petroleum, and natural gas products, while alternative and nuclear energy such as hydropower, nuclear, geothermal, and solar power is clean energy which does not produce CO2 emission. As seen in the figure, energy consumption which causes GHG emission declines gradually as of 1960 in Canada, France, Germany, the UK, and the US. The rate of fossil fuel use in Japan has been steadily declining since 1960, but it has risen rapidly since 2011. The biggest reason for this is the terrible accident that occurred on March 11, 2011 in Japan's Fukushima nuclear plant. In Italy, the rate of fossil fuel use increases slightly from 1960 to 2000; however, the rise of alternative energy use leads to a downward trend after 2000. All in all, the share of non-emitting alternative energy in final energy consumption grows modestly from 1960 to 2014 in all the G-7 countries.

Figure 4 The Composition of Energy Sources for G-7 Countries (% of total)



The historical decomposition results of CO2 emissions, energy consumption and output for Canada are shown in Figure 5. The blue lines indicate the median value of estimation results and the green lines show one standard deviation lower and upper bounds. Also, the gray shaded areas denote the periods when the cumulative effect of related shocks are greater than zero[2]. The results given in Panel (a1) of Figure 5 shows that the rise in energy consumption has a significantly negative impact on environmental quality during most of the sample period, while it has a statistically significant positive impact on environmental quality in 1965, in 1972, and the 1980-1984, 1995-2003 and 2007-2011 sub-periods. Furthermore, the findings provided in Panel (c2) of Figure 5 indicate that the increase in energy consumption contributes to economic growth nearly in all empirical analysis with the exception of 1998 in Canada. In line with these findings, it can be inferred that Canada has to sacrifice economic growth if it wants to reduce greenhouse gas emissions. Although the

[2] These explanations are valid for the same figures shown below for the other countries.

increase in energy consumption has no harmful effect on environment in some periods mentioned above, it is generally not possible to ensure economic growth without causing global warming. The rise in CO_2 emission contributes to the output growth roughly in all periods with the exception of two years which are 1986 and 1991 as shown in Panel (c1) of Figure 5.

The estimation results regarding the effect of economic growth on pollutant emissions are shown in Panel (a2) of Figure 5. The EKC hypothesis is rejected strongly for Canada over the entire period. The empirical evidence advocates that the output growth per capita cannot be a solution to lessen the environmental degradation in Canada.

The estimated results regarding the impact of GDP growth on energy consumption is reported in Panel (b2) of Figure 5. As seen in the figure, the real GDP growth per capita explains the variability of energy consumption in positive manner over the entire analysis period. This means that an energy conservation policy should be employed by Canada including public awareness raising strategy on energy saving and energy efficiency. When the impact of CO_2 emissions on energy consumption in Panel (b1) of Figure 5 is examined, it is observed that the possible improvement in environmental quality has a decreasing effect on energy consumption during most of the analysis period except for a few time intervals.

Figure 5 Historical Decomposition Results for Canada

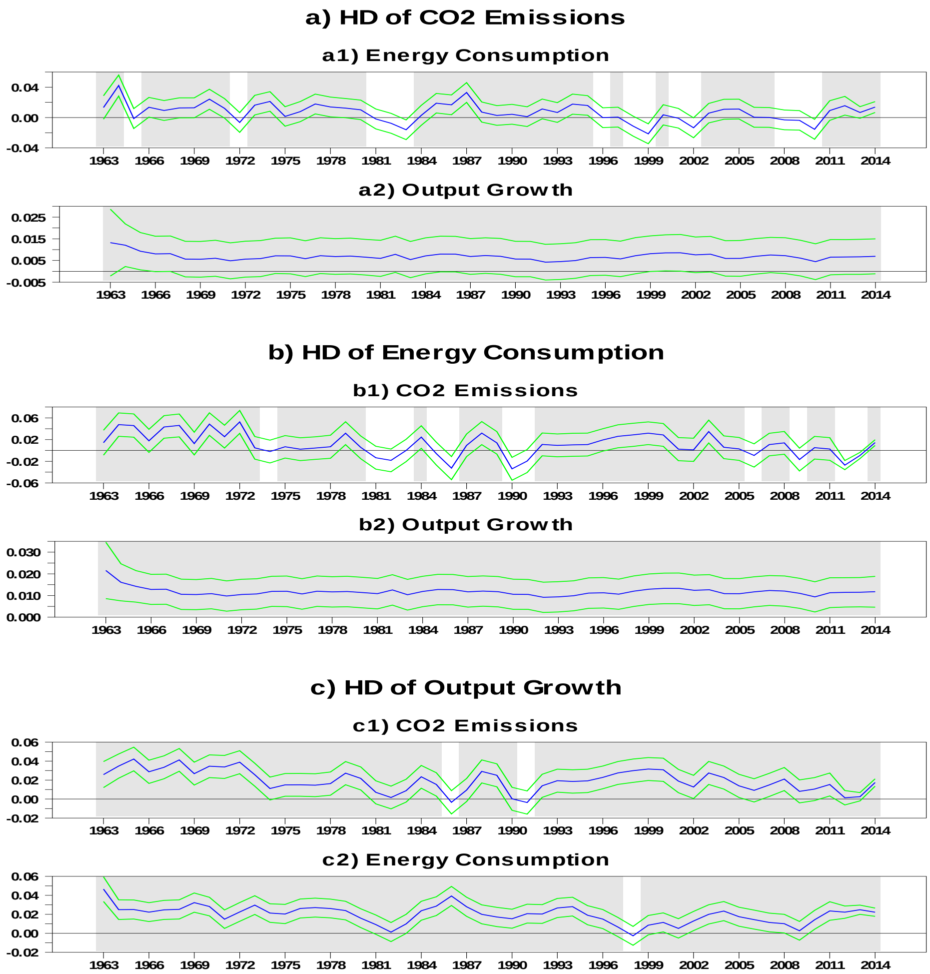
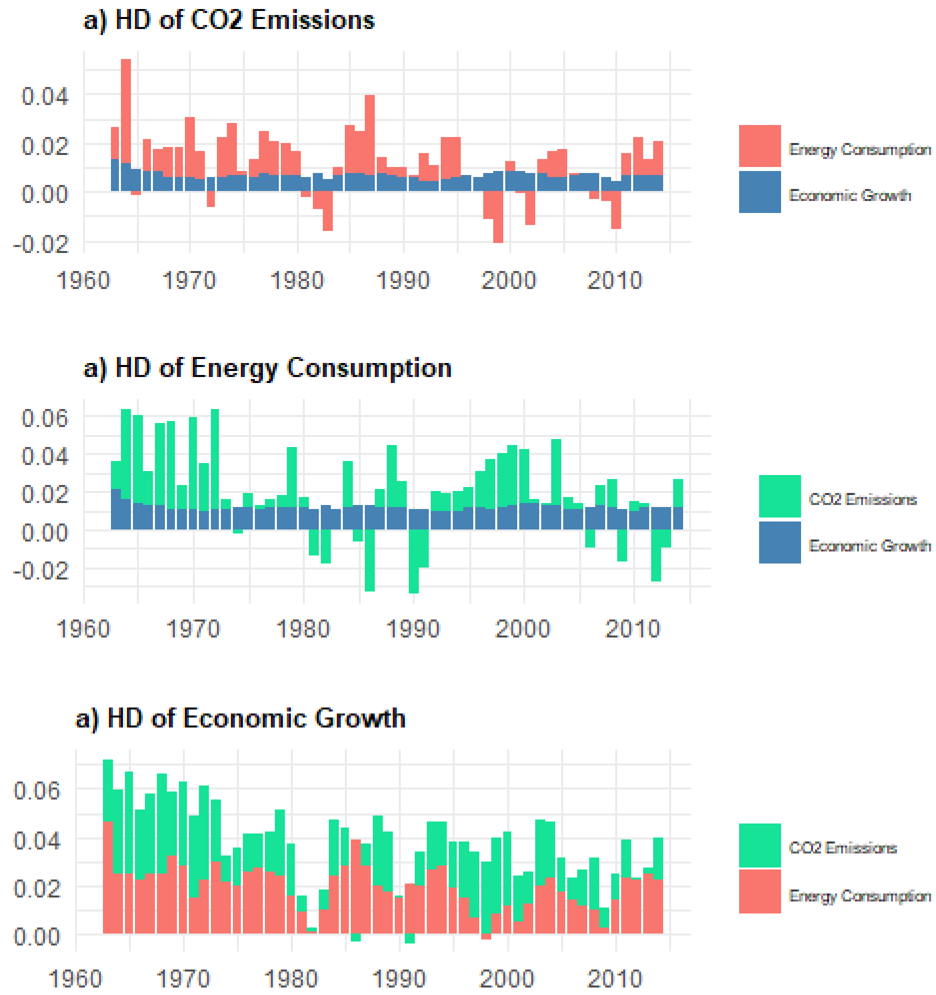


Figure 6 reveals the stacked graph of historical decompositions of CO2 emission, energy consumption and output growth. Each sub-figure is achieved by stacking the median value of cumulative effect of related shocks of these three variables. Although this notion appears to be a recapture of Figure 6, it is highly beneficial to be able to discuss the factors that are more effective in a time varying manner. The HD of the CO2 emission is shown in Panel (a) of Figure 6 and it is proved that energy consumption shock on environment is usually larger than the nearly constant magnitude output growth shock in terms of size over the period. However, in some periods, the effect of output growth on environmental degradation is greater. The result in Panel (b) of Figure 6 does not give clear evidence as to which factor is more dominant on energy consumption over the period. While in some periods the influence of CO2 emissions on energy consumption is greater than the influence of economic growth on energy consumption, this situation is reversed in favor of economic growth in some certain years. Also, similar to the preceding results, the size of economic growth shock on energy consumption remains the same over the analysis period. There is no visible distinction between the effects of CO2 emissions on output growth and the effects of energy consumption on output growth in terms of magnitude during the whole analysis period for Canada as shown in Panel (c) of Figure 6.

Figure 6 Stacked Graphs of Historical Decomposition Results for Canada

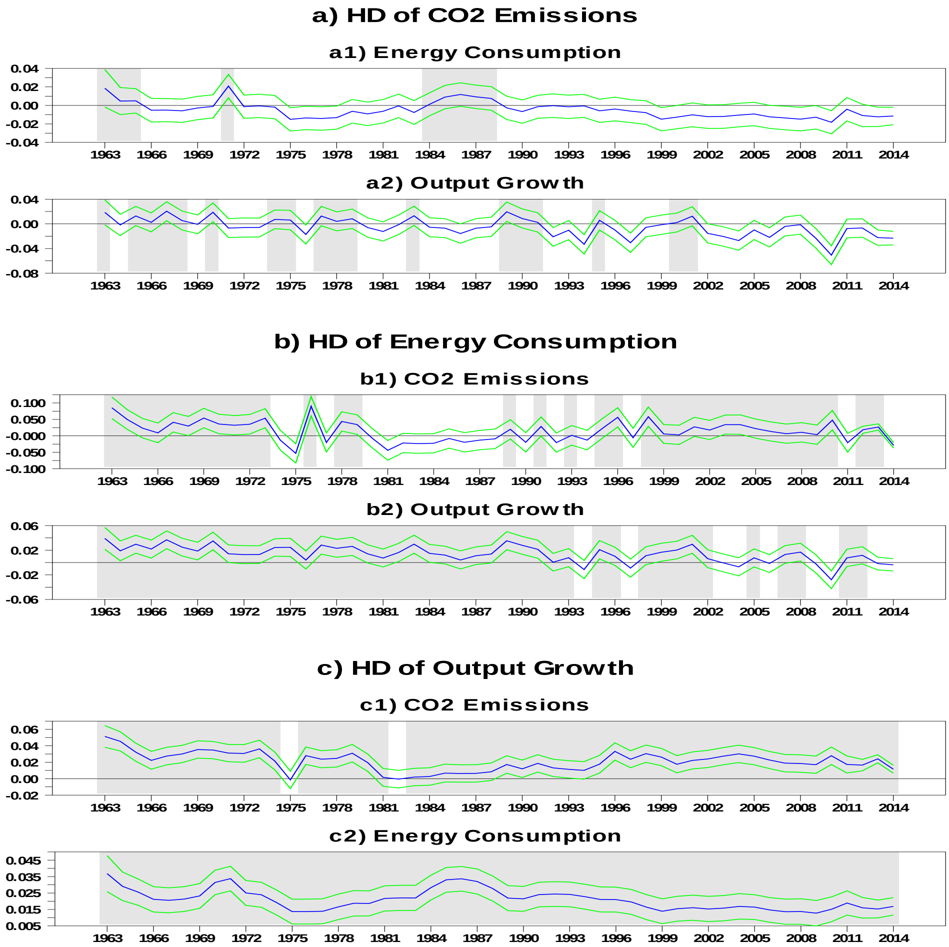


The panels in Figure 7 illustrate the HD of CO2 emissions, energy consumption and the HD of output growth findings for France from 1963 to 2014. The rise in energy consumption has a positive impact on environmental quality during the 1963-1965, 1971 and 1984-1988 sub-periods as shown in Panel (a1) of Figure 7. In addition to this finding, the empirical evidence in Panel (c2) of Figure 7 proves that the rise in energy consumption contributes to the economic expansion of France in all analysis periods. Thus, France is able to increase energy consumption by ensuring the sustainability of economic growth during nearly the entire analysis period with the exception of the sub-periods mentioned above without damaging the environment. Moreover, Panel (c1) of Figure 7 reveals that the rise in CO_2 emissions contributes to economic growth in nearly all years except for 1975 and 1982.

Panel (a2) of Figure 7 plots the impact of output growth shock on CO_2 emissions for France. This effect fluctuates prior to the 2000s; nonetheless, the expansion of economy has a statistically positive contribution to environmental quality thereafter. The findings obtained regarding the EKC hypothesis for France bring a different perspective to the literature because, for the first time, we showed here that the assumptions that apply to the validity of EKC hypothesis can include the business cycle effect. We define this situation as BC-shaped curve (business cycle shaped curve) for the first time in the literature. That is, the positive shock of economic growth has a cyclical effect on environment up to some threshold level, and it continuously improves environmental quality afterwards. Therefore, the HD method can enable to have a different perspective into academic studies which produce diverse shapes (U-shape, N-shape, inverse N-shape, M-shape and so on) of EKC hypothesis for countries.

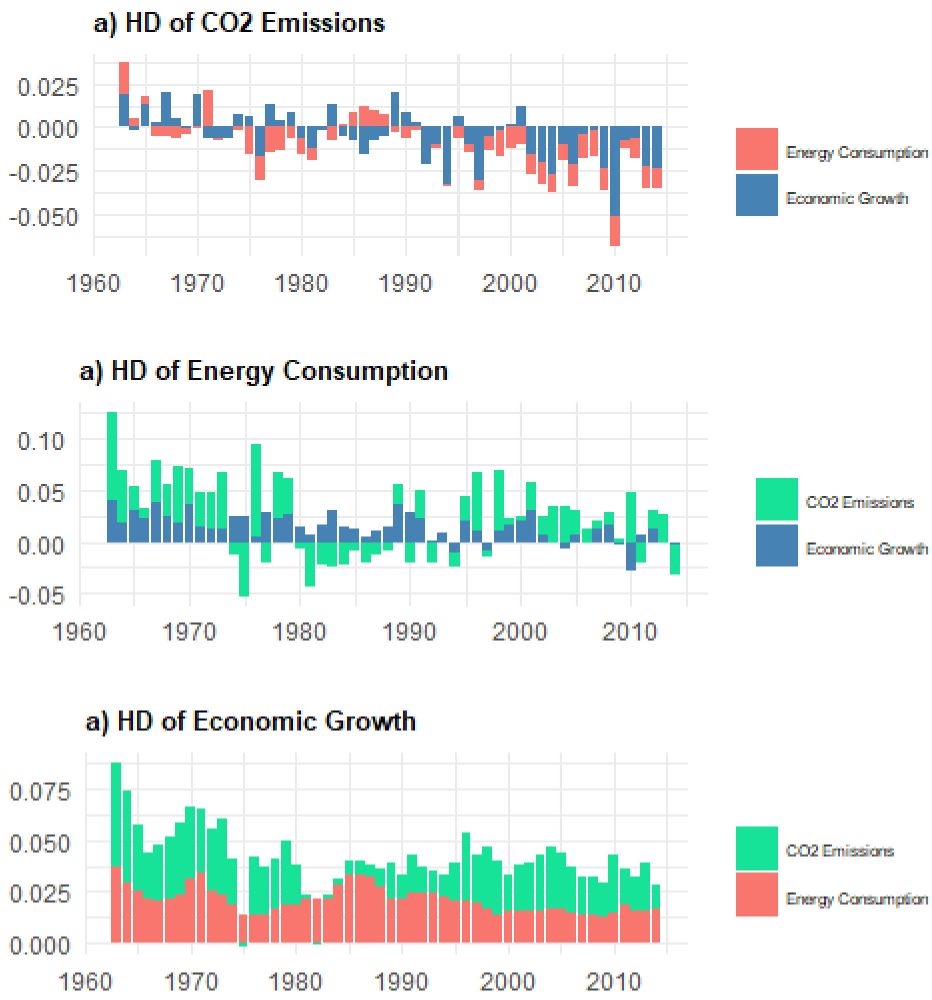
Panel (b2) of Figure 7 indicates that the positive output growth shock escalates the demand for energy consumption from 1960 to 1993. Then, this impact falls under horizontal line and then fluctuates around it. In other words, the energy conservation theory and the related policy recommendations are strongly valid until 1993, while they are not valid for the 1994, 1997, 2003-2004, 2009-2010 and 2013-2014 sub-periods in France. According to the findings shown in Panel (b1) of Figure 7, the decrease in CO_2 emissions intensifies energy consumption for the 1974-1975, 1977, 1980-1988, 1990, 1992, 1994, 1997, 2011 and 2014 sub-periods.

Figure 7 Historical Decomposition Results for France



Panel (a) of Figure 8 shows the stacked graph of the historical decomposition of CO2 emissions for France. The results indicate that there is no major difference between the contributions of the related shocks to the environment. However, as illustrated in Panel (b) of Figure 8, the effect of carbon dioxide emissions on energy consumption is somewhat greater than the effect of economic growth on energy consumption over the period in question. On the other hand, as shown in Panel (c) of Figure 8, no significant difference is observed between the impacts of both shocks on economic growth during the analysis period.

Figure 8 Stacked Graphs of Historical Decomposition Results for France



The historical decomposition results for CO2 emissions, energy consumption and output for Germany are illustrated in Figure 9. Panel (a1) of Figure 9 reveals that the rise in energy consumption decreases CO2 emissions over the entire analysis period for Germany. On the other side, as illustrated in Panel (c2) of Figure 9, more energy consumption leads to more economic expansion during the whole analysis period. This means that, similar to the results for France, Germany does not have to sacrifice economic growth to decrease greenhouse gas emissions by reducing fossil fuel energy usage. These findings prove that Germany has developed effective methods to use the fossil fuels and the derivatives that cause environmental pollution. What is more, Panel (c1) of Figure 9 shows that the increase in CO2 emissions causes more economic expansion over the entire analysis period excluding 2009.

There is no empirical evidence to support the EKC hypothesis as illustrated in Panel (a2) of Figure 9 from 1975 to 2014. As we see in the graph, the positive economic growth shock improves the environment during almost all the analysis period except for 1996, 1999, 2006 and 2012 sub-periods. Thus, it can be said that economic growth in Germany has not been a threat to the environment except for some certain years as of 1975.

Figure 9 plots the HD of energy consumption from 1975 to 2014 for Germany. Panel (b) of Figure 9 illustrates the impact of economic growth on energy consumption. It is revealed that economic expansion increases the use of fossil based energy for the 1978, 1984, 1990, 1996, 1998-1999, 2004-2007 and 2011-2012 sub-periods. In addition, the effect of CO2 emissions on energy consumption is cyclical around the horizontal line as indicated in Panel (b1) of Figure 9. When the findings are examined more in detail, one can observe that the increase in CO2 emissions leads to an upsurge in energy consumption for the 1976, 1979, 1983-1985, 1990, 1993-1996, 2000-2001, 2003, 2006, 2008, 2010 and 2013 sub-period. In other periods, environmental degradation has a negative impact on energy use in Germany.

Figure 9 Historical Decomposition Results for Germany

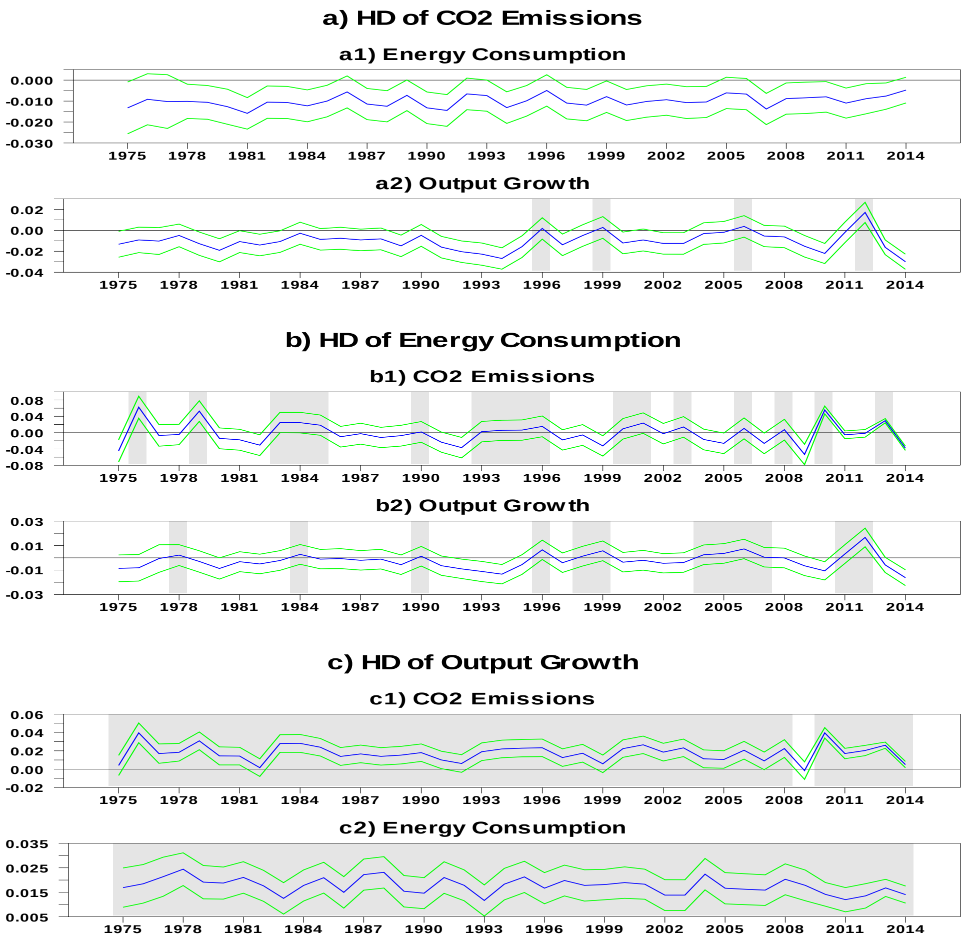


Figure 10 shows the stacked graph of HD results of CO2 emissions, energy consumption and the output growth for Germany. Panel (a) of Figure 10 reveals that the variation in CO2 emissions is explained by the same magnitude shocks to energy consumption and shocks to output growth. On the other hand, CO2 emissions have a greater impact on energy consumption than the effect of the economic growth on the energy consumption as illustrated in Panel (b) of Figure 10. Finally, in the light of the findings in Panel (c) of Figure 10, we can say that the variation in economic growth is attributed to approximately the same size of CO2 emissions shock and energy consumption shock.

Figure 10 Stacked Graphs of Historical Decomposition Results for Germany

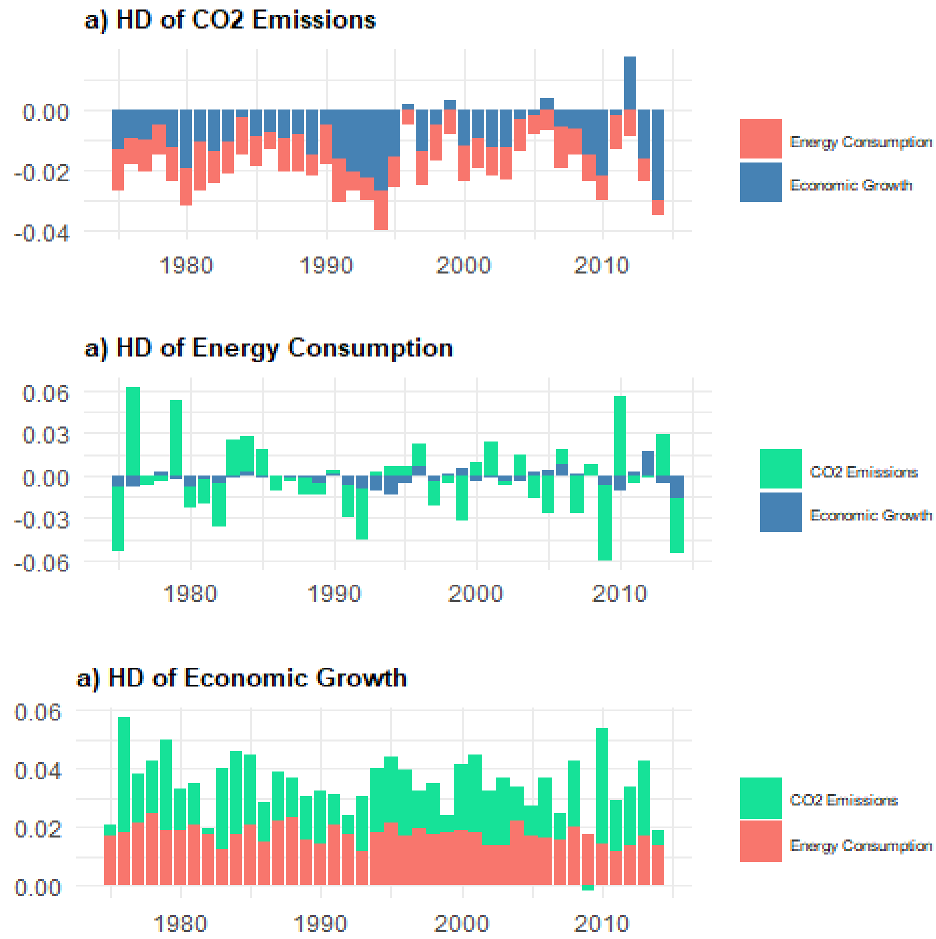


Figure 11 plots the HD analysis results of CO2 emissions, energy consumption and economic growth for Italy. The plots reported in Panel (a1) of Figure 11 point out that the rise in energy consumption has a detrimental effect on the environment in Italy. Moreover, the increase in energy use has positive explanatory power on output growth over the whole analysis period as shown in Panel (c2) of Figure 11. It can be inferred that economic expansion cannot be achieved if the level of CO2 gases is to be restrained for Italy from 1963 to 2014. Excluding findings for the 1975, 2008-2009 and 2012-2014 sub-periods, Panel (c1) of Figure 11 shows strong evidence that the possible steps to reduce greenhouse gas emissions hamper economic growth in Italy even if the effect weakens over time.

For Italy, important findings supporting the EKC hypothesis are obtained up to 1990 as illustrated in Panel (a2) of Figure 11. Whilst the positive output growth shock has an undesirable impact on environment before 1973, it improves the environment from 1973 to 1990. However, economic growth starts to damage the environment again and its effect continuously increases from 1990 to 2014. Thus, we find strong evidence to support N like -shaped EKC hypothesis over the analysis period if we ignore the two years (1976 and 1984) when the economic growth degrades environmental quality.

With regards to energy conservation hypothesis, we find strong evidence to support this hypothesis over the period excluding 1980-1981 sub-periods. As shown in Panel (b2) of Figure 11, output growth can explain the variation in energy consumption in a positive manner. Additionally, Panel (b1) of Figure 11 implies that the increase in CO2 emissions raises energy consumption during the entire analysis period with the exception of 1975, 1977, 1981-1983, 1993-1994, 1996, 2005-2009 and 2011-2014 sub-periods. The impact of CO2 emissions on energy consumption has a downward trend from 1963 to 1975, and then it oscillates around the horizontal line until it tends to decrease again after 2003.

Figure 10 Historical Decomposition Results for Italy

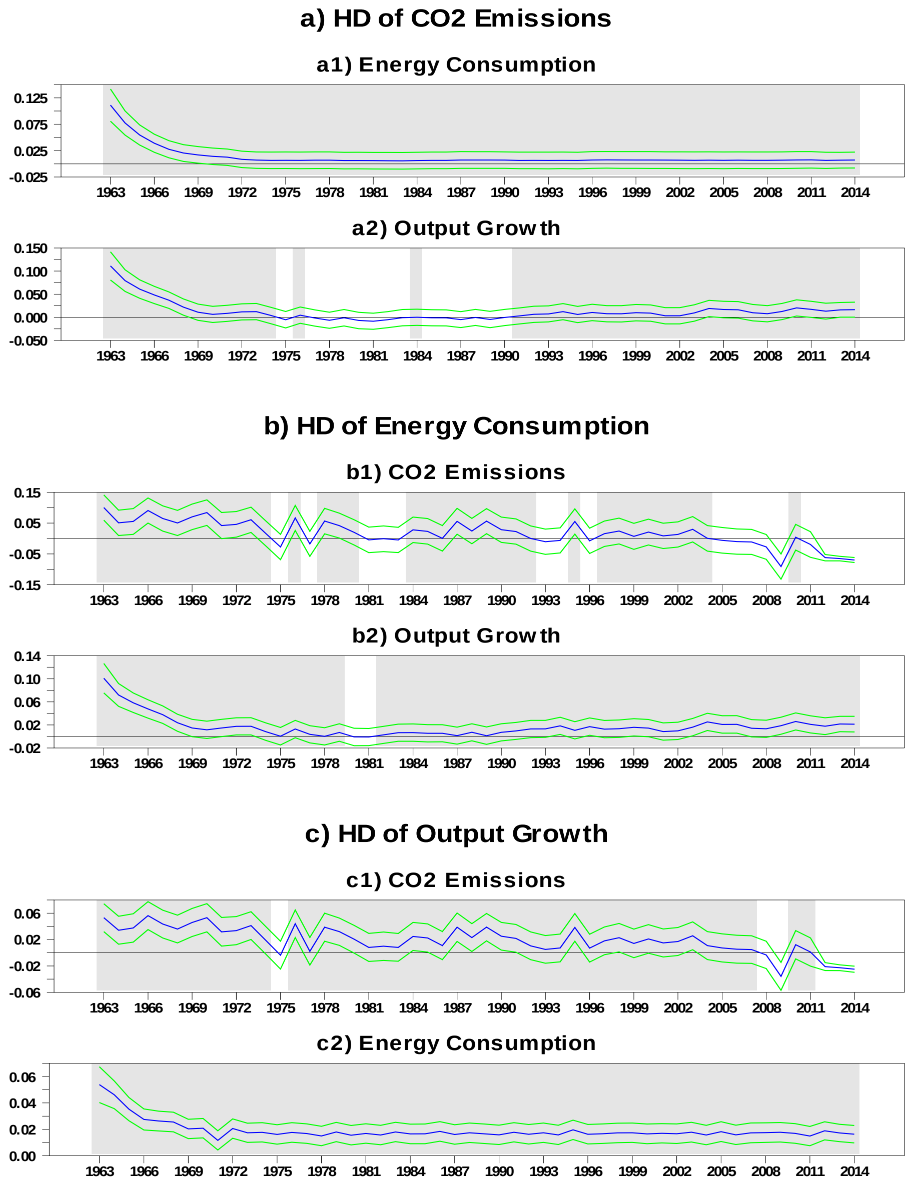


Figure 12 indicates the stacked graph of historical decomposition results for CO2 emissions, energy consumption and economic growth for Italy. As seen in Panel (a) of Figure 12, the energy consumption shocks and the output growth shocks can explain the changes in CO2 emissions with the same magnitude over the period. It can be suggested that the effect of economic growth on environment is greater than the effect of energy consumption on environment possibly from 1990 onwards. When both shocks are evaluated together, it is observed that the total effect on carbon dioxide emission decreases rapidly from 1963 to 1990, and then it partly tends to increase. Panel (b) of Figure 12 reveals that the impact of CO2 emissions on energy consumption is greater than the impact of output growth on energy consumption during almost all analysis period for Italy. Also, the magnitude of both shocks on energy consumption tends to decrease from the beginning till the end of the observation. On the one hand, Panel (c) of Figure 12 indicates that the energy consumption shock on output growth decreases steadily as of the early 1970s, and then its magnitude remains the same over the period. On the other hand, the effect of CO_2 emissions shock on growth diminishes over time. It even falls under the horizontal line in recent times.

Figure 11 Stacked Graphs of Historical Decomposition Results for Italy

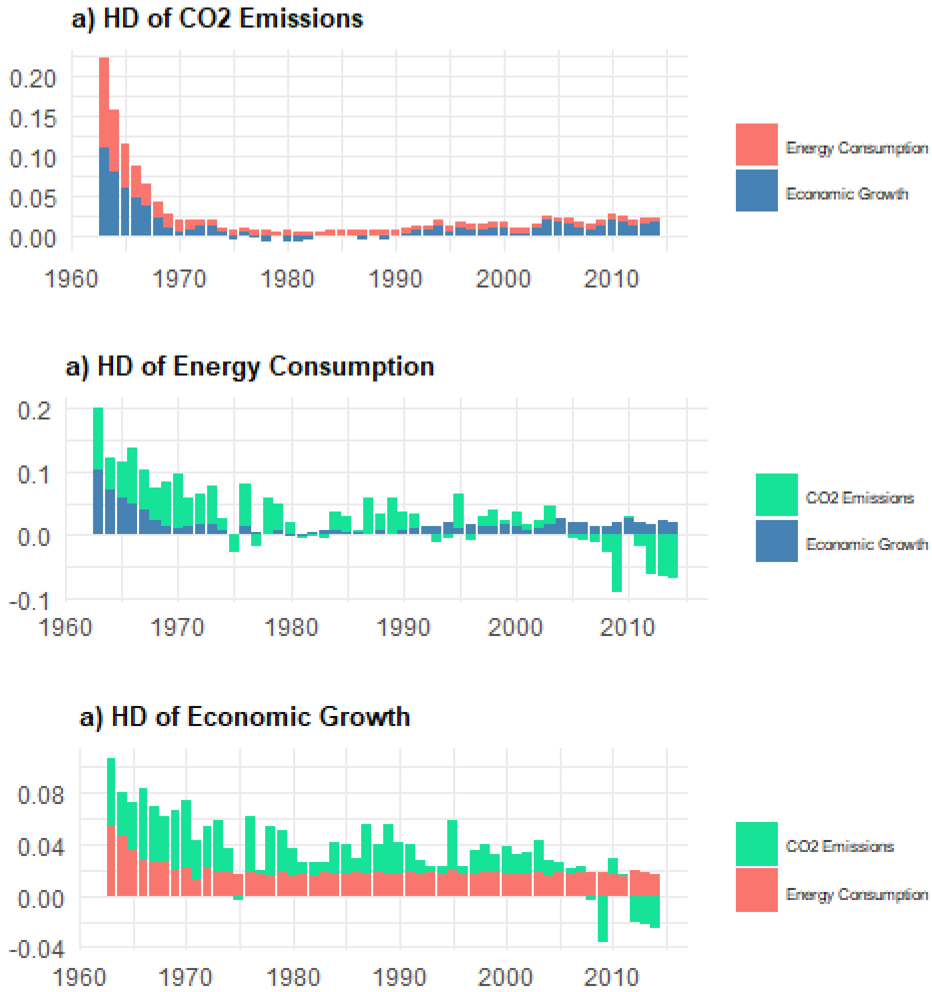


Figure 13 shows the findings of the HD of CO_2 emissions, energy consumption and economic growth for Japan. The increase in energy consumption demand has a devastating effect on the environment during nearly the entire period except for the last three years for Japan as shown in Panel (a1) of Figure 13. In addition, our analysis in Panel (c2) of Figure 13 reveals an empirical result which indicates that a positive energy consumption shock boosts economic growth at each point in time excluding 2011-2012 sub-periods. This implies that Japan must address the problem of inadequate economic growth if it tries to reduce CO_2 emissions before 2011 when three nuclear reactors melted down after an earthquake. Panel (c1) of Figure 13 shows that CO_2 emission shocks have a positive impact on economic growth over the horizontal axis during almost all the analysis period except for the 1982-1983, 1986 and 2009 sub-periods.

Considering Panel (a2) of Figure 13 to evaluate whether the EKC hypothesis works for Japan or not, we can see that the output growth shock has a significant positive effect before the 1990s except for the 1971-1972 and 1975 sub-periods. However, the magnitude of this effect decreases after that time and then fluctuates around the horizontal axis. Even if the impact of economic growth on the environment lessens, it cannot be said that this effect improves the environment quality because it has taken a positive value during almost all the rest of the period after 1990. Consequently, this cyclical movement between the variables demonstrates that the period when economic expansion has a reformative effect on the environment is longer than the period when it has a destructive effect on the environment.

The finding about the impact of output growth on energy consumption is similar to the impact of output growth on CO_2 emissions. Both CO_2 emissions and energy consumption series follow almost the same path as illustrated in Panel (b1) of Figure 13. Excluding the 1971-1972, 1975, 1995-1996, 1999-2000 and 2010 sub-periods, energy conservation measures can be considered mandatory for Japan throughout the sample period. Panel (b1) of Figure 13 reveals that the reduction in CO_2 emissions decreases energy consumption over the period excluding 1974-1975, 1978, 1980-1983, 1985-1987, 1991, 1998, 2008-2009 sub-periods.

Figure 12 Historical Decomposition Results for Japan

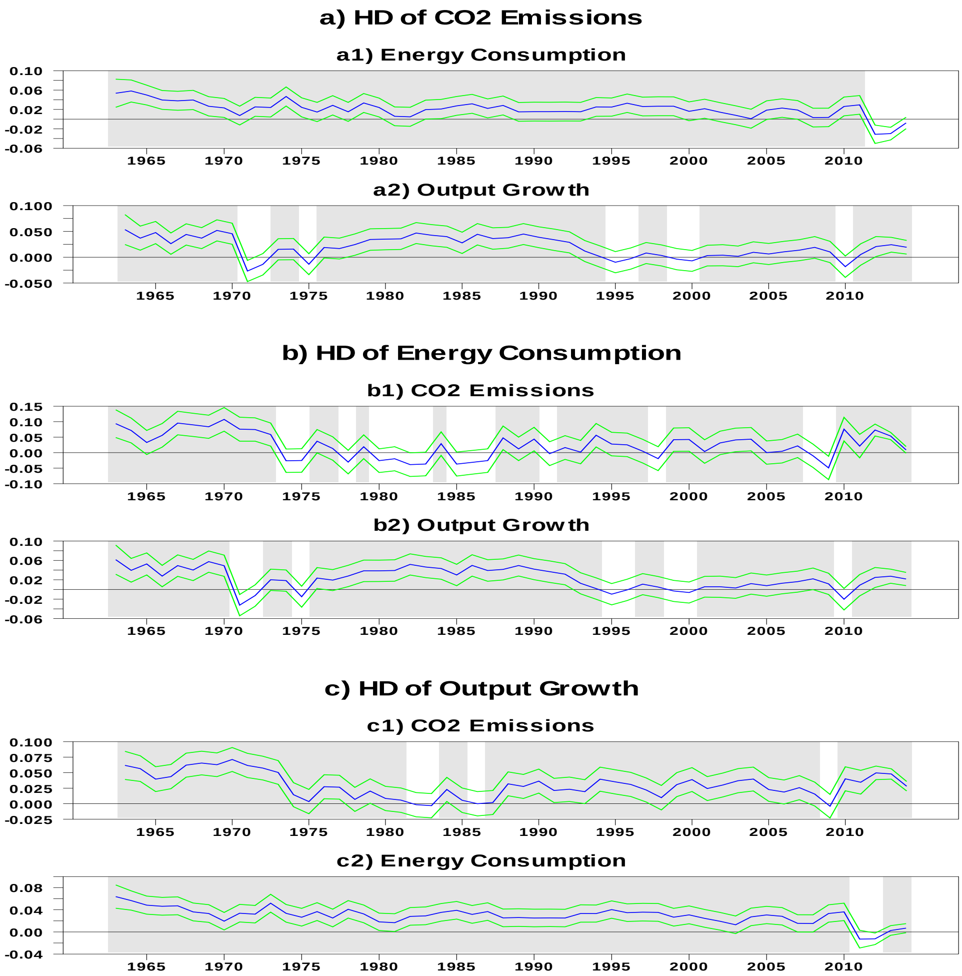


Figure 14 illustrates the stacked graph of HD of three variables used in this study for Japan. The first panel of Figure 14 shows that both energy consumption and output growth have a statistically significant positive effect on environmental degradation for Japan, while the response of CO2 emissions to these two shocks shows a smooth decrease over the analysis period. As regards the comparison of the magnitudes of these two shocks, while the economic growth has a larger impact on the environmental quality than energy consumption between 1975 and 1992, the effect of the former is less than that of the latter from 1993 to 2005. The variation in energy consumption is largely driven by CO2 emissions compared to the contribution of output growth as observed in Panel (b) of Figure 14. Panel (c) of Figure 14 indicates that both the CO2 emissions shock and the energy consumption shock lead to economic progress perpetually during the entire analysis period. In addition, it is also revealed that the effect of these two shocks has decreased over time. Finally, the stacked graph of HD results for Japan illustrates that after the Fukushima Daiichi disaster, the positive shock of energy consumption on both economic growth and CO2 emissions has undergone a structural change. That is, after the disaster, the rise in energy consumption starts to contribute to environmental degradation, but it leads to economic contraction.

Figure 13 Stacked Graphs of Historical Decomposition Results for Japan

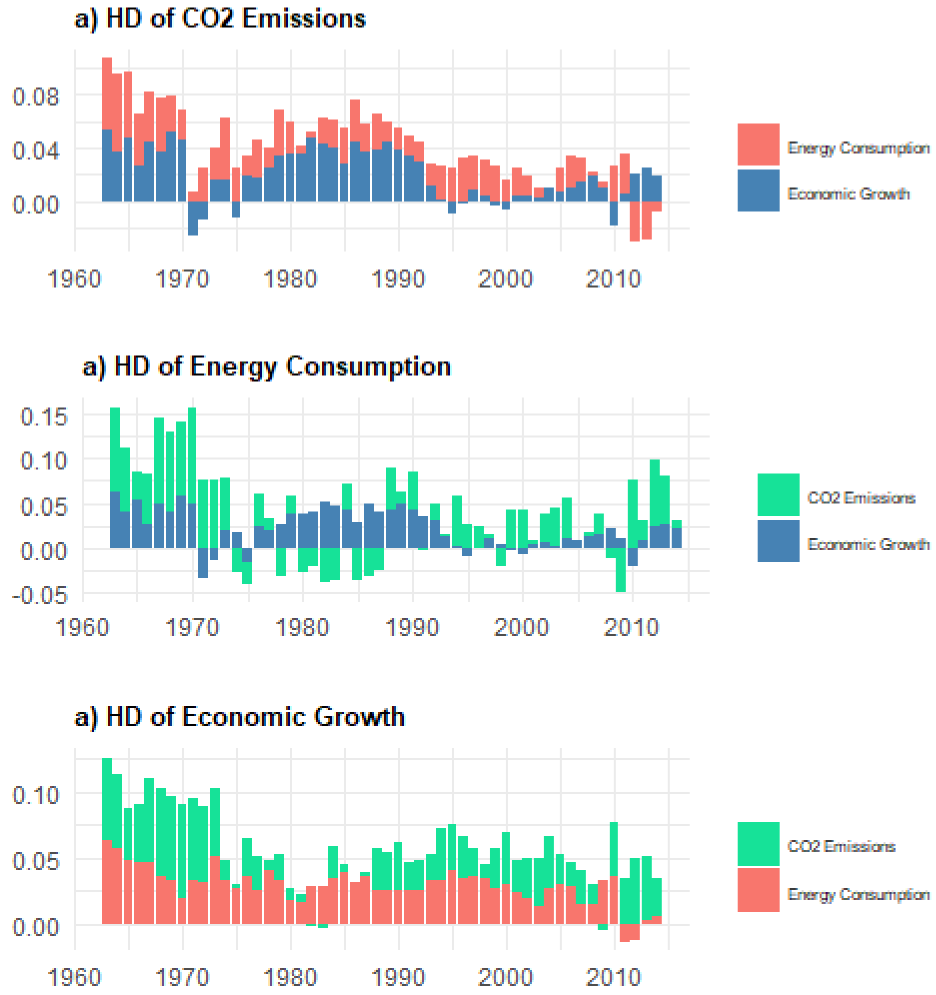
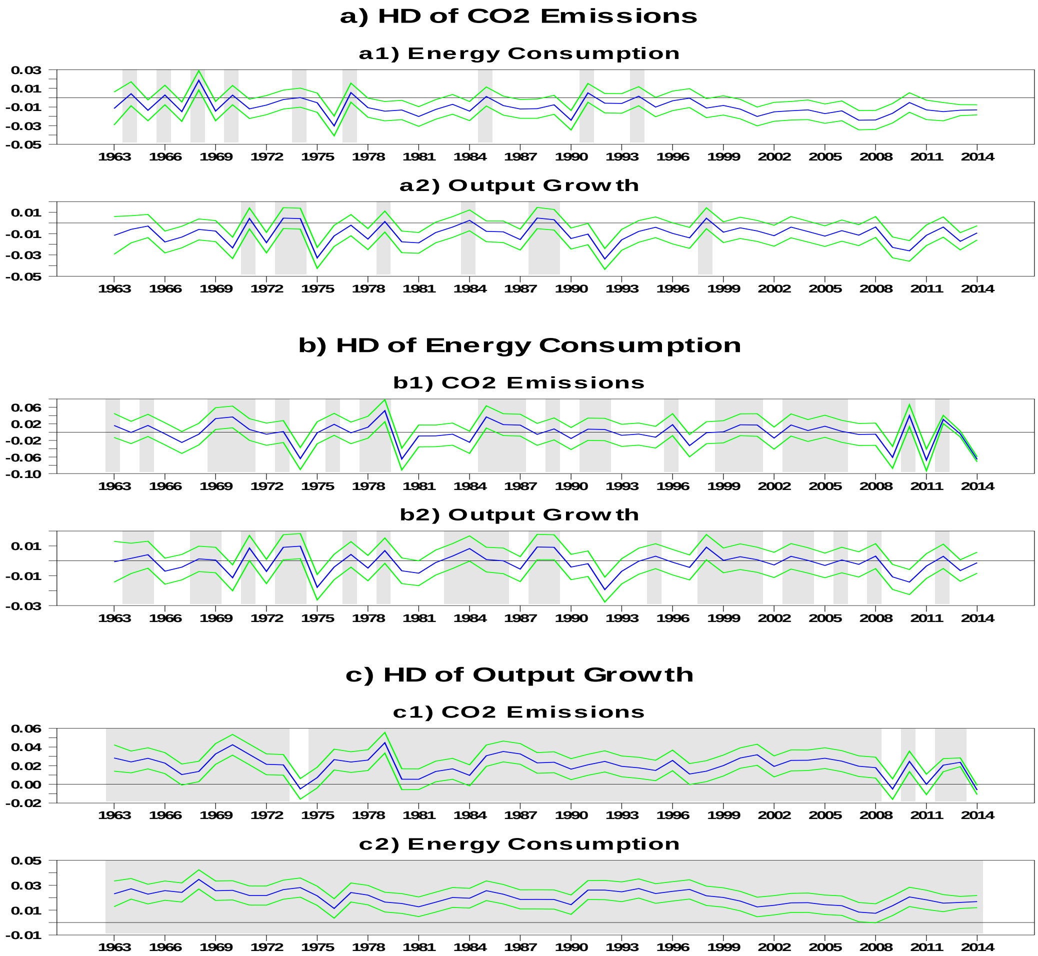


Figure 15 indicates the results of the HD regarding CO2 emissions, energy consumption and economic growth for Japan. Panel (a1) of Figure 15 illustrates the impact of energy consumption on environmental degradation over the period for the UK. The rise in energy use does not cause CO2 emissions nearly during the whole period with the exception of 1964, 1966, 1968, 1970, 1974, 1977, 1985, 1991 and 1994 sub-periods. On the other hand, energy consumption has a considerably positive impact on economic growth during the whole period as illustrated in Panel (c2) of Figure 15. A significant conclusion that these two facts reveal for the UK is that it could achieve an aggregate output during the whole period without considering the environmental problems. Furthermore, Panel (c1) of Figure 15 shows us that CO_2 emissions meaningfully contribute to output growth in the entire analysis period except for the 1974, 2009, 2011 and 2014 sub-periods.

We cannot find strong evidence supporting the EKC hypothesis for the UK after 1963. This result is similar with the evidence for Germany. Although the impact of economic growth on the environment has a business cycle character, the evidence is weak because the impact of positive shock does not reach a noteworthy level. It seems to move around zero. The positive output growth shock improves the quality of environment strongly nearly during the whole period except for some years, i.e. 1971, 1973-1974, 1979, 1984, 1988-1989 and 1998 sub-periods. After 1998, economic growth has a positive effect on environmental quality.

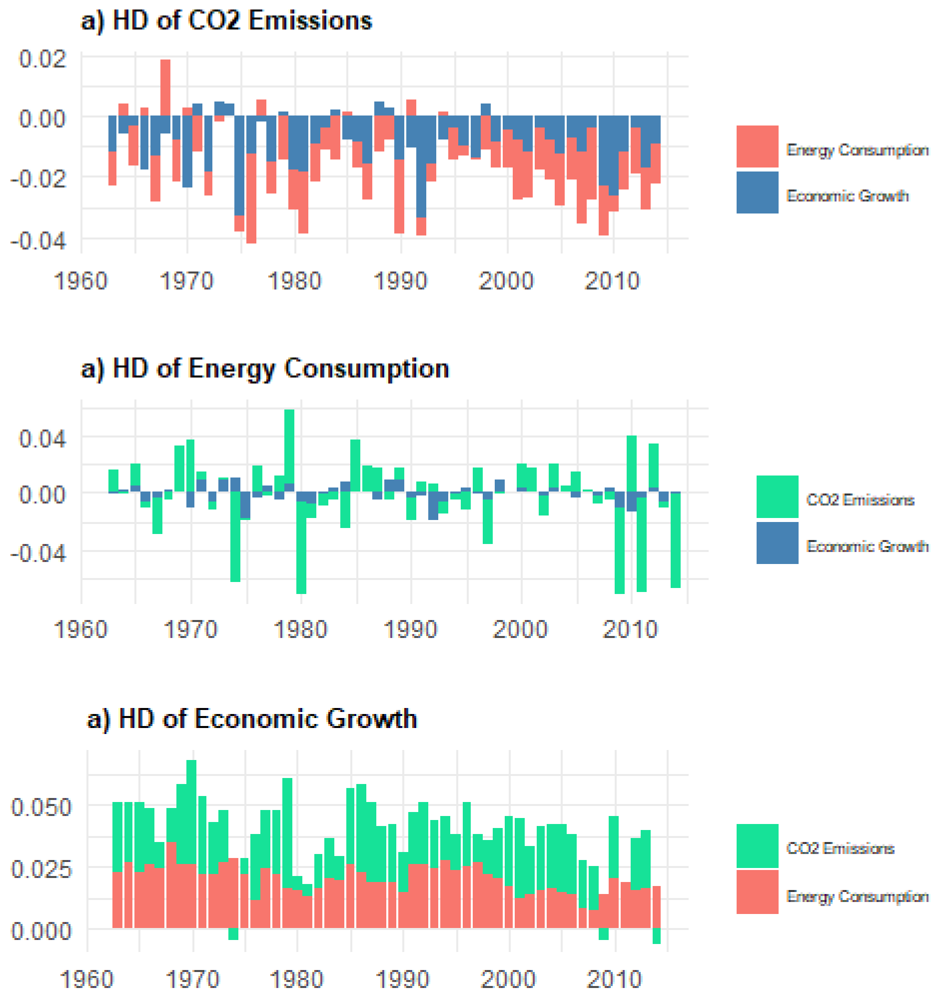
The finding in Panel (b2) of Figure 15 gives some clues regarding the historical perspective of whether the implementation of conservation measures is necessary for the UK or not. As seen in the figure, the effect of output growth on energy consumption shows some cyclical features which have a variable frequency. We can list the sub-periods in which the implementation of energy saving measures for the UK is appropriate: 1964-1965, 1968-1969, 1971, 1973-1974, 1977, 1979, 1983-1986, 1988-1989, 1995, 1998-2001, 2203-2004, 2006, 2008 and 2012. On the other hand, the impact of the CO_2 emissions shock on energy consumption seems to have a business cycle character as seen in Panel (b1) of Figure 15. Similar to the preceding analysis, the frequency of this effect varies over time.

Figure 14 Historical Decomposition Results for United Kingdom



Panel (a) of Figure 16 reveals the stacked graph of HD results for CO2 emissions in the UK. It indicates that the effect of energy consumption on the environment is larger than the effect of output growth on environment during the whole analysis period. According to the results in Panel (b) of Figure 16, the changes in energy consumption are attributed more to the CO2 emission shocks rather than to the output growth shocks in most of the years. Finally, the size of the related shocks on economic growth is close to each other in the empirical analysis period.

Figure 15 Stacked Graphs of Historical Decomposition Results for United Kingdom



The historical decomposition results for CO2 emissions, energy consumption and economic growth in the US are shown in Figure 17. The rise in energy consumption degrades the environment during the 1963-1970, 1972-1973, 1975-1979, 1985-1986, 1990-1993, 1995-1996, 2000, 2005 and 2012-2012 sub-periods as shown in Panel (a1) of Figure 17. In addition to this finding, Panel (c2) of Figure 17 illustrates that the decrease in energy consumption has a negative impact on output growth during the entire analysis period. It can be inferred that the reduction in energy consumption eradicates environmental degradation, yet adversely affects the growth of the US during the above mentioned period. In this case, the US may consider transforming its conventional forms of energy sources to renewable sources of energy (such as those derived from wind, the sun and wave) to meet its energy needs and to achieve sustainable economic growth when energy consumption degrades the environment. It seems that the adoption of this policy is important for the US, especially in the short-term when the greenhouse effect negatively affects the environment.

As regards the EKC hypothesis, it cannot be substantiated conclusively for the US when the evidence for the output growth impact on CO2 emissions is examined as indicated in Panel (a2) of Figure 17. The response of CO2 emissions to the economic growth shock can be deduced to substantiate the business cycle effect over the analysis period for the US.

We observe from Panel (b2) of Figure 17 that economic growth leads to energy consumption which requires energy conservation policy for the US in all the periods with the exception of 1985. Moreover, the positive shock of CO2 emissions on energy consumption fluctuates during the analysis period with ascending and descending frequency as shown in Panel (a1) of Figure 17. The rise in environmental degradation increases energy consumption during the 1963-1973, 1976, 1978, 1983-1984, 1987-1989, 1993-2000, 2002-2004, 2007, 2010 and 2014 sub-periods.

Figure 16 Historical Decomposition Results for United States

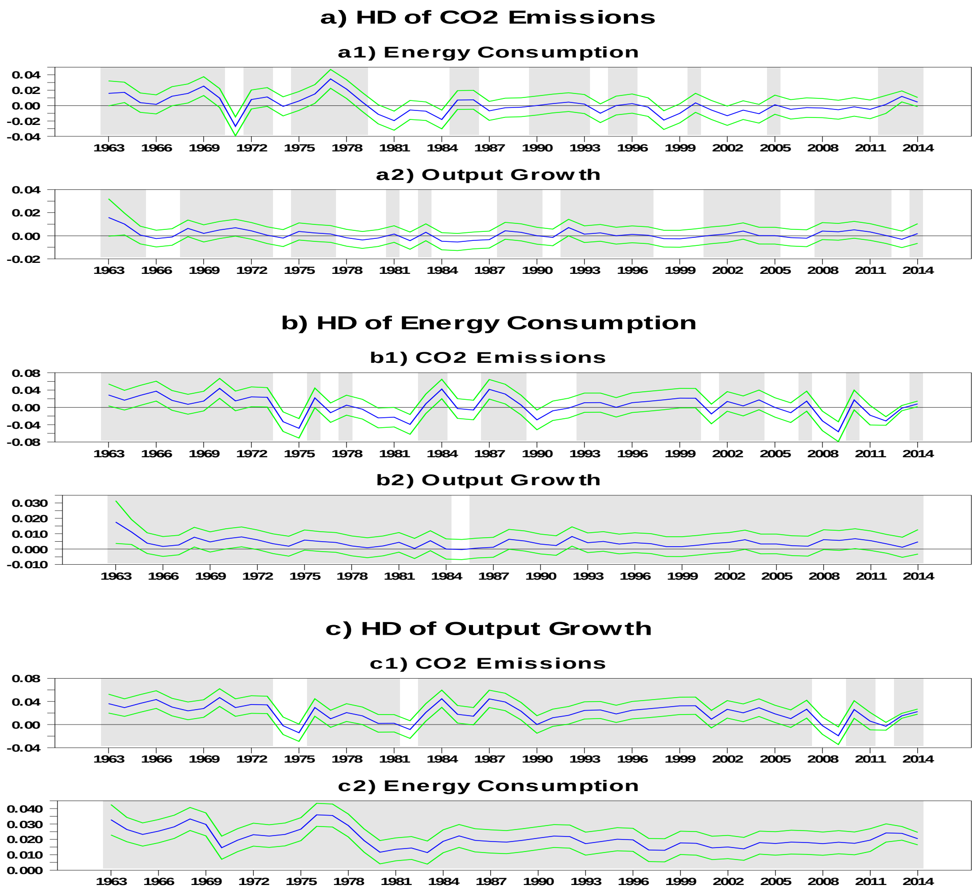
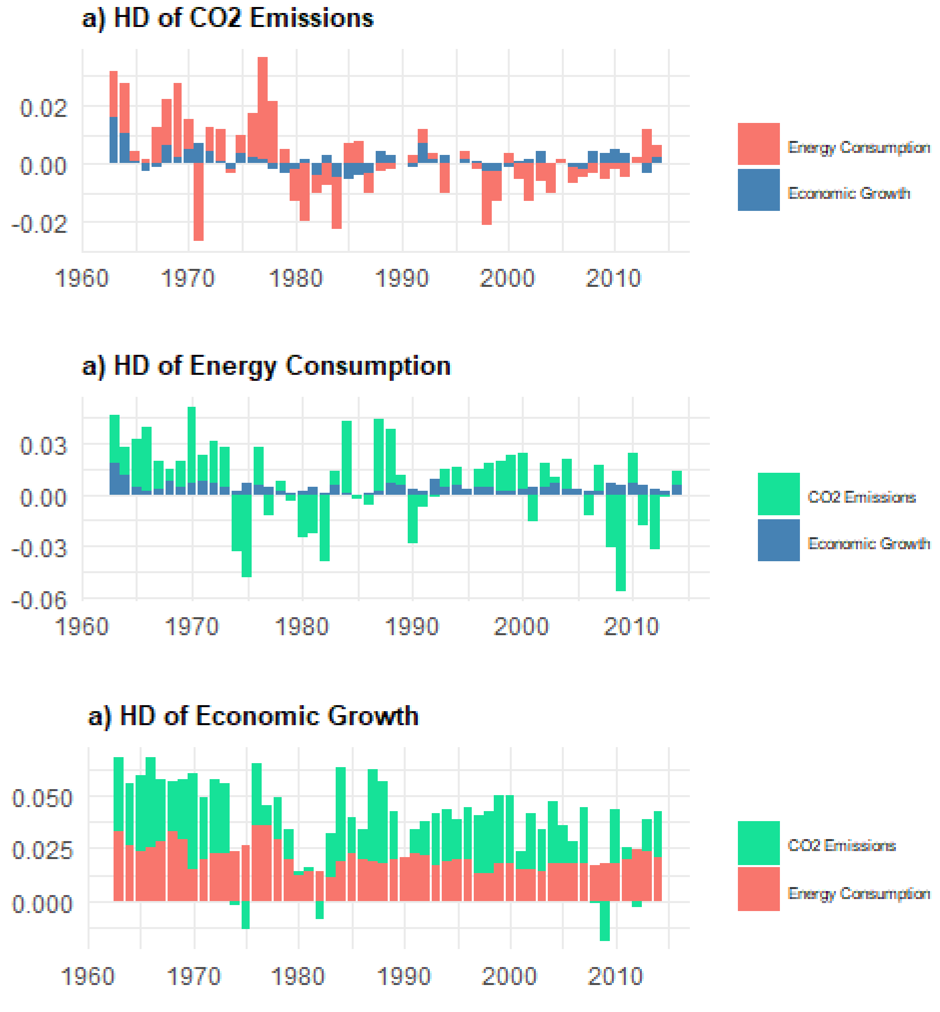


Figure 18 shows the stacked graph of historical decomposition for the US. When considered from this point of view, energy consumption has more impact on CO2 emission than output growth. A similar situation is observed when the historical decomposition results of energy consumption are evaluated. The effect of carbon dioxide emission on energy consumption is greater than output growth during the entire period. However, the variation in output growth contributes approximately at the same size to shocks on CO2 emissions and to shocks on energy consumption for the US.

Figure 17 Stacked Graphs of Historical Decomposition Results for United States



IV Discussion and policy implications

Table 2 summarizes the empirical findings in this study for the G-7 countries. We categorize our findings into four different political conclusions: (i) forgoing economic growth to reduce CO2 emissions, (ii) the EKC curve, (iii) the conservation theory, and (iv) the growth theory. Most of the previous studies do not elaborate on these policy implications together although they measure the three-variable model rather than the bivariate model. Table 2 allows us to evaluate these four political implications together and to decide which policy implementations fit in with the G7 countries to achieve sustainable growth without destroying the environment.

Table 2 Summary of empirical findings of G-7 countries

No.	Country	The country must forgo economic growth in case it attempts to reduce CO2 emissions	The EKC Hypothesis	Conservation Theory	Growth Theory
1	Canada	Business cycle	No evidence of EKC hypothesis.	Valid	Valid
2	France	It is not valid except some sub-periods before late 1980s	BC-Shaped Curve	Business Cycle	Valid
3	Germany	Not Valid	No evidence of EKC hypothesis. But growth has no harmful impact on environment except some sub-periods	Business Cycle	Valid
4	Italy	Valid	N-shaped Curve	Valid	Valid
5	Japan	Valid except last 3 periods	No evidence of EKC hypothesis.	Almost valid	Valid
6	UK	Not valid except some sub-periods	No evidence of EKC hypothesis. But growth has no harmful impact on environment except some sub-periods	Business Cycle	Valid
7	US	Business cycle	Business Cycle	Valid	Valid

A few studies in the literature evaluate the first policy case which asserts whether a country may sacrifice economic growth if it attempts to decrease energy usage due to the environmental problems. In his pioneer study, Ang [9] finds evidence that France must forgo economic development if it decreases fossil based energy sources to improve air quality. Nevertheless, our finding for France provides strong evidence that this transmission mechanism does not work except for some sub-periods before the late 1980s. Furthermore, while the validity of this mechanism is rejected for the US by Soytas et al. [70], our findings indicate that this condition is periodic. As regards the previous studies on the EKC hypothesis, it can be said that our finding for Canada is consistent with that of Day and Grafton [28]. Moreover, although Ang [9] points to the existence of the inverted-U shaped EKC hypothesis for France in his seminal paper, for the first time the results of HD analysis claims that the EKC hypothesis is valid for France as BC-shaped curve. By utilizing the autoregressive distributed lag (ARDL) bounds testing approach of cointegration for nineteen European countries, Acaravci and Ozturk [1] investigated the causal relationship between carbon dioxide emissions, energy consumption, and economic growth and found evidence for the validity of the EKC hypothesis in Italy, but not in Germany. Nonetheless, they did not reach any conclusion statistically regarding the EKC hypothesis for France and the UK. In the light of our findings, the N-shaped[3] EKC curve is strongly supported for Italy, but our results provide evidence contrary to the EKC hypothesis for Germany and the UK. Furthermore, our empirical evidence precludes reaching incomplete and inaccurate political conclusions due to the inefficiency of traditional causality methods. For instance, although our empirical findings reveal that the EKC hypothesis is not valid for Germany and the UK, this does not mean that economic growth has a harmful effect on environment; conversely, it continuously improves environmental quality over the period. On the other hand, Tamazian et al. [71] also support the existence of EKC hypothesis for Japan and the US as well as other BRIC countries, but our results do not coincide with those results. As shown in Table 2, the feedback hypothesis is valid for Canada, Italy, Japan and the US. These results are consistent with the empirical results in the previous studies such as Ghali and El-Sakka [37] for Canada, Chontanawat et al. [26] for Italy and Japan, and Lee [46] for the US. In addition, the last column of Table 2 indicates that the growth theory is valid for France, Germany and the UK, while the implementation of the conservation theory is suitable periodically. Although they do not exactly coincide with our findings due to the full sample approximation, the empirical

[3] The shape of the relationship with respect to the per capita output is indirectly inferred from the observation that the per capita output was increasing through the study period.

evidence in Soytas and Sari [69] for France and Germany and in Erol and Yu [35] for the UK supports a unidirectional causality from energy consumption to economic growth, which may support our findings for these countries as well.

V Conclusion

In this paper, we examine the dynamic relationship between CO2 emissions per capita, energy consumption per capita and output growth per capita for the G-7 countries using the historical decomposition method. Also, we utilize the bootstrap method to compute the confidence intervals. In the literature, most of the studies that examine the bivariate and three-way linkages produce conflicting results. To overcome this problem, some researchers have employed new econometric techniques which take the structural break and regime shifts into account. Despite all these struggles, miscellaneous consequences continue to be obtained in the literature for single country and multi-country analysis. Moreover, the literature seems to rule out the legitimacy of business cycle effect on these three variables so far. The HD method takes into consideration both structural break and regime shifts with its time varying analysis method. Also, the HD method can detect the turning points in business cycles regarding the impact of any variable on other variables in a robust manner and fill the gap in the literature. This method particularly enlightens the discussions about the turning points in the EKC literature. We can summarize our findings obtained from the HD method as follows.

Firstly, we have discussed the transmission mechanism consisting of two channels which are *economic growth – energy consumption* and *energy consumption – environment* relationship for all the G-7 countries. The logic behind this transmission mechanism is that when economic growth requires energy consumption and the rise in energy consumption causes CO2 emissions, one should switch from fossil fuel-based energy consumption to renewable energy consumption. According to the HD results for the G-7 countries, this situation is valid for Canada, Italy, Japan and partly the US. This policy implication is not practical for France since the early 1990s, and it is not convenient for Germany throughout the analysis period. Also, the possible application of this policy proposal is not suitable for the UK during nearly the whole analysis period except for some sub-periods.

Secondly, the EKC hypothesis can be seen as an alternative to switching from fossil fuel-based energy consumption to renewable energy consumption to prevent environmental destruction. It is evident that economic expansion degrades the environment in all the analysis period for Canada, while economic development has almost no harmful impact on environment throughout the entire analysis period in Germany and in the UK. In Japan, economic expansion has a negative effect on environmental quality over the period except for some sub-periods. In addition, we find robust evidence to support N-shaped EKC hypothesis in a time varying way in Italy. Furthermore, in France, the impact of output growth has a cyclical effect on the environment until the early 2000s, whereas it constantly improves the environment afterwards. Finally, the EKC hypothesis is rejected but the effect of economic growth on environment has a cyclical behavior during the entire analysis period for the US.

Lastly, the findings regarding the effect of output growth on energy consumption, i.e. conservation theory, provide diverse results for the G-7 countries. The energy conservation theory is fully supported for Canada, while it is strongly supported for France, Italy, Japan and the US with the exception of some periods. However, the impact of economic growth on energy consumption fluctuates around the horizontal line for Germany and the UK. The estimation results demonstrate that the growth theory is strongly supported for all the G-7 countries.

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