Renewable Energy Consumption, Income, CO2 Emissions and Oil Prices in G7 Countries: The Importance of Asymmetries

Shahbaz, Muhammad and Lahiani, Amine and Sinha, Avik

Montpellier Business School, Montpellier, France, Administrative Staff College of India

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Renewable Energy Consumption, Income, CO_2 Emissions and Oil Prices in G7 Countries: The Importance of Asymmetries

Muhammad Shahbaz
Energy and Sustainable Development
Montpellier Business School, Montpellier, France
Email: muhdshahbaz77@gmail.com

Amine LAHIANI
LEO – University of Orléans, France
Professor - Montpellier Business School, Montpellier, France
Email: amine.lahiani@univ-orleans.fr

Avik Sinha
Centre for Economics and Finance
Administrative Staff College of India
Email: f11aviks@iimidr.ac.in

Abstract:

This paper investigates the asymmetric transmission of income, carbon emissions and oil prices to renewable energy consumption for the long-run and short-run in G7 countries using quarterly data over the period from 1955Q1 to 2014Q4. We employ the nonlinear ARDL (NARDL) model to test for the long-run and short-run sensitivity of renewable energy consumption to its determinants. We find that income significantly influences renewable energy consumption in a symmetric manner in the long-run for the US, UK, France and Germany and in an asymmetric manner in Japan. However, renewable energy consumption is found to be insensitive to income in the long-run for Italy. Renewable energy consumption is positively and symmetrically affected by carbon emissions in the long-run for USA, France, Germany, Japan and Italy. Carbon emissions impact renewable energy consumption in an asymmetric manner for Canada but insignificant for the UK in the long-run. In the long-run, oil prices influence renewable energy consumption in an asymmetric manner in USA, symmetrically in the UK and France but insignificantly in Canada, Germany, Japan and Italy. Given the need to establish a global green energy environment our findings have important implications for energy policy makers in the world.

Keywords: Renewable Energy, Economic Growth, Carbon Emissions, Oil Prices, NARDL

I. Introduction

A rising level of anthropogenic greenhouse gas (GHG) emissions is aggravating the global warming problem.[1] Contemporary research suggests that human interaction with nature in the form of unsustainable economic growth is the root cause of global warming (Shahbaz et al. 2016, Sinha 2016). The environmental pressure in the form of ambient air pollution is primarily created by continuous consumption of fossil fuels. The rising level of GHG emissions has manifested itself in several forms, including the rise in surface temperature, melting of glaciers, the rise in sea levels, changes in the rainfall patterns, changes in patterns of El Niño and La Niña, and several others (Wigley 1991, Sinha and Bhattacharya 2014).

Economic growth cannot take place without consumption of energy. As a nation moves along its growth path, demand for energy rises along with it. According to U.S. Energy Information Administration (EIA) (2016), energy demand will rise by 48% from 2012 to 2040. EIA (2016) has also forecasted that global crude oil consumption will rise from 45.5 million barrels per day in 2012 to 46.1 million barrels per day in 2040. Similarly, crude oil is expected to be available at USD 76 per barrel in 2040, which is a rough figure about the required expected expenditures in the oil sector in order to meet the growing future demand for energy. This situation has given the nations an opportunity to shift from non-renewable to renewable energy sources (i.e. solar, wind, tidal, waste, and others). Compared to non-renewables, renewable energy sources are eco-friendly and non-depletable. Nations are gradually realizing the potential and significance of renewable energy. By the end of 2015, nearly 66 countries have issued biofuel mandates at central or provincial levels (Nabavi-Pelesaraei et al. 2016, REN21 2016).

Along with the problem of staggering energy demand, the rising level of emissions is catalyzing nations to explore the possibilities of generating renewable energy. The continuous

[1] The Intergovernmental Panel on Climate Change (IPCC) (2014)

consumption of fossil fuel has raised the level of carbon dioxide emissions (CO_2) in the atmosphere. According to EIA (2016), by 2040, electricity generation will increase by 69%, which is far below the projected level of energy demand. Also, the projected generation of coal-based energy is expected to increase by 25%. As such, policymakers are also concerned with the resulting CO_2 emissions, and a need to move towards clean and renewable energy sources. The proposal of Intended Nationally Determined Contributions (INDCs) for reduction of CO_2 emissions put forward in 21st Conference of Parties (COP21) meetings held in Paris exposed that nations are moving towards exploration of renewable energy sources (IISD, 2015). Moreover, EIA (2016) has also projected a global expansion of nearly 29% in renewable energy generation by 2040.

The rising demand for renewable energy is instrumental in addressing energy security issues as well as CO_2 emissions-related issues. Owing to these growing problems, policymakers across the globe are gradually paying more attention to renewable energy sources. Renewable energy generation in 2012 was only 23% of the entire energy generation across the globe (EIA, 2016). As for individual G7 countries, hare of renewables (as a percentage of primary energy) were 17 percent for Canada, 13% for France, 12% for Germany, 12% for Italy, 6.9% for Japan, 3.8% for the United Kingdom, and 13% for the United States (REN21, 2016). Canada's rising share of renewables deserves special attention. Apart from its massive hydropower generation infrastructure (376 TW), Canada is gradually expanding the scope of renewable energy sources into tidal (20 MW), wind (6.2 GW), and biofuel (1.9 billion liters).[2]

Global investment in renewable energy sector in 2015 reached USD 285.9 billion, an increase of 4.9 percent relative to 2014 (UNEP Center, 2016). Interestingly, developing

[2]Based on the state-level policies, Canada has introduced "*Greenest City 2020*" initiative, which has the objective of attaining carbon-neutral and waste-free ecosystem by 2020.

economies have taken the leadership in investment in renewable energy with total investment of USD 156 billion relative to USD 130 billion for developed economies. This may partly be explained by the fall in subsidies for wind and solar photovoltaic (PV) power projects in European and North America, falling price of wind and solar PV technologies, and rising demand for renewable energy in developing and emerging economies (REN21, 2016). This may suggest that renewable energy markets in these G7 countries are gradually losing their significance among the investors.

This is the motivation of researchers for investigating the drivers of renewable energy production in G7 countries. Previous studies on investigating main determinates of renewable energy production provide mixed results. Also, drivers of renewable energy production might change with the change of scenario in G7 countries. For instance, some of these driver are (i) the rising demand and growing attractiveness of renewable energy market in developing and emerging economies; (ii) the fall in oil prices due to economic slowdown in China, which is the market leader in solar power generation; (iii) increased policy level concerns regarding CO_2 emissions, and (iv) a higher pursuit of renewable energy sources in the Asian and African nations, following the COP21 meeting. Therefore, keeping the objective of G7 nations for 2020, requires an understanding of the relationship among renewable energy generation, economic growth, CO_2 emissions and oil prices.

The primary purpose of this paper is to investigate the long-run relation and short-run dynamics among renewable energy consumption, CO_2 emissions and oil prices in G7 countries. In particular, the paper makes the following contributions to the existing literature: (1), We use the multivariate nonlinear ARDL (NARDL) method, proposed by Shin et al. (2014), to assess the asymmetric association, both in long-run and short-run between renewable energy consumption,

real income, CO_2 emissions and oil prices. Intricacy of economic structure and mechanism may result in possible non-linearity and asymmetry among these variables. If the changes in structural and policy regimes, national and global events, and economic disturbances are taken into consideration, then its multifarious impacts on time series data can be observed. (2), We carry out the empirical work using quarterly data over 1955-2014 following Shahbaz et al. (2017) for robust empirical analysis by avoiding sample size problem.[3] In the literature of energy economics, majority of the studies have used annual data, and a number of studies have pointed out the differential consequences of choice of frequency (see for more details, Shahbaz et al. 2017). The quarterly frequency is also useful in capturing potential non-linearity and asymmetry in the relationships. (3) We test for unit roots in individual variables using Zivot and Andrews (1992) method, which allows for endogenous structural breaks in variables.

Our empirical evidence indicates that income has significant effect on renewable energy consumption in symmetric manner in the US, UK, France and Germany and in an asymmetric manner in Japan but renewable energy consumption is insensitive to income for Italy in long run. Carbon emissions positively affect renewable energy consumption in symmetric manner for USA, France, Germany, Japan and Italy in long run. Renewable energy consumption is asymmetrically affected by carbon emissions in Canada but insignificant for the UK in the long-run. Renewable energy consumption is asymmetrically is influenced by oil prices in USA and symmetrically in the UK and France. This suggests for a dire need to establish a global green energy environment our findings have important implications for energy policy makers in the world.

[3] We applied quadratic match-sum method to transform data from annual to quarter frequency following Sbia et al. (2014).

II. Literature Review

There has been a voluminous research on the context of the association between energy consumption, economic growth, and emissions (some of the recent studies are, Apergis 2016, Asongu et al. 2016, Bedir and Yilmaz 2016, Chen et al. 2016, Robaina-Alves et al. 2016, Saidi and Hammami 2016, Shahbaz et al. 2016a, b, Sinha and Sen 2016, and many others). Most of the studies carried out in this context are based on non-renewable fossil fuel consumption, and the present context calls for the new evidences on the impact of renewable energy consumption on economic growth and CO_2 emissions. Therefore, we will focus on the recent studies on the impacts of renewable energy consumption.

Marques et al. (2010) analyzed the determinants of renewable energy supply for 24 European countries during 1990-2006. By applying fixed effects vector decomposition (FEVD), the authors have found that deployment of renewable energy is held back by traditional non-renewable energy sources and CO_2 emissions. Rafiq and Alam (2010) replicated Sadorsky's (2009) renewable energy consumption function for energy investor emerging economies. They noted that income and carbon emissions have positive and significant effect on renewable energy consumption but oil prices affect renewable energy consumption negatively but insignificantly.

Marques and Fuinhas (2011a) replicated the previous study for 21 European countries during 1990-2006, and found that the lobbying effect of traditional non-renewable energy sources on restraining renewable energy utilization in the presence of structural break. The subsequent study by Marques and Fuinhas (2011b) analyzed 24 European countries during 1990-2006, and they applied generalized method of moments (GMM) in this case. Apart from the lobbying effect of traditional non-renewable energy sources on renewable energy sources, their study divulged that the awareness level, climate change and CO_2 emissions targets, rising price

level of non-renewable energy sources are not adequate to develop the market of renewable energy in the European market. Tiwari (2011) analyzed the association between renewable energy consumption, economic growth, and CO_2 emissions for India. By applying innovations analysis, the author found that renewable energy consumption leads to rise in GDP and decline in CO_2 emissions. Aguirre and Ibikunle (2014) analyzed the determinants of renewable energy growth in BRICS nations for 1990-2010. By applying FEVD, panel corrected standard errors (PCSE), and generalized least squares (GLS) estimation techniques, they found that although, renewable energy consumption can address the environmental degradation issues, stringent and rising energy demand conditions restrict the policymakers to increase the share of renewable energy in energy mix. Apergis and Payne (2014a) analyzed the same for 25 OECD countries during 1980-2011. They considered per capita renewable energy consumption, per capita real GDP, per capita CO_2 emissions and real oil prices in their model, and by applying panel cointegration and error-correction model, they noted the evidence of feedback hypothesis between all the variables. In a nearly similar study by Apergis and Payne (2014b) that was carried out on the context of seven Central American nations, authors tried to find out the impact of the establishment of Energy and Environment Partnership with Central America initiative for developing the utilization of renewable energy sources in 2002. They noted that the influence of renewable energy consumption on coal and oil prices strengthened during the post-2002 period. During the same period, authors found a greater sensitivity of real GDP per capita to carbon missions per capita. A subsequent study by Apergis and Payne (2015) was carried out on the context of 11 South American nations and the similar results were obtained in that context also. Indeed, renewable energy consumption is found to be positively sensitive to variations of real GDP per capita, carbon emissions per capita and real oil prices in the long-run. Their empirical

results also indicate a feedback effect indicating the importance of renewable energy consumption in improving the growth of output and the mastering of carbon emissions. Omri and Nguyen (2014) analyzed the association between renewable energy consumption, CO_2 emissions, real oil prices, per capita GDP, and trade openness for 64 countries over the period 1990-2011. By applying system-GMM method on the dataset, they reported that CO_2 emissions and trade openness are the major determinants of renewable energy consumption. Furthermore, Omri et al. (2015a) disclosed that the results obtained in the previous study did not change with application of different methodologies, thereby reinstating the robustness of the findings. Omri et al. (2015b) investigated the determinants of renewable energy consumption for developed and developing economies. By using simultaneous equation GMM approach, they noted that income, carbon emissions and oil prices affect renewable energy consumption positively but oil consumption is negatively and significantly with it. Rafiq et al. (2014) analyzed the relationships among output, CO_2 emissions and renewable energy generation of India and China during 1972-2011. Following a multivariate error-correction approach, they found the evidence of conservation hypothesis between CO_2 emissions and renewable energy generation, and between renewable energy generation and output for short-run, whereas feedback hypothesis for long-run, in case of Indian context is also found. For Chinese context, they found the evidence of conservation hypothesis between CO_2 emissions and renewable energy generation, and growth hypothesis between renewable energy generation and output for short-run, whereas feedback hypothesis was found for long-run. Tiwari et al. (2015) analyzed the association between economic growth, renewable and nonrenewable energy production for 12 Sub-Saharan African countries during 1971-2011. Following both linear and hidden cointegration techniques, they

found the mixed results in terms of the effects of conservation policies on economic growth, thereby determining the future of energy security.

One of the recent studies by Vaona (2016) demonstrated an innovative approach of finding the association between renewable energy generation and import demand. The author analyzed 26 different countries over a range of periods, and by different estimation methods. The result of this study was that renewable energy generation can ensure the sustainability of import by reducing the dependence on fossil fuel based energy. Lin et al. (2016) explored the macroeconomic determinants of renewable electricity consumption for Chinese economy. They found that economic growth and financial development have positive impact on renewable electricity consumption. Foreign direct investment, trade openness and fossil fuels consumption have negative effect on renewable electricity consumption. Similarly, Dogan and Serker (2016) applied Dumitrescu-Hurlin non-causality approach to examine causal relationship between CO_2 emissions and its determinants. They found the feedback effect between renewable energy consumption and carbon emissions but non-renewable energy consumption is cause of carbon emissions[4].

It can be observed following discussion that the need of renewable energy in sustaining economic growth in various aspects is gradually turning out to be important, and this can as well solve the problem of climatic shift. Following the COP21 meeting, this issue has gained more prominence in the global scale, and therefore, in this background, the present study might find its own relevance in the existing body of existing literature. A nonlinear and asymmetric association between renewable energy consumption and its determinants may be owing to the uncertain consequence of macroeconomic and environmental reforms and reforms implemented in energy

[4] Ince et al. (2016) reported that informal institution paly important role in renewable energy development for Caribbean region.

markets. In order to analyze this uncertainty, these two factors need to be considered within the model framework. Over and above, we have not come across any study, which has analyzed the nonlinear and asymmetric causal association between economic growth and energy consumption for the case of G7 countries. As described by Chiou-Wei et al. (2008), the intricacy of this association can be elucidated by shifts in regimes and economic affairs, i.e. shifts in economic scenarios, movements of energy prices, and developments in energy policies.

III. Overview of energy policies in G7 countries

The economic growth of G7 economies entails the higher level of energy consumption for sustaining the level of industrialization. Across every sector in these nations, consumption of commercial electricity is facilitating to economic growth. As these economies are developed and industrially privileged, they have been able to exert a pull on potential investment historically, and this scenario is depicted in their GDP growth (Figure-1). As on 2014, these countries encompass nearly 45.52 percent share of the global income, 35.23 percent share of the global fossil fuel consumption, and 27.22 percent share of global CO_2 emissions (World Bank 2015). During 1960-2014, per capita income of G7 economies has grown nearly 32.59 times, whereas the global per capita income has grown only 2.32 times (World Bank, 2015). In order to catalyze and sustain this growth, the demand for energy has grown up, and a major portion of this demand is catered by renewable energy.

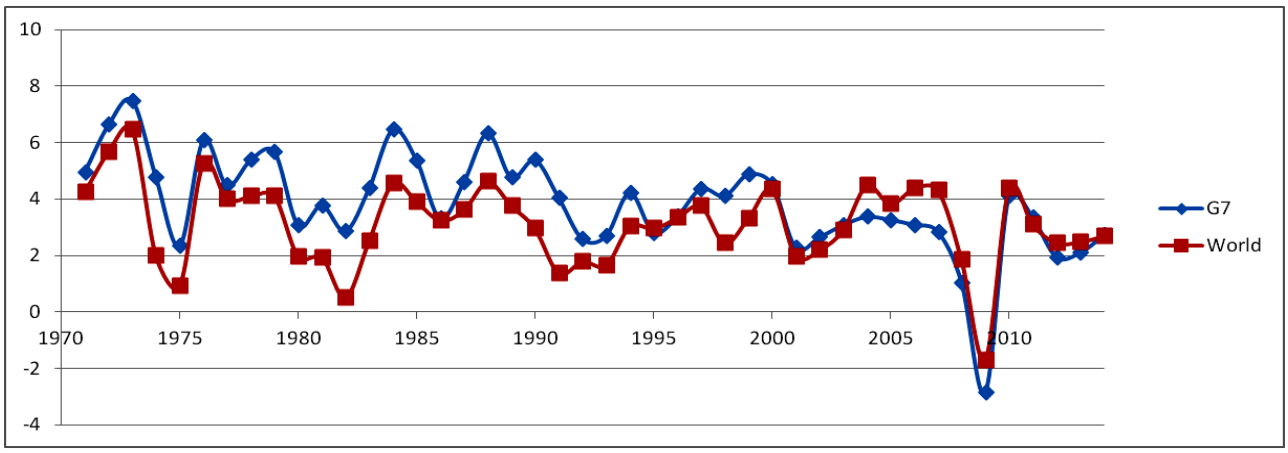

Figure 1: Comparison of GDP Growth – G7 economies viz-a-viz the World

The reforms in the energy policies of Canada started after the 1973 oil crisis, and these policies were targeted at energy conservation and reduction in CO_2 emissions (Yergin, 2006). In order to achieve this, Canada has been using its natural resources and geographical diversities in a way, so that they can generate a substantial amount of clean and renewable energy out of it. As on 2014, renewable energy constitutes nearly 19 percent of the primary energy supply of Canada. Owing to the geographical diversity and large number of streams, the hydropower generation in Canada amounts to nearly 59.2 percent of the total electricity production (NRC, 2014). The wind and biomass energy generation amounts to nearly 3.5 percent and 1.4 percent in the electricity production, respectively (NRC, 2014). Based on the New Brunswick's 2007 Climate Change Action Plan (CCAP), the fifth assessment of CCAP for 2014-2020 has projected to reduce CO_2 emissions 10 percent below the 1990 level by 2020, and 75-80 percent by 2050 (IEA, 2014). In order to achieve this, the Government of Brunswick has also described the need of sustainable economic growth path, by ensuring energy efficiency and promotion of renewable energy sources.

As Japan is a net importer of crude oil (second highest in the world), any fluctuations in the oil price can have a direct impact on the trade deficit. Rise in the liquid natural gas (LNG)

prices in the Asian market till 2014 caused a serious pressure on the Japanese economy (Stern, 2014). Following the Fukushima Daiichi nuclear accident, the government is looking forward to more innovations in the energy sector for sustaining the economy and catering to the rising demand of energy. As a result, the government initiated the fourth Strategic Energy Plan (SEP), which focused at energy security, economic efficiency and environmental protection. This plan was targeted at reducing the share of fossil fuel based energy sources and increasing the share of nuclear and renewable energy sources by 2030 (Ohnishi et al. 2016). Following the COP21 meet in 2015, Japan also targeted at reducing CO_2 emissions by 26 percent by 2030, and 80 percent by 2050 (Boyd et al. 2015). Introduction of feed-in tariff mechanism in 2012 for catalyzing the renewable generation process had opposite consequences, i.e., on one hand, capacities of solar photovoltaics (PV), wind and geothermal energy were increased substantially, and on the other hand, the continuous rise in the subsidies for renewable energy generation in turn resulted in severe cost implications, which affected their economic growth (Ayoub and Yuji, 2012).

Though France has been one of the largest exporters of crude oil, the falling price of crude oil is compelling them to shift their energy base to renewable energy sources. Acquiring of the battery manufacturing firm *Saft* gave an indication that France is not only aiming at the renewable energy solutions, but also is looking forward to storage solutions (Macalister, 2016). This event was the result of the National Renewable Energy Action Plan (NREAP), according to which the share renewable energy in final energy consumption should reach 23 percent by 2020. In 2015, the parliament of France passed a comprehensive energy and climate law, according to which the share of renewable energy generation should reach 40 percent of total energy generation by 2030 (Patel, 2015). As on 2014, the share of renewable energy in electricity production is nearly 19.5 percent, comprising of hydropower with 13.8 percent amounting to

nearly 28 TW, wind energy with 3.5 percent amounting to nearly 9,100 MW, and PV with 1.2 percent amounting to nearly 5,300 MW (RTE, 2015). Decommissioning of coal-fired power plants complemented this growth in renewable energy generation.

If the GHG emission reduction target of Germany is scrutinized, then it can be seen that they will be able to achieve a 32 percent reduction, against the target of 40 percent compared to the 1990 levels. This can be attributed to the 24.7 percent usage of brown coal, 18.3 percent usage of hard coal, and 8.3 percent usage of natural gas for electricity generation (Burger, 2016). In 2013, the coalition government in Germany revised the renewable energy targets, according to which the share of renewable energy consumption is 18 percent by 2020, 30 percent by 2030, 45 percent by 2040, and 60 percent by 2050 (Hong et al. 2013). Presently, the share of renewable energy generation is 33.9 percent in the total energy generation, and it is majorly consumed in electricity sector, heating sector, and transportation sector. In order to hedge against the possible fluctuations in crude prices and to shift the energy base towards a sustainable solution, the government is looking into different forms of biofuel, hydropower, PV, and wind energy. Recently, they are catalyzing the growth in geothermal energy generation by bringing in feed-in tariff. However, the increased uncertainty in the European Union and policy level voids is creating problems for renewable energy solution providers by increased cost and lack of supportive infrastructure (Chilcoat, 2016).

In order to cater the demand of electricity in Italy, the existing energy infrastructure is proving to be inadequate, and therefore, Italy is relying on the electricity import. As on 2010, 12.9 percent of electricity supply in Italy is imported, and therefore, the trade balance of Italy is highly dependent on the crude oil price movements, via the electricity import route (REN21, 2015). Along with this, Italy is also the fourth highest importer of natural gas in the world. Apart

from that, in 2010, nearly 67.2 percent of the energy demand was met by the electricity generated from fossil fuel based sources and only 20.6 percent from renewable energy sources (REN21, 2015). As a consequence of the Fukushima Daiichi nuclear accident in 2011, the nuclear program in Italy was abandoned. Therefore, sustain the economic growth and ensure energy security, Italy is required to abide by the EU renewable energy directive, according to which they have a target to generate at least 17 percent of their final consumption from renewable energy sources by 2020 (Spugnoli et al. 2012). Their government has initiated the National Renewable Energy Action Plan, and it has set the renewable energy generation target of 26.4 percent by 2020 (Jäger-Waldau et al., 2011). In order to achieve this target, they have introduced feed-in tariffs, tradable renewable energy, market premiums, and reverse auctions. In 2012, Italy became the second highest solar market in the world, with an installed capacity of 17,000 MW (Barbose et al. 2015). However, subsidization of PV at this level might make the players less competitive in the global scale, and it can affect the economic growth pattern by increasing cost burden. Therefore, they are trying to capitalize the other renewable energy sources, like hydropower and wind power.

During 1980-2010, the crude oil import of the US has increased by 200 per cent (EIA, 2011), and that exposes them to the high volatility of the crude oil prices (Baumeister and Peersman, 2013). In order to combat this situation, the US has given prudent importance to the renewable energy sources, and as a result, in 2011, the energy generated from renewable energy sources exceeded the contribution of nuclear energy. The renewable energy sources in the US include hydropower, wind energy, PV, and geothermal energy. In the pursuit of the renewable energy sources, agricultural waste is being transformed into the bioethanol and biodiesel. These renewable energy sources are produced domestically, and it is expected that these forms of clean

fuels can not only reduce the cost of oil import, but also can ensure energy security at the grassroots level. Though there has been a significant protest against these forms of biofuels owing to their contribution towards environmental degradation, the introduction of second generation biofuels have been replacing them rapidly. Saying this, it is also to be noted that due to the American Recovery and Reinvestment Act of 2009, huge amount of direct investment and tax credits were sanctioned for boosting the growth of renewable energy sector (Strobel, 2009), and to manage the cost implications, SunShot initiative was introduced in 2011 to lower the production cost of PV systems by 75 percent by 2020, so that the solar energy can become cost-competitive (Schwartz, 2011).

Lastly, like the rest of the G7 countries, the UK was also exposed to the crude oil prices volatility due to the rising volume of crude oil import, and the January 2008 Energy Bill was legislated to ensure the energy supply security, with a special focus on offshore natural gas and crude oil (Cuce, 2016). This framework was also focused at addressing the problem of rising level of CO_2 emissions and climatic shift. As on 2012, the UK was in the phase of turning out to be a net importer of energy, as they have been relying mostly on natural gas and coal, which have 41 percent and 29 percent of shares respectively in the energy mix (MacLeay et al. 2013). As on 2012, renewable energy shared only 12 percent and nuclear energy shared only 18 percent in the energy mix. Among the renewable energy sources, biomass energy has the maximum share of 36.8 percent, followed by onshore wind energy, with the share of 29.4 percent (MacLeay et al. 2013). However, the growth in the population and transportation indicated the problems of energy security, as the existing share of renewable energy has not been enough to cater to this rising demand of energy. As on 2014, introduction of hybrid vehicles and Energy Performance Certification of the building being made after 2007 have been able to tackle the

situation (Offer et al. 2011, Wang et al. 2012). In order to handle this issue and sustain the economic growth, the government of UK needs to look into the other emerging forms of renewable energy, such as hydropower and PV. They might need to transfer the cost of import towards the feed-in tariffs of these energy systems, so that these sectors can be boosted. However, for energy security to be ensured, they need to focus more on the nuclear power generation, which is presently running below its full capacity, and due to political issues, the future of the nuclear power plants is quite uncertain (Maddox, 2012).

IV. Methodology and data

IV.I Methodology

Recent studies reveal that tests of cointegration using linear econometric methods may lead to erroneous conclusions (Xiao, 2009). Shin et al. (2014) propose the nonlinear autoregressive distributed lag (NARDL) model that allows for nonlinearity and asymmetry while testing for long-run and short-run relations. The linear ARDL model has the following form:

$$\Delta REC_t = \rho_0 + \rho_{REC} REC_{t-1} + \rho_Y Y_{t-1} + \rho_{CO_2} CO_{2,t-1} + \rho_{OP} OP_{t-1} + \sum_{i=1}^{p-1} \alpha_i \Delta REC_{t-1} + \sum_{i=1}^{p-1} \alpha_i \Delta Y_{t-1} + \sum_{i=1}^{p-1} \alpha_i \Delta CO_{2,t-1} + \sum_{i=1}^{p-1} \alpha_i \Delta OP_{t-1} + \varepsilon_t \quad (1)$$

where REC_t, Y_t, CO_{2t} and OP_t refer respectively to renewable energy consumption, real gross domestic product (measure of income), carbon emissions and real oil prices; Δ denotes change, and p represents the lag orders for the variables, respectively. The ARDL model (1) is suitable

when the relationship among the variables is linear and symmetric. Absent linear and symmetric relations, the model may generate erroneous results. The NARDL model proposed by Shin et al. (2014) allows for nonlinearity and asymmetry. Decomposing exogenous variables into positive X_t^+ and negative X_t^- partial sums such that $X_t^+ = \sum_{j=1}^{t} \Delta X_j^+ = \sum_{j=1}^{t} \max(\Delta X_j, 0)$ and $X_t^+ = \sum_{j=1}^{t} \Delta X_j^- = \sum_{j=1}^{t} \min(\Delta X_j, 0)$ and introducing long-run and short-run asymmetries in equation-1 leads to the following general form of the NARDL model (Shin et al. 2014):

$$\begin{aligned}\Delta REC_t = {} & \rho_0 + \rho_{REC} REC_{t-1} + \rho_{Y^+}^+ Y_{t-1}^+ + \rho_{Y^-}^- Y_{t-1}^- + \rho_{CO_2^+}^+ CO_{2,t-1}^+ + \rho_{CO_2^-}^- CO_{2,t-1}^- + \rho_{OP^+}^+ OP_{t-1}^+ \\ & + \rho_{OP^-}^- OP_{t-1}^- + \sum_{i=1}^{p} \alpha_i \Delta REC_{t-i} + \sum_{i=1}^{p} (\alpha_i^+ \Delta Y_{t-i}^+ + \alpha_i^- \Delta Y_{t-i}^-) + \sum_{i=1}^{p} (\beta_i^+ \Delta CO_{2,t-1}^+ \\ & + \beta_i^- \Delta CO_{2,t-i}^-) + \sum_{i=1}^{p} (\gamma_i^+ \Delta OP_{t-i}^+ + \gamma_i^- \Delta OP_{t-i}^-) + \varepsilon_t \end{aligned} \quad (2)$$

Long-run asymmetries are tested using a Wald test of the respective null hypotheses $\rho_{Y^+}^+ = \rho_{Y^-}^-$, $\rho_{CO_2^+}^+ = \rho_{CO_2^-}^-$ and $\rho_{OP^+}^+ = \rho_{OP^-}^-$. The long-run effects of positive and negative shocks of exogenous variables on renewable energy consumption are computed as $L_{X^+} = -\rho_X^+ / \rho_{REC}$ and $L_{X-} = -\rho_X^- / \rho_{REC}$ where X_t denotes respectively Y_t, CO_2 and OP_t. Similarly, short-run asymmetry of the reaction of renewable energy consumption to changes in explanatory variables is tested using a Wald test of the null hypotheses $\alpha_i^+ = \alpha_i^-$, $\beta_i^+ = \beta_i$ and $\gamma_i^+ = \gamma_i^-$ for $i =$,1, … , p. Failure to reject long-run and short-run asymmetries leads to traditional ARDL model while non-rejection of either long-run or short-run asymmetry lead to NARDL model with short-run or long-run asymmetry.

Once the appropriate NARDL model is selected based on an information criteria and the results of long-run and short-run asymmetry tests, we proceed to compute the asymmetric

responses of renewable energy consumption to unit positive and negative changes in income, carbon emissions and oil prices using numerical derivatives of REC_t relative to the desired factor as follows:

$$m_h^+ = \sum_{j=0}^{h} \frac{\partial REC_{t+j}}{\partial X_t^+} \text{ and } m_h^- = \sum_{j=0}^{h} \frac{\partial REC_{t+j}}{\partial X_t^-} \text{ with } X_t \in \{Y_t, CO_{2,t}, OP_t\} \text{ and } h = 0,1,..... \quad (3)$$

where $h \to \infty, m_h^+ \to L_{X^+}$ and $m_h^+ \to L_{X^+}$ (Shin et al. 2014).

IV.II Data

The data on renewable energy consumption (kg of oil equivalent) is from BP Global (http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/renewable-energy.html). The data on real gross domestic product (constant 2010 US$) and carbon emissions (metric tons) is obtained from World Development Indicators (CD-ROM, 2015). The data on crude oil price is collected from Federal Reserve Bank of ST. Louis (https://fred.stlouisfed.org/series/DCOILWTICO/downloaddata). The study covers the period of 1955-2014 for G7 countries. Total population is used to transform all the variables into per capita units except real oil prices.

V. Empirical Results and Their Interpretations

Table-1 presents the descriptive statistics and stochastic properties of data series. The average renewable energy consumption ranges from 1382.809 in the UK to 6562.210 in the US. It is worth noting that energy consumption is more important in America (US and Canada) as compared to that in Europe and Japan. The previous empirical results could be explained by at-least two reasons. First, the US produces most of the world's necessary energy to the survival of

the world population. Indeed, the US is the second producer of energy in the world and it has only 4.5% of the world population. Second, the US industry is an old capital-intensive industry which is very costly to change towards more energy efficient process. Maximum renewable energy consumption is recorded in the 70s in the US and Germany, in late 90s in the UK and in the years 2000 in Japan, France, Italy and Canada. Renewable energy consumption is negatively skewed and displays excess kurtosis. The Jarque-Bera statistic indicates the non-normality of renewable energy consumption for all countries except the UK.

The average income is the highest for the UK and not surprisingly the lowest for Italy which is caused by the recent Italy's economic crisis. Y_t shows negative skewness and positive excess kurtosis but not for the US. The Jarque-Bera test fails to reject normality of income for all countries but Japan and Italy where income weakly deviates from normality. CO_2 emissions and oil prices are, on average, the highest in the US and the lowest respectively in Italy and Japan. CO_2 emissions is negatively skewed while oil prices are positively skewed except for the UK and Canada. CO_2 emissions and oil prices show positive excess Kurtosis. Jarque-Bera test rejects the null of normality for CO_2 emissions and oil prices in most of the countries. Even distribution on both sides of the mean of a bell curve symbolizes the symmetric distribution of the data. However, this distribution is an idealistic one, and can be hardly found in any practical scenario. This in turn leads towards the reliance on asymmetric empirical analysis. The presence of non-normality, verified by Jarque-Bera statistics, is handled by asymmetric ARDL model, as has the capability of taking the nonlinearities of the data into account (Shin et al. 2014). Before proceeding to nonlinear ARDL bounds testing approach, we need to test the order of integration of renewable energy consumption, income, CO_2 emissions and oil prices. In doing so, we have applied Zivot-Andrews (ZA) unit root test that accommodates single unknown structural break

stemming in the variables. The choice of performing the ZA test rather than ADF or PP tests is justified by possible existence of a structural change in the time series due to occurrence of crises and geopolitical events during the 1955-2014 period. The results are reported in Table-2. The empirical results indicate that all the variables are I(1) for all countries except for Germany where REC_t, Y_t and CO_2 are found to be stationary at I(0).

<*Insert Table 1 here*>

We now estimate the models specified in equations 1–2 to explain the impact of income, carbon emissions and oil prices on renewable energy consumption in G7 countries. The results are reported in Table-2. We find that loading on the lagged renewable energy consumption is negative and significant for all G7 countries indicating that the estimated NARDL model is stable for these countries.

The pass-through of income on renewable energy consumption reveals that income has a symmetric positive but long-run effect on renewable energy consumption in the US, France and Germany. Income has a weak symmetric negative effect on renewable energy consumption in the UK. Income is found to have no long-run effect on renewable energy consumption in Italy. Additionally, income impacts renewable energy consumption in an asymmetric manner in Canada and Japan. Indeed, an increase in income will increase renewable energy consumption in Japan but decreases renewable energy consumption in Canada in long-run. However, a decrease of income raises renewable energy consumption in both countries. It is worth noting that renewable energy consumption in the UK is the most sensitive to variation of income in long-run as it shows the highest long-run coefficient relative to income in absolute value. In fact, in the UK policy makers may want to target lower carbon prices on poorer energy users. Or, in practice this can lead to problems in identifying people eligible for support, administrative complexity

and take-up as well as problems of reducing the incentives for those affected to work if support is conditional on income or employment status (IFS Report R84, 2013). In short-run income contemporaneous changes positively impact renewable energy consumption in the US, Canada and Italy but do not impact renewable energy consumption in the UK, France and Germany. In Japan, contemporaneous increases of income and one-period lagged changes of income cause renewable energy consumption to move up. The empirical results reveal that income plays an important role in raising demand for renewable energy. These results are consistent with Sadorsky (2009) for G 7 countries, Rafiq and Alam (2010) for emerging economies, Omri et al. (2015b) for developed and developing countries, Lin et al. (2016) for China who reported that income is positively linked with renewable energy consumption.

The pass-through of carbon emissions on renewable energy consumption indicates that carbon emissions show a symmetric positive long-run effect on renewable energy consumption in the US, France, Germany, Japan and Italy but impact is found insignificant in the UK. Actually, countries have adopted different policies to promote the use of renewable energy. Nonetheless, the different experiences show that some policies failed in achieving their goals. Indeed, the US adopted a production tax credit for wind, closed-loop biomass and poultry waste in order to make it more cost effective to produce electricity from renewable energy rather than from fossil fuels. These taxes present the advantages of being uncertain as to when the law will be repealed. In fact, if there is a lack of credit the company does not receive compensation and it may no more be profitable to produce electricity from renewable energy. Similar reluctance was observed in Germany and France. Actually, in Germany the amount of money set aside to support renewable energy use has been already reached. In France, bidders receiving financial aids do not always translate into renewable energy projects on ground. However, in the UK the

government adopted a Feed-in-Tariffs with Contract for Difference[5] to encourage low-carbon electricity projects (Abdelmouleh et al. 2015). Renewable energy consumption is the most sensitive to carbon emissions in Germany with long run coefficient equal to 3.354 and the less sensitive to CO_2 emissions in France with a long-run coefficient equal to 0.391. The previous results could be due to the differences of policies adopted by the different countries and what extend those policies was successful. This can be attributed to the share of renewable energy in the energy mix of Germany and France, i.e. the percentage of renewable energy consumption in Germany is more than 30 per cent, whereas the same from France is near to 11 per cent (EEA, 2016). Moreover, in Canada an increase of carbon emissions causes renewable energy consumption to move up while a decrease of carbon emissions does not impact renewable energy consumption significantly. Turning to the analysis of short-run effect of carbon emissions on renewable energy consumption, empirical results reveal that contemporaneous changes of carbon emissions have a symmetric positive impact on renewable energy consumption in the US, Canada, France, Japan and Italy. Moreover, in Italy, one period lagged changes of carbon emissions impact negatively renewable energy consumption leading to an overall positive short-run effect of carbon emissions on renewable energy consumption. Additionally, changes in carbon emissions do not show any significant short-run impact on renewable energy consumption in the UK and Germany. In France, carbon emissions impact renewable energy consumption asymmetrically, a contemporaneous increase of carbon emissions cause renewable energy consumption to move up while a contemporaneous decrease of former does not impact significantly the latter. Overall, our empirical analysis indicates the positive impact of carbon emissions on renewable energy consumption. This empirical finding is similar with Sadorsky

[5] The mechanism consists in a long-term contract between an electricity generator and a contract counter party, which will enables the generator to have a constant level of revenues at a pre-agreed price, called strike price.

(2009), Rafiq and Alam (2010), Omri and Nguyen (2014) who noted the significant role of carbon emissions in stimulating renewable energy consumption.

The pass-through of oil prices on renewable energy consumption reported in Table-3 show that in long-run, oil prices increase causes renewable energy consumption to move up in the UK and France with a higher magnitude in the UK. Nevertheless, oil prices changes impact renewable energy consumption in long-run in Canada, Germany and Japan insignificantly. Oil prices show an asymmetric impact on renewable energy consumption in long-run for the US and Italy. Indeed, an increase of oil prices tends to raise renewable energy consumption in Italy but a decrease of oil prices causes renewable energy consumption to decrease in the US and to increase in Italy. Oil prices have a significant short-run effect on renewable energy consumption in 3 out of 7 countries. Indeed, one (two) lagged period changes in oil prices impact positively (negatively) renewable energy consumption in the US (Italy). However, oil prices changes drive renewable energy consumption in an asymmetric manner in France where it is noted that a contemporaneous increase of oil prices causes renewable energy consumption to move up. The positive impact of oil prices on renewable energy consumption in G 7 countries is consistent with existing studies in energy literature such as Sadorsky (2009), Rafiq and Alam (2010), Omri and Nguyen (2014).

<*Insert Table 2 here*>

<*Insert Table 3 here*>

Figures 2 to 8 depict the predicted asymmetric adjustment paths from an initial long-run equilibrium to a new long-run equilibrium following a unitary positive or negative shock hitting

each of income, carbon emissions and oil prices. The asymmetry path is calculated as a linear combination of the dynamic multipliers associated with positive and negative shocks. We also report the predicted adjustment paths following a positive (positive change curve) and negative (negative change curve) together with lower and upper 95% confidence bands for asymmetry for a given prediction horizon. The asymmetry path for income shows a greater reaction of renewable energy consumption to a decrease in income. When symmetric of income on renewable energy consumption is selected as best specification it is clear from the graphs of dynamic multipliers that the effect of income on renewable energy consumption stabilizes after almost eight quarters. Regarding the adjustment paths of renewable energy consumption following positive and negative shocks of CO_2 emissions the graphs show that for Canada the impact of a positive unitary shock to CO_2 emissions is greater than that to a negative unitary shock. The cumulative renewable energy consumption response to oil prices shock is significantly negative in the US. The new equilibrium between the two variables is reached after 20 quarters indicating that the effects oil prices shocks are persistent. For the other countries the new equilibrium after an oil prices shock is reached faster after 10 quarters.

<*Insert Figure 2 here*>

<*Insert Figure 3 here*>

<*Insert Figure 4 here*>

<*Insert Figure 5 here*>

<*Insert Figure 6 here*>

<*Insert Figure 7 here*>

<*Insert Figure 8 here*>

VI. Conclusion and Policy Implications

Problems regarding deteriorating quality of environment have led policy-makers to push forward a green economy by promoting the use of renewable energy, and substituting fossil fuel energy. Indeed, the rise in greenhouse emissions is yielding environmental pressure consisting of the rise in surface temperature, melting of glaciers, rise in the sea levels, and changes in the rainfall patterns. For promoting the use of renewable energy requires adoption of appropriate energy policies and the development of inexpensive alternative energy sources, so that the industry gets involved in the transition process towards the use of renewable energy and detriment of the pollutants.

For formulating a roadmap for appropriate energy policy focused at renewable energy adoption, parametric analysis of the scenario was required. Keeping focus at G7 countries, we employed the nonlinear autoregressive distributed lags model to investigate the asymmetric transmissions of economic growth, carbon emissions, and oil prices to renewable energy consumption in the long-run and short-run using quarterly data over the period 1955Q1-2014Q4. This empirical setting helps in assessing the effects of positive and negative changes of real economic growth, carbon emissions and oil prices on the levels of renewable energy consumption in G7 countries, while accounting for the potential long-run cointegration relationship between renewable energy consumption and its determinants. The results show that renewable energy consumption is significantly sensitive to economic growth in all countries in the long-run, except in the UK, where economic growth is found to have no influence on renewable energy consumption. Moreover, asymmetric long-run relationship between renewable energy consumption and economic growth is observed in Japan. Similarly, carbon emissions

asymmetrically influence renewable energy consumption in Canada and linearly in USA, France, Germany, Japan and Italy, in the long-run. In the UK, no long-run relationship is found between renewable energy consumption and carbon emissions. Oil prices demonstrate a nonlinear influence on renewable energy consumption in the US, and this effect is linear in the UK and France. However, no evidence of such impact is found in Canada, Germany, Japan and Italy. In the short-run, results reveal a nonlinear pass through of income to renewable energy consumption in Japan and an asymmetric transmission of oil prices to renewable energy consumption in USA and France. Additionally, carbon emissions have a symmetric impact on renewable energy consumption for short-run in all G7 countries.

The empirical findings are crucial for policy-makers to draw up a new energy policy roadmap, aiming at promoting the use of renewable energy consumption. Sustainable development is possible via instruments, like income, carbon emissions and oil prices, and results of this study demonstrates the nature of the long-run and short-run influences of these instruments on renewable energy consumption, particularly in case of G7 countries. In addition, while making any energy policy concerning the promotion of renewable energy, the decision makers in G7 countries should consider oil prices and global CO_2 emissions. However, decision makers should recognize that differences in effect of economic growth and national CO_2 emissions are observed across countries. Consequently, common energy policies should be coupled with country-specific strategies via domestic levels of economic growth and carbon emissions in the setting of sustainable development plan.

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