Energy Consumption, CO_2 Emissions, and Economic Growth: An Ethical Dilemma

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Abstract

In this study we examine the dynamic interrelationship in the output–energy–environment nexus by applying panel vector autoregression (PVAR) and impulse response function analyses to data on energy consumption (and its subcomponents), carbon dioxide emissions and real GDP in 106 countries classified by different income groups over the period 1971–2011. Our results reveal that the effects of the various types of energy consumption on economic growth and emissions are heterogeneous on the various groups of countries. Moreover, causality between total economic growth and energy consumption is bidirectional, thus making a case for the feedback hypothesis. However, we cannot report any statistically significant evidence that renewable energy consumption, in particular, is conducive to economic growth, a fact that weakens the argument that renewable energy consumption is able to promote growth in a more efficient and environmentally sustainable way. Finally, in analysing the case for an inverted U-shaped EKC, we find that the continued process of growth aggravates the greenhouse gas emissions phenomenon. In this regard, we cannot provide any evidence that developed countries may actually grow-out of environmental pollution. In the light of these findings, the efficacy of recent government policies in various countries to promote renewable energy consumption as a means for sustainable growth is questioned. Put differently, there seems to be a moral dilemma, between high economic growth rates and unsustainable environment and low or zero economic growth and environmental sustainability.

Keywords: Energy Consumption, Economic Growth, CO_2 Emission, Panel Vector Auto Regression, Panel Impulse Response Function

JEL codes: C33, O13, O44, P28, P48, Q42, Q56

1 Introduction

The increasing threat of global warming and climate change has been a major, worldwide, ongoing concern for more than two decades. It was in 1995 when the Intergovernmental Panel on Climate Change (IPCC) for the first time announced that "the balance of evidence suggests that there is a discernible human influence on global climate." (IPCC, 1995, p. 22). Nevertheless, this statement acknowledged a number of uncertain and perhaps dubious – at the time - assertions and thus, these results were treated as tentative. More recently, though, the IPCC (2014) reported that global warming is being caused by the ever increasing concentration of greenhouse gases (GHG), as well as, other anthropogenic activities. They maintain that the key factors that lead to increased GHG emissions are, among others, the economic activity and energy usage.

The link among energy consumption, emissions and economic growth has received considerable attention over the years by both policy makers and researchers, as the achievement of sustainable economic growth has gradually become a major global concern. It should also be noted that interest in this field has been further escalated due to the rather intricate character of this particular nexus, both from a theoretical and an empirical perspective.

The existing literature in this field can be classified under three strands. The first group consists of studies that investigate the causal links between energy consumption and economic growth (see, among others, Kraft and Kraft, 1978; Chiou-Wei et al., 2008; Chontanawat et al., 2008; Huang et al., 2008; Akinlo, 2009; Apergis and Payne, 2009b; Ghosh, 2009; Payne, 2010; Ozturk, 2010; Eggoh et al., 2011; Joyeux and Ripple, 2011; Chu and Chang, 2012; Dagher and Yacoubian, 2012; Abbas and Choudhury, 2013; Bozoklu and Yilanci, 2013; Dergiades et al., 2013; Yıldırım et al., 2014). The second group of studies concentrates its attention on the relationship between economic activity and emissions (e.g. Grossman and Krueger, 1991; Dinda, 2004; Stern, 2004; Kijima et al., 2010; Al-Mulali et al., 2015; Furuoka, 2015; Wang and Feng, 2015b). Finally, the third group of studies combines the two aforementioned relationships and thus uses a unified framework to identify the links among energy consumption, emissions and economic growth (e.g. Soytas et al., 2007; Ang, 2008; Apergis and Payne, 2009a; Soytas and Sari, 2009; Zhang and Cheng, 2009; Halicioglu, 2009; Wang et al., 2012b,a; Wang and Yang, 2015).

The main conclusion among the aforementioned studies in any of these three strands of the literature is that results are contested (a point discussed in more detail in the following section). Potential explanations for the conflicting results of previous studies could be, among others, due to the different time-periods and country-sample data used, different econometric approaches and/or the omitted variables bias. In addition, the majority of these studies are based on static and not dynamic analysis, on aggregated (total) data of energy consumption and/or focus on a small group of countries.

In this study, we attempt to shed more light into the intricate and complex relationships of the energy–growth–emissions nexus by accounting for the shortcomings of the existing literature. Thus, our contributions can be summarized as follows. First, we build a very comprehensive dataset of energy consumption, economic growth and CO_2 emissions consisting of 106 countries over the period 1971-2011. Second, we classify countries according to their level of development (i.e. low income, lower middle income, upper middle income and high income) and control for any omitted variable bias by the inclusion of control variables typically used in the neoclassical growth theory. Third, we disaggregate total energy consumption into 5 subcategories (i.e. electricity, oil, renewable, natural gas and coal energy consumption) in an attempt to examine whether the links between energy consumption, economic growth and emissions differ among the various sources of energy consumption. Finally, and most importantly, we examine the dynamic links between our endogenous series (energy consumption, economic growth and CO_2 emissions) using a Panel Vector Auto Regression (PVAR) approach, originally developed by Holtz-Eakin et al. (1988), along with panel impulse response functions.[1]

Panel VARs have been used to address a variety of issues of interest to applied macroeconomists and policymakers, such as, business cycle convergence and cross sectional dynamics (Canova et al., 2007; Canova and Ciccarelli, 2012), the construction of coincident or leading indicators of economic activity (Canova and Ciccarelli, 2009), financial development and dynamic investment behavior (Love and Zicchino, 2006a), housing price dynamics (Head et al., 2014) and exchange rate volatility dynamics (Grossmann et al., 2014), among others.

The advantages of using a PVAR methodology relative to methods previously used to examine the relation between energy consumption, economic growth and CO_2 emissions are several. First, PVARs are extremely useful when there is little or ambiguous theoretical information regarding the relationships among the variables to guide the specification of the model. Second, and more importantly, PVARs are explicitly designed to address the endogeneity problem, which is one of the most serious challenges of the empirical research on energy consumption, economic growth and CO_2 emissions. PVARs help to alleviate the endogeneity problem by treating all variables as potentially endogenous and explicitly modeling the feedback effects across the variables. Thus, we use a generalised identification scheme in line with Koop et al. (1996), Pesaran and Shin (1998) and Diebold and Yilmaz (2012), in which the results are invariant to the ordering of the variables in the PVAR, unlike those under the Cholesky identification scheme. In the context of the present study, this is particularly important since it is hard, if not impossible, to justify one particular ordering between the energy consumption, economic growth and CO_2 emissions. Put differently, shocks are highly intertwined, and this feature is very well captured by the generalised PVAR framework that we employ. Third, impulse response functions based on PVARs can account for any delayed effects on and of the variables under consideration and thus determine whether the effects between energy consumption, economic growth and CO_2 emissions are short–run, long–run or both. Such dynamic effects would not have been captured by panel regressions. We thus conduct panel impulse response function analysis so as to examine both the short-run and the long-run interdependencies in the energy–growth–emissions nexus. Fourth, PVARs allow us to include country fixed-effects that capture time-invariant components that may affect energy consumption and growth, and global time effects that affect all countries in the same period. Fifth, time fixed-effects can also be added to account for any global (macroeconomic) shocks that may affect all countries in the same way. Both time and country fixed-effects are included in our analysis. Last but not least, PVARs can be effectively employed with relative short-time series due to the efficiency gained from the cross-sectional dimension.

Our findings suggest that the effects of the various types of energy consumption on eco-

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[1] For a recent survey on PVARs, readers are referred to study of Canova and Ciccarelli (2013).

nomic growth and CO_2 emissions are heterogeneous across the various groups of countries and sources of energy consumption. In particular, despite causality between economic growth and energy consumption being bidirectional in the case of the full sample of countries and of total energy consumption (i.e. evidence for the feedback hypothesis), the same does not hold true for all sub-sources of energy consumption and country income groupings. For instance, the feedback hypothesis is only supported for oil energy consumption (in the lower middle, upper middle and high income countries) and to a lower extent for electricity energy consumption (only in lower middle income countries), while no significance evidence of the feedback hypothesis is documented for renewable energy, natural gas and coal energy consumption. Importantly, our findings do not point to any statistically significant evidence that renewable energy consumption in particular is conducive to economic growth, a fact that weakens the argument that renewable energy consumption is able to promote growth in a more efficient and environmentally sustainable way. Finally, in analysing the case for an environmental Kuznets curve (EKC), we find that the continued process of growth aggravates the greenhouse gas emissions phenomenon. Put differently, CO2 emissions increase with the level of development. In this regard, our findings do not provide any evidence that developed countries may actually grow-out of environmental pollution.

In the light of these findings, the efficacy of recent government policies in various countries to promote renewable energy consumption as a means for sustainable growth is questioned. At the same time, it puts forward the argument that perhaps decisions should be made not on the basis of how developed societies may sustain current levels of growth by employing renewable energy consumption strategies (as this might in fact be an infeasible approach in the long run), but rather, to concentrate on more communally just ways and ideas of social conduct such as the ones endorsed by the process of degrowth or a-growth. Put differently, there seems to be a moral dilemma, between high economic growth rates and unsustainable environment and low or zero economic growth and environmental sustainability. Interesting avenues for future research might include the investigation of other pollutants in order to get a more complete picture of the effects of energy consumption and growth on the environment.

The rest of this paper is organised as follows: Section discusses the key related studies in this field. Section 3 describes the data used and the econometric models employed. Section 4 presents the empirical results. Section 5 concludes the paper and discusses potential avenues for further research.

2 Brief Literature Review

Although literature in this area is very crowded, the aim of this section is not to provide a comprehensive review of the related studies but rather to highlight their key findings.

In short, there are three main groups of studies under this line of research. The first group comprises those studies that investigate the causal links between energy consumption and economic growth and it was initiated by Kraft and Kraft (1978). A rather complete review of the related literature can be found in Payne (2010), Ozturk (2010), Abbas and Choudhury (2013) and Yıldırım et al. (2014). Existing work in this group of study does not provide a single interpretation to describe the aforementioned relationship, but rather, four alternative hypotheses: i) the growth hypothesis, ii) the conservation hypothesis, iii) the feedback hypothesis and iv) the neutrality hypothesis.

The growth hypothesis is supported when there is evidence of unidirectional causality running from energy consumption to economic growth. In such case, energy consumption plays an important direct role in the process of economic growth and/or as a complement to capital and labor, and thus energy conservation policies aiming at protecting the environment are expected to erode the process of economic growth. The conservation hypothesis is verified when there is unidirectional causality flowing from economic growth to energy consumption. If the latter hypothesis prevails, then energy conservation policies can be implemented to reduce carbon dioxide (CO_2) emissions and global warming without negatively affecting the process of economic growth. The feedback hypothesis postulates a bi–directional causality between energy consumption and economic growth. In this case, energy policies should be carefully regulated, as one sided policy selection is harmful for economic growth or ecological balance and budget for energy consumption. Finally, the neutrality hypothesis suggests no causality between energy consumption and economic growth, and as such, conservation policies devoted to reducing energy consumption will not have any influence on economic growth.

Studies in this area mainly focus on the total energy consumptions and on particular groups of countries (e.g. South Asia, G7, Central America, etc.), although some studies disentangle the energy usage by energy source, such as, electricity, coal, nuclear and renewables (see, for example, Chiou-Wei et al., 2008; Akinlo, 2009; Apergis and Payne, 2009b; Ghosh, 2009; Eggoh et al., 2011; Chu and Chang, 2012; Dagher and Yacoubian, 2012; Abbas and Choudhury, 2013; Bozoklu and Yilanci, 2013; Dergiades et al., 2013; Yıldırım et al., 2014). Furthermore, there are studies that assess whether the level of development or income plays a role in the energy-growth nexus (see, *inter alia*, Chontanawat et al., 2008; Huang et al., 2008; Joyeux and Ripple, 2011), reporting different results among developed and developing countries or countries that belong to different income groups.

The second group of studies concentrates its attention on the relationship between economic activity and emissions. These studies are fuelled by the Environment Kuznets Curve (EKC) hypothesis, which was developed in the 1950s and 1960s. The seminal paper by Grossman and Krueger (1991) paved the way for the empirical testing of the EKC theory and allowed numerous studies to explore linear and non–linear relationships between economic activity and emissions. Dinda (2004), Stern (2004), Kijima et al. (2010), Furuoka (2015) and Al-Mulali et al. (2015) provide an exhaustive list of studies in this strand of the literature. Findings are once again inconclusive and country or region specific, as in the case of the energy–growth relationship.

The third group of studies combines the two aforementioned relationships and thus uses a unified framework to identify the links among energy consumptions, emissions and economic growth. Despite the fact that is a relatively new area of study (early studies in this area include those by Soytas et al., 2007; Ang, 2008; Apergis and Payne, 2009a; Soytas and Sari, 2009; Zhang and Cheng, 2009; Halicioglu, 2009), a wealth of literature has emerged, given its importance to policy makers. Table 1 presents some of the most recent studies.

[Insert Table 1 here]

As suggested in Table 1, it is not a surprise that even in this more holistic approach, results remain conflicting and often contradicting among the different studies. It is worth noting that the majority of these studies provide evidence based on total energy consumption and focusing on small groups of countries (e.g. ASEAN, BRICS, etc.). On a parallel note, it is perhaps not surprising that the nexus among economic activity, energy consumption and environmental waste has received considerable attention in developing economies in which the continuing development of the secondary sector has caused major environmental concerns and has stressed the necessity to identify efficient ways of energy consumption and growth (see, for example, Zhang, 2003; Wang et al., 2015; Wang and Feng, 2015a; Zhang and Wang, 2014).

As pointed out by Stern and Common (2001), Toman and Jemelkova (2003), Dinda (2004), Stern (2004) and Yang and Zhao (2014), among others, the fact that a consensus has not been reached in any of the three strands of the literature could be due to the different data that have been used, the different econometric approaches but more importantly due to the omitted variables bias, among other reasons.

3 Empirical methodology

3.1 Data

In this study we collect annual data from the World Development Indicators database maintained by the World Bank[2] for real GDP per capita (in 2005 US$) and CO_2 emissions (metric tones per capita) for 106 countries (see Table 2) between 1971–2011. CO_2 emissions for 2011 are supplemented by Emissions Database for Global Atmospheric Research (EDGAR). In addition, we collect from the International Energy Association (IEA) for final consumption of total energy consumption along with its 5 subcomponents i) electricity, ii) oil, iii) renewable, iv) gas and v) coal energy consumption (each measured in kilotons of oil equivalent per capita) over the period 1971–2011.[3]

[Insert Table 2 here]

In table 2 and Figure 1, which present the aforementioned series, it becomes clear that, overtime, economic development (indicated by higher income) is associated with an increasingly higher share of environmentally pollutant energy consumption sources. For instance, high income countries have the highest share of oil and coal energy consumption (the most pollutant energy sources), while the share of renewable energy consumption (an environmental-friendly energy source) declines as country income increases. The only exception is for gas consumption (a relatively pollutant-free source of energy consumption), with its share rising as country income increases. These developments pose several questions about environmental sustainability and pollution, as well as their impact on economic growth across countries with different economic development. Thus, the investigation of the causal linkages among alternative sources of energy consumption, CO_2

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[2] The database was accessed on March 25, 2014.

[3] We have ensured that in the construction of the aforementioned 5 subcategories of energy consumption there is not any double-counting (i.e. overlapping).

emissions and economic growth across countries of different income groups is of paramount importance and which we explore in detail below.

[Insert Figure 1 here]

[Insert Table 3 here]

3.2 Panel unit root tests

The first step for the investigation of causality is to determine whether the series has any integration orders. For this purpose, this study employs panel unit root tests developed by Levin et al. (2002) (hereafter LLC) and Im et al. (2003) (hereafter IPS).

The LLC (2002) unit root test considers the following panel ADF specification:

$$\Delta \ln Y_{it} = \rho_i Y_{it-1} + \sum_{j=1}^{p_i} \delta_{i,j} \Delta \ln Y_{it-j} + \varepsilon_{it}, \tag{1}$$

where Y_{it} is a vector of our key endogenous variables: energy consumption per capita growth, CO_2 emissions per capita growth and real GDP per capita growth.

The LLC (2002) assumes that the persistence parameters ρ_i are identical across cross-sections (i.e., $\rho_i = \rho$ for all i), whereas the lag order p_i may freely vary. This procedure tests the null hypothesis $\rho_i = 0$ for all i against the alternative hypothesis $\rho_i < 0$ for all i. Rejection of the null hypothesis indicates a possible panel integration process.

The IPS (2003) test, which is also based on Eq. (1), differs from the LLC test by assuming ρ_i to be heterogeneous across cross–sections. The IPS tests the null hypothesis H_0: $\rho_i < 0$ against the alternative hypothesis H_1: $\rho_i < 0$, $(i = 1, ..., N_1)$; $\rho_i = 0$, $(i = N_1, ..., N)$ for all i. Acceptance of the alternative hypothesis allows the individual series to be integrated.

The LLC and IPS tests were executed on data both in levels and first differences of the natural logarithms, and results were reported in Table 4. It is evident that all of the variables are stationary in first differences, while the level results indicate the presence of a unit root.

[Insert Table 4 here]

3.3 Panel Granger–causality

Next we examine the direction of causality among GDP per capita growth, energy (and its subcomponents) per capita consumption growth and CO_2 emissions per capita growth in a panel context. The Granger causality test is as follows:

$$\begin{aligned}
\Delta \ln G_{it} &= \alpha_{1t} + \sum_{l=1}^{mlG_i} \beta_{1i,l} \Delta \ln G_{it-l} + \sum_{l=1}^{mlEC_i} \gamma_{1i,l} \Delta \ln EC_{it-1} + \sum_{l=1}^{mlCO2_i} \delta_{1i,l} \Delta \ln CO2_{it-l} + \varepsilon_{1it} \\
\Delta \ln EC_{it} &= \alpha_{2t} + \sum_{l=1}^{mlG_i} \beta_{2i,l} \Delta \ln G_{it-l} + \sum_{l=1}^{mlEC_i} \gamma_{2i,l} \Delta \ln EC_{it-1} + \sum_{l=1}^{mlCO2_i} \delta_{2i,l} \Delta \ln CO2_{it-l} + \varepsilon_{2it}
\end{aligned}$$

$$\Delta \ln CO2_{it} = \alpha_{3t} + \sum_{l=1}^{mlG_i} \beta_{3i,l} \Delta \ln G_{it-l} + \sum_{l=1}^{mlEC_i} \gamma_{3i,l} \Delta \ln EC_{it-1} + \sum_{l=1}^{mlCO2_i} \delta_{3i,l} \Delta \ln CO2_{it-l} + \varepsilon_{3it} \quad (2)$$

where index i refers to the country (see Table 2), t to the time period ($t = 1, ..., T$) and l to the lag. $\Delta \ln G$ denotes the real GDP per capita growth, $\Delta \ln EC$ denotes energy (and its subcomponents) per capita consumption growth, and $\Delta \ln CO2$ denotes CO_2 emission per capita growth, and ε_{1it}, ε_{2it} and ε_{3it} are supposed to be white-noise errors.

According to model (2), for instance, in country group i there is Granger causality running only from EC to G if in the first equation not all γ_{1i}'s are zero but all β_{1i}'s and δ_{1i} are zero. The Chi^2 statistic tests the null of no causal relationship for any of the cross-section units, against the alternative hypothesis that causal relationships occur for at least one subgroup of the panel. Rejection of the null hypothesis indicates that e.g. EC Granger causes G for all i.

3.4 Panel VAR approach

PVAR methodology, originally developed by Holtz-Eakin et al. (1988), combines the traditional VAR approach, which treats all the variables in the system as endogenous, with the panel-data approach, which allows for unobserved individual heterogeneity. In its general form, our model can be written as follows:

$$\Delta \ln Y_{it} = A_0 + A_1 \Delta \ln Y_{it-1} + A_2 \Delta \ln Y_{it-2} + ... + A_j \Delta \ln Y_{it-j} + BX_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

where Y_{it} is a 1×3 vector of our three key endogenous variables, namely: (i) energy consumption per capita growth, (ii) CO_2 emissions per capita growth and (iii) real GDP per capita growth. $\Delta \ln$ denotes the first difference of the natural logarithm. The autoregressive structure allows all endogenous variables to enter the model with a number of j lags. The optimal lag-length is determined by the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). X_{it} is a 1×3 vector of the exogenous variables (commonly used in endogenous growth models) comprising: (i) labour force participation rate, capturing labour input, (ii) gross fixed capital formation as a % of GDP, measuring capital input, and (iii) imports plus exports over GDP, capturing the degree of openness. The inclusion of these control variables is to avoid any potential omitted variable bias.

The advantage of the PVAR is the same as the advantage of any panel approach; i.e., it allows for the explicit inclusion of country fixed-effects in the model, denoted μ_i, which capture all unobservable time-invariant factors at a country level. This is important for our purposes as inclusion of these fixed-effects allows each country to have a country specific level of each of the factors in the model, and, in addition, to capture other time-invariant factors, such as country size. However, inclusion of country fixed-effects presents an estimation challenge, which arises in any model which includes lags of the dependent variables: the fixed-effects are correlated with the regressors and, therefore, the mean–differencing procedure commonly used to eliminate country fixed effects would create biased coefficients. To avoid this problem we use forward mean-differencing, also referred to as the 'Helmert procedure' (Arellano and Bover, 1995). This procedure removes only the forward mean, i.e., the mean of all the future observations available for each country-year. This transformation preserves the orthogonality between transformed variables and lagged regressors, which allows us to use lagged regressors as instruments and estimate the coefficients by system GMM. Our PVAR estimation routine follows Holtz-Eakin et al. (1988) and Love and Zicchino (2006b).[4]

Another benefit of the panel data is to allow for time fixed effects, λ_t, which are added to model (3) to capture any global (macroeconomic) shocks that may affect all countries in the same way. For example, time fixed effects capture common factors such as key global risk factors. To deal with the time fixed effects, we time difference all the variables prior to inclusion in the model, which is equivalent to putting time dummies in the system.

The prime benefit of the PVAR is to allow the evaluation of the effect of the orthogonal shocks i.e., the impact of a shock of one variable on another variable, while keeping all other variables constant. This is accomplished with the use of panel impulse-response functions, which identify the reaction of one variable to the innovations in another variable in the system, while holding all other shocks equal to zero. However, since (i) the actual variance-covariance matrix of the errors is unlikely to be diagonal (e.g. errors are correlated), (ii) the results of the panel Granger causality tests revealed multidirectional causality among our variables and (iii) given that any particular particular ordering of the variables in our PVAR model would be hard to justify, we use generalised PVAR framework (in the spirit of Koop et al., 1996; Pesaran and Shin, 1998), in which forecast error variance decompositions are invariant to the ordering of the variables.

In order to get a more complete picture of the dynamic interactions among energy consumption, economic growth and CO_2 emissions, we perform a panel generalised impulse-response function (PGIRF) analysis, in order to assess the speed of adjustments to shocks originating in our aforementioned three variables. The panel generalised impulse response function analysis employed, which is based on Koop et al. (1996) and Pesaran and Shin (1998), provides a natural solution when theory does not provide a clear cut guidance on the identification of the aforementioned endogenous variables, as discussed above. Moreover, the PGIRFs are also decomposed into the responses of shocks to specific variables by taking out from the PGIRFs the effects of shocks to all other variables (Koop et al., 1996), which gives us further insights into the transmission mechanisms of the energy-growth–emissions nexus.

4 Empirical findings

4.1 Panel causality tests

We begin our analysis by focusing on panel Granger causality tests, discussed in Section 3.3 above, among different groups of countries. In particular, we adopt World Banks classification of countries by virtue of their income, which basically entails five groups. These groups are (i) all countries, (ii) low income countries, (iii) lower-middle income countries, (iv) upper-middle income countries and (v) high income countries. What is more, in each panel, we consider 6 different types of energy consumption; namely, (i) total energy consumption (EC), (ii) electricity consumption (ELEC), (iii) oil consumption

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[4] More recently, Love and Rima (2014) have employed the same approach to examine the impact of macroeconomic shocks on bank loan portfolio quality.

(OILC), (iv) renewable energy consumption (REC), (v) natural gas consumption (GASC), and (vi) coal consumption (COALC). Results are given by table 5.

[Insert Table 5 here]

According to these results, some interesting patterns are revealed. First, total energy consumption along with electricity and oil consumption Granger-cause economic growth in almost all country groupings, while renewable energy consumption does not Granger-cause economic growth in any of the country groupings. Second, CO_2 emissions Grnager-cause economic growth only in the high income countries. Third, economic growth, in general, Granger-causes total energy (and it subcomponents) consumption in every country grouping, while CO_2 emissions Granger-cause total energy consumption, electricity and oil consumption only in high income countries. Fourth, economic growth Granger-causes CO_2 emissions in all country groups apart from lower middle income countries. Fifth, total energy consumption, electricity and oil consumption Granger-cause CO_2 emissions in lower middle income, upper middle income and high income countries, while renewable energy consumption, as expected, is pollutant free as it does not Granger-cause CO_2 emissions across all country groups, apart from that in high income countries, albeit at the 10% level of significance. Finally, the evidence of a three-way (i.e from EC to G, EC to CO_2, G to EC, G to CO_2, CO_2 to G and from CO_2 to EC) Granger causality in many of the country groups, motivates the use of generalised forecast error variance decomposition in our impulse response analysis below (for more details, please refer to the next section).

In particular, concentrating on the first column of Table 5 we are able to extract information relating to the effect of each type of energy consumption on economic growth. We notice that EC causes growth only in upper-middle and high income countries. However, this result is rather generic and fails to capture specific differences in energy consumption among the different country classifications. To this end, we proceed with decomposing our results into the various types of energy consumption. In turn, we notice that ELEC causes growth only in low and lower-middle income countries. On the other hand, OILC appears to cause growth in lower and upper-middle, as well as, high income countries. What is more, we cannot find any effect of REC on growth. Apparently, GASC causes growth only in the high income group. Finally, COALC causes growth only in the lower-middle income countries. Adding CO_2 emissions to our analysis (see columns two and three of Table 5); we notice that CO_2 emissions significantly drive growth in the high income group. Furthermore, considering CO_2 emissions and energy consumption in tandem, we ascertain that growth in both the upper-middle and the high income countries is significantly driven both by CO_2 emissions and energy consumption. On the basis of these results, we provide evidence that causality runs from energy consumption to economic growth; although, as we show later in this section, causality between the two is rather bilateral. Apparently, this evidence holds considering most types of energy consumption, as well as, most groups of countries. Nonetheless, it should be emphasized that there is no direct statistically significant impact of REC on growth for any group of countries. Despite the fact that REC is a key factor for energy security and environmental sustainability, apparently, it does not promote growth. In this regard, we cannot report any causality running specifically from REC to growth for any of the groups. Our findings further indicate that CO_2 emissions appear to be an integral part of the growth process. Overall, we provide evidence of the existence of a rather monotonically increasing EKC. This is also supported by Figure 2, which presents the EKC based on a scatter plot of 1971-2011 average values between real GDP per capita and CO_2 emissions per capita. In particular, it is evident from this figure that CO_2 emissions increase with the level of development.

[Insert Figure 2 here]

Turning to the effects of growth on the various types of energy consumption, initially we concentrate on the fourth column of Table 5. Obviously, statistically significant relationships suggest that growth leads to the consumption of energy in almost all groups of countries and for any type of electricity consumption, with the exception of GASC and COALC. In other words, we find that, for most types of energy consumption and groups of countries, causality runs towards energy consumption as well. If we combine this piece of information with the results presented earlier in this section we can deduce that there is in fact a strong case for the ***feedback*** hypothesis of causality between energy consumption and growth. Nevertheless, if we concentrate on REC, then we notice that causality only runs from growth to REC implying that it is rather the ***conservation*** hypothesis of causality which qualifies in the case of REC. The fifth column of Table 5 shows that CO_2 emissions are conducive to energy consumption in all high income countries, with the exception of REC. Most importantly, considering the effects of both CO_2 emissions and growth on all types of energy consumption (i.e. column 6) we show that in lower, upper-middle and high income countries energy consumption is mainly caused by these effects.

Nevertheless, the picture becomes clearer when we look at the effects of growth and energy consumption on CO_2 emissions. In columns seven, eight and nine of Table 5, we notice that with the exception of low income countries, the process of growth and energy consumption has a statistically significant effect on CO_2 emissions. Apparently, in this group of countries, there can be no further growth without CO_2 emissions. In addition, looking closely at columns one and eight of Table 4, we notice that (REC) is not conducive to growth and it does not produce any CO_2 emissions. At the same time though, it is obvious that in all groups of countries it is only the polluting types of energy consumption which lead to growth.

In the section that follows, we present impulse response functions (IRFs) per group of country in order to get a more complete picture regarding the interrelation of different types of energy and growth.

4.2 Impulse response functions

In this section, we present the results of the panel generalised impulse responses functions discussed in Section 3.4. We begin with the discussion of the results based on the full sample of countries and then examine whether the results differ among subgroups of countries classified according to their level of income.

Figure 3 presents the panel generalised impulse responses functions for the full sample of countries. On general principles, we find positive and statistically significant results that are quite similar irrespective of the type of energy source, with the exception of REC. In particular, we notice that innovations in most types of energy consumption have a positive impact on growth. The same holds true for the effect of CO_2 emissions on growth. At the same time, both growth and CO_2 emissions have a positive effect on most types of energy consumption. Finally, results show that growth, as well as, most types of energy consumption positively affect CO_2 emissions. With regard to REC, we can only report that growth responds positively and statistically significantly only to CO_2 emissions, while the reverse is also true. We cannot report any statistically significant evidence that growth responds in any way to consumption of renewable energy. In addition, there is not any statistically significant indication that growth exerts positive impact on REC.

[Insert Figure 3 here]

With reference to the magnitude of the relevant statistically significant IRFs we find that a positive shock in COALC has a smaller impact on growth compared to other types of energy consumption. What is more, a positive change in economic growth exerts a smaller relative effect on both GASC and COALC. It is also worth noting that a positive change in OILC has a stronger relative impact on CO_2 emissions. At the same time, a positive shock in CO_2 emissions exercises a stronger relative impact on OILC.

These findings strengthen our initial view that growth is in fact closely linked to environmental pollution. However, in order to attain a better understanding, it would be instructive at this point to investigate IRFs by group of country. First we turn to low income countries. Results relating to IRFs in low income countries are presented in Figure 4.

[Insert Figure 4 here]

We notice that as in the case of the full sample of countries all statistically significant effects are positive. What is more, we find that REC, GASC, as well as, COALC, do not have any effects on either growth or CO_2 emissions. At the same time, these three sources of energy do not appear to influence CO_2 emissions as well. On a final note it is perhaps not surprising for this particular type of country considering the EKC hypothesis that growth has a statistically significant impact on CO_2 emissions. This is actually true irrespective of the type of energy consumption under consideration.

Turning to the magnitude of statistically significant IRFs we notice that compared to its effects on any other type of energy consumption, a positive shock in economic growth has a very strong positive impact on OILC. Furthermore, compared to other types of energy consumption, CO_2 emissions appear to have a very strong impact on OILC, while in the case of COALC a positive change in economic growth has a very strong relative impact on CO_2 emissions.

Next, we focus on lower-middle income countries. Results are shown in Figure 5.

[Insert Figure 5 here]

Prominent among our results is the fact that COALC aside, all other types of energy consumption appear to exert positive impact on growth. Nonetheless, it should be noted that effects from both REC and GASC on growth are barely statistically significant.

It is also worth mentioning that for this specific group of countries REC also responds positively to a positive shock in growth; however this response is relatively short-lived. Finally, evidence shows that there is no significant effect of growth on GASC.

The magnitude of the statistically significant IRFs for this particular group of countries - illustrated in Figure 5 - reveals that a positive change in ELEC has a stronger relative impact on economic growth, while, at the same time, economic growth appears to have a stronger relative impact on both ELEC and OILC. We also notice that, in contrast with all other types of energy consumption, positive changes in CO_2 emissions have a stronger impact on OILC, while the reverse is also true.

We then concentrate on upper-middle income countries. Results are displayed on Figure 6.

[Insert Figure 6 here]

Similarly to the previous group, growth does not seem to receive any significant effect from REC, GASC, as well as, COALC; although with the exception of REC, both GASC and COALC respond positively to positive changes in growth. Furthermore, for all types of energy consumption growth appears to be conducive to CO_2 emissions. Consistent with results reported for all other groups of countries, positive changes in REC do not trigger any responses from CO_2 emissions.

As far as the magnitude of the statistically significant IRFs for this group of countries is concerned, we observe that positive changes in economic growth have a stronger relative impact on both ELEC and OILC. It should also be noted that in the case of COALC, economic growth has a stronger relative impact on CO_2 emissions. What is more, as has already been noted for all of the previous groups of countries, positive changes in CO_2 emissions have a stronger relative impact on OILC, while the reverse is also true.

Finally, we consider high income countries. The results for this group of countries are presented in Figure 7.

[Insert Figure 7 here]

As far as the effects on growth are concerned, we cannot really report any significant differences to all other cases. In particular, we notice that equally to all other groups of countries, changes in REC and COALC do not have a statistically significant effect on growth. Apparently, for high income countries, GASC is significantly affecting growth. Finally, as in all previous cases considering all different groups of countries and all types of energy consumption, growth statistically significantly affects CO_2 emissions.

With regard to the magnitude of the statistically significant IRFs of this particular group of countries we notice that a positive shock in ELEC exerts a stronger effect on economic growth compared to shocks in other types of energy consumption. As has been previously reported, in the case of COALC, economic growth has a stronger relative impact on CO_2 emissions. What is more, the relationship between CO_2 emissions and OILC appears to be again bidirectional and greater in magnitude compared to the relationship between CO_2 emissions and other sources of energy consumption. On a final note, positive changes in economic growth have a relatively stronger impact on OILC.

Summarising these results we are able to draw very useful conclusions. To begin with, it is important to note that IRFs reflect positive statistically significant responses of all the variables of the system to respective innovations. Furthermore, responses appear to be quite similar among the groups. It should be noted though, that if we consider the magnitude of these responses, we notice that there are certain differences among the various groups of countries. In turn, we notice that growth is conducive to CO_2 emissions and this is true irrespective of the particular group of country under investigation. What is also true for all groups of countries is the fact that COALC is losing its importance as an energy source. This could be indicative of a recent trend in both developed and developing countries to produce oil and natural gas via the method of fracking as opposed to the emission-intensive source of coal (see, inter alia Howarth et al., 2011; Yang et al., 2012; Chen and Golley, 2014). A final issue that deserves mention is that focusing on the REC-growth nexus, IRFs indicate that REC does not instigate growth in any of the groups under investigation. Findings relating to REC are in line with Ocal and Aslan (2013) who report that there is negative impact of REC on economic growth. What is more, Ocal and Aslan (2013) provide evidence in support of the conservation hypothesis, while at the same time, they stress the fact that renewable energy is an expensive energy resource especially for developing countries. Re-iterating a point made in the previous section, these results pose a criticism of the ***inverted U-shaped EKC***. To be more explicit, according to our results, countries cannot simply grow out of environmental pollution, as, apparently, the process of growth even at advanced stages of economic development inevitably entails the degradation of the physical environment.

Furthermore, these findings question the efficacy of government policies initiated in various countries to the effect that REC can be promoted as a substitute for non-renewable sources of energy, sufficient to promote growth. Such policies might include, among others, tax credits for the production of renewable energy, certain reimbursements for installing renewable energy systems, as well as, the establishment of a market for renewable energy certificates (see Apergis and Payne, 2012, 2014). In the light of our findings, should greater use of renewable energy sources be promoted in countries who plan to sustain their current growth pace? Arguably, REC is important when the discussion revolves around the sustainability of the environment, the necessity for fewer greenhouse gas emissions or even the dependency of some nations on imports of energy; however, is there a case for any group of countries to adopt REC-intensive technologies when the goal is unrelenting growth? Dincer (2000) investigating the relationship between renewable energy and sustainable development puts forward the argument that – although sustainable development should be predicated upon the unremitting supply of energy deriving from renewable resources – additional research and development is required to the effect that the actual economic and environmental benefits of renewable energy resources can be more accurately assessed.

In many respects, our findings manage to steer the discussion towards the very topical issue of whether societies should impose limits to growth or not. According to authors such as Galli et al. (2012), Hoekstra and Wiedmann (2014), as well as, Weinzettel et al. (2014) the current ***environmental footprint*** poses a material challenge to the capacity of the natural environment to assimilate waste. Decomposing environmental footprint into its main elements, these authors argue that overproduction in developed societies results not only to higher greenhouse gas emissions (i.e. carbon footprint) and depletion of fresh water resources (i.e. water footprint), but also, to an over-exploitation of biologically productive land in general (i.e. ecological footprint). In this regard, it is of cardinal importance for current generations to carefully decide upon the desired path of sustainable growth. This discussion is also closely related to the rebound effect argument, according to which even more efficient and more energy-saving technologies do not necessarily lead to reduced energy consumption and thus do not necessarily alleviate environmental concerns (see, inter alia, Bentzen, 2004; Jin, 2007; Sorrell and Dimitropoulos, 2008; Wang et al., 2014a,b). By all accounts, achieving sustainable growth appears to be a rather cumbersome task.

Thought provokingly, the answer may not even be that of sustainable growth. To be more explicit, findings give outright prominence to alternative paradigms, such as those of ***degrowth*** and ***a-growth***. With regard to degrowth, (Kallis, 2011, p. 874) explains that this is 'a socially sustainable and equitable reduction of society's throughput'. Throughput, defined by Daly (1996) as the material and energy required by contemporary societies for the production, distribution, as well as, consumption of goods and assimilation of waste, has to be reduced in order for environmental degradation to be kept within specific limits and to start decelerating (Kallis, 2011). It follows that degrowth, contrary to sustainable growth, cannot occur within a framework of rising GDP. The paradigm of a-growth, on the other hand, can be described as even more radical one, as it implies that societies should concentrate solely on rigorous environmental policies disregarding the effects this might have on the future levels of GDP (van den Bergh, 2011).

Although a thorough analysis of both degrowth and a-growth falls beyond the scope of this study, it should be noted that these concepts are particularly complex, as they involve a generalised deviation from the standard practices of the capitalist economy which qualify GDP as a suitable measure of social welfare (van den Bergh, 2011; van den Bergh and Kallis, 2012; Bauhardt, 2014; Buch-Hansen, 2014; Videira et al., 2014). Nonetheless, both paradigms should be emphasized as alternative routes to current production patterns, particularly in the absence of the inverted U-shaped EKC.

In retrospect, we provide evidence that causality between growth and energy consumption runs both ways; that is, we provide evidence that the ***feedback*** hypothesis of causality is in play. If however, we focus specifically on causality between REC and growth we find that it is rather the ***conservation*** hypothesis which best describes the state of this particular affair. In this respect, our findings contradict Apergis and Payne (2012) who opine that both non-renewable and renewable sources of energy are conducive to economic growth and that there is in fact a high degree of substitutability between the two types. With reference to specific types of energy we notice that OILC and GASC are significant factors of growth especially for middle and high income countries. At the same time, COALC does not appear to be a significant driver of growth in these countries. Prominent among our results though, is the fact that economic growth is closely linked to the greenhouse effect (see column seven of Table 4), strongly suggesting that we could not argue in favour of the inverted U-shaped EKC hypothesis. In this regard, countries are faced with a ***moral dilemma*** on whether or not they should promote REC given that on one hand, it promotes environmental sustainability, but on the other, it does not promote growth.

5 Summary and concluding remarks

In this study, we investigate the complex and intricate linkages between economic growth, energy consumption and CO_2 emissions, for 106 countries which are classified into distinct groups in virtue of their income. In addition, energy consumption is decomposed into various types, including renewable energy consumption (REC), electricity consumption (ELEC), oil consumption (OILC), natural gas consumption (GASC) and coal consumption (COALC). We implement a PVAR approach along with panel impulse response functions in order to identify the direction of causality that characterises and explains developments in the aforementioned variables, as well as to examine the short-run and long-run effects of shocks originating in the aforementioned variables. In this regard, the main contribution of the study is the investigation of this particular nexus for different groups of countries and different types of energy consumption.

The underlying objectives of the study relate to the investigation (i) of whether our findings provide support for any of the existing hypotheses pertaining to the growth-energy consumption nexus; namely, the growth, the conservation, the feedback, as well as, the neutrality hypothesis, (ii) of whether there are any types of energy consumption which are not conducive to growth whatsoever, (iii) of the argument that REC can indeed constitute a reliable (in terms of its impact on the process of growth) substitute for non-renewable sources of energy, (iv) of the existence or not of the inverted U-shaped EKC.

Our findings suggest that the effects of the various types of energy consumption are heterogeneous on the various groups of countries. We also find that coal consumption is apparently losing its importance as an energy source. What is more, causality between economic growth and energy consumption is bidirectional, thus making a case for the feedback hypothesis. However, we cannot report any statistically significant evidence that renewable energy consumption in particular is conducive to economic growth, a fact that weakens the argument that renewable energy consumption is able to promote growth in a more efficient and environmentally sustainable way. Finally, in analysing the case for an inverted U-shaped EKC, we find that the continued process of growth aggravates the greenhouse gas emissions phenomenon. In this regard, we cannot provide any evidence that developed countries may actually grow-out of environmental pollution.

In the light of these findings, the efficacy of recent government policies in various countries to promote renewable energy consumption as a means for sustainable growth is questioned. At the same time, it is put forward the argument that perhaps decisions should be made not on the basis of how developed societies may sustain current levels of growth by employing renewable energy consumption strategies (as this might in fact be an infeasible approach in the long run), but rather, to concentrate on more communally just ways and ideas of social conduct such as the ones endorsed by the process of degrowth or a-growth. Put differently, there seems to be a moral dilemma, between high economic growth rates and unsustainable environment and low or zero economic growth and environmental sustainability. Interesting avenues for future research might include the investigation of other pollutants in order to get a more complete picture of the effects of energy consumption and growth on the environment.

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Table 1: Summary of recent studies

Authors	**Countries**	**Period**	**Data**	**Methodology**	**Main findings**
Apergis et al. (2010)	Developed and developing countries (19)	1984-2007	Real GDP, nuclear and renewable energy consumption and CO_2 emissions	Panel cointegration and error correction model	NUC $\Rightarrow$ CO_2, REC $\nRightarrow$ CO_2, REC $\Leftrightarrow$ G, NUC $\Leftrightarrow$ G.
Chang (2010)	China	1981-2006	Oil, coal, natural gas, electricity consumption, CO_2 emissions and real GDP	Vector error correction model	G $\Rightarrow$ CO_2, OILC and COALC, ELEC $\Rightarrow$ G and CO_2.
Ozturk and Acaravci (2010)	Turkey	1968-2005	GDP per capita, CO_2 emissions per capita total energy consumption per capita and employment ratio	ARDL coitegration and Granger causality test	No evidence of EKC. CO_2 and EC $\nRightarrow$ G
Pao and Tsai (2010)	BRICS	1971-2005	GDP per capita, CO_2 per capita and total energy consumption per capita	Panel cointegration and VECM	Short-run: EC $\Leftrightarrow$ CO_2, EC and CO_2 $\Rightarrow$ G Long-run: EC $\Leftrightarrow$ G, CO_2 $\Rightarrow$ EC and G.
Alam et al. (2012)	Bangladesh	1972-2006	GDP per capita, energy consumptions per per capita, electricity consumption per capital and CO_2 emissions per capita	ARDL and VECM	Short-run: EC $\Rightarrow$ G, ELEC $\nLeftrightarrow$ G, EC $\Rightarrow$ CO_2, CO_2 $\Rightarrow$ G Long-run: EC $\Rightarrow$ G, ELEC $\Leftrightarrow$ G, EC $\Leftrightarrow$ CO_2, CO_2 $\Rightarrow$ G.
Jayanthakumaran et al. (2012)	China, India	1971-2007	GDP per capita, CO_2 emissions per capita and total energy consumption per capita	ARDL bounds test approach	Evidence in favour of EKC, G and EC $\Rightarrow$ CO_2
Govindaraju and Tang (2013)	China, India	1965-2009	GDP per capita, CO_2 emissions per capita and coal consumption per capita	Cointegration test VECM	China: G $\Leftrightarrow$ COALC, COALC $\Leftrightarrow$ CO_2, G $\Rightarrow$ CO_2 India: G $\Leftrightarrow$ CO_2, COALC $\Leftrightarrow$ CO_2, G $\Rightarrow$ COALC
Ozcan (2013)	Middle East countries (12)	1990-2008	Real GDP per capita, CO_2 emissions per capita and total energy consumption per capita	Panel cointegration FMOLS and Panel VECM	Evidence in favour of EKC (5 out 0f 12 countries) G $\Rightarrow$ EC, EC $\Rightarrow$ CO_2.
Saboori and Sulaiman (2013)	ASEAN (5)	1971-2009	Real GDP per capita, CO_2 emissions and total energy consumption	ARDL bounds test approach to cointegration and VECM	Mixed results depending on the country
Shahbaz et al. (2013)	Indonesia	1975-2011*	Real GDP per capita, CO_2 emissions per capita, total energy consumption per capita, financial development and trade openess per capita	ARDL bounds test approach to cointegration and VECM	G $\Rightarrow$ CO_2, EC $\Leftrightarrow$ CO_2
Cowan et al. (2014)	BRICS	1990-2010	Electricity consumption, cardon dioxide emissions and real GDP	Panel Granger causality	Mixed results depending on the country.
Farhani et al. (2014)	Tunisia	1971-2008	Real GDP per capita, CO_2 emissions per capita, total energy consumption per capita and trade openness	ARDL bounds test approach to cointegration and VECM	G and EC $\Rightarrow$ CO_2, CO_2 and G $\Rightarrow$ EC.
Salahuddin and Gow (2014)	GCC	1980-2012	CO_2 emissions, total energy consumptions and real GDP per capita	Panel Granger causality	EC $\Leftrightarrow$ CO_2, G $\Rightarrow$ EC, G $\nLeftrightarrow$ CO_2,

Note: The numbers in the parenthesis under the Countries' column denote the number of countries considered in these studies. All studies are based on annual data. EC = Total energy consumption, $ELEC$ = electricity consumption, REC = renewable energy consumption, $OILC$ = oil consumption, $COALC$ = coal consumption, $GASC$ = natural gas consumption, NUC = nuclear energy consumption, $HYDC$ = hydrocarbons consumptions, CO_2 = CO_2 emissions, G = economic growth, EKC = Environmental Kuznets Curve. *This study used quarterly data. FMOLS = Fully Modified OLS, DOLS = Dynamic OLS, DFE = Dynamic Fixed Effects. $\Rightarrow$ ($\nRightarrow$) denotes unidirectional (non-) causality. $\Leftrightarrow$ ($\nLeftrightarrow$) denotes bidirectional (non-) causality.

Table 1: Summary of recent studies...continued

Authors	**Countries**	**Period**	**Data**	**Methodology**	**Main findings**
Sebri and Ben-Salha (2014)	BRICS	1971-2010	Real GDP, renewable energy consumption, CO_2 emissions and trade openess	ARDL bounds test approach to cointegration and VECM	REC $\Leftrightarrow$ G, CO_2 $\Rightarrow$ REC, CO_2 $\Rightarrow$ G
Yang and Zhao (2014)	India	1970-2008	Real GDP, real gross fixed capital formation, total energy consumption, CO_2 emissions and trade openness	Granger causality test and directed acyclic graphs	EC $\Rightarrow$ CO_2 and G, G $\Leftrightarrow$ CO_2
Alshehry and Belloumi (2015)	Saudi Arabia	1971-2010	GDP per capita, total energy consumption per capita, CO_2 emissions per capita and energy prices	Cointegration and VAR	Long-run: EC $\Rightarrow$ G, EC $\Rightarrow$ CO_2, CO_2 $\Leftrightarrow$ G Short-run: CO_2 $\Rightarrow$ EC and G.
Begum et al. (2015)	Malaysia	1970-2009	GDP per capita, total energy consumption CO_2 emissions and population growth	ARDL approach to cointegration, DOLS and SLM U tests	No evidence of EKC. EC and G $\Rightarrow$ CO_2
Heidari et al. (2015)	ASEAN (5)	1980-2008	Total energy consumption, cardon dioxide emissions and real GDP	Panel Smooth Transition Regression (PSTR) model	Evidence in favour of the EKC, EC $\Rightarrow$ CO_2
Jammazi and Aloui (2015)	GCC	1980-2013	GDP per capita, CO_2 emissions per capita and total energy consumption per capita	Wavelet window cross correlation	EC $\Leftrightarrow$ G, EC $\Rightarrow$ CO_2
Long et al. (2015)	China	1952-2012	Real GDP, CO_2 emissions and coal, oil, natural gas, electricity, hydrocarbons and nuclear consumption	Granger causality test, static and dynamic regression models	COALC $\Rightarrow$ CO_2 and G, OILC $\Rightarrow$ CO_2 G $\Leftrightarrow$ CO_2, COALC, GASC and ELEC, HYDC and NUC $\Rightarrow$ G
Salahuddin et al. (2015)	GCC	1980-2012	Real GDP per capita, CO_2 emissions per capita, electricity consumption per capita and financial development	DOLS, FMOLS, DFE	ELEC and G $\Rightarrow$ CO_2

Note: The numbers in the parenthesis under the Countries' column denote the number of countries considered in these studies. All studies are based on annual data. EC = Total energy consumption, $ELEC$ = electricity consumption, REC = renewable energy consumption, $OILC$ = oil consumption, $COALC$ = coal consumption, $GASC$ = natural gas consumption, NUC = nuclear energy consumption, $HYDC$ = hydrocarbons consumptions, CO_2 = CO_2 emissions, G = economic growth, EKC = Environmental Kuznets Curve. *This study used quarterly data. FMOLS = Fully Modified OLS, DOLS = Dynamic OLS, DFE = Dynamic Fixed Effects. $\Rightarrow$ ($\nRightarrow$) denotes unidirectional (non-) causality. $\Leftrightarrow$ ($\nLeftrightarrow$) denotes bidirectional (non-) causality.

Table 2: Country list by income group

	Low Income		**Lower Middle Income**		**Upper Middle Income**		**High Income**
1	Bangladesh	1	Bolivia	1	Albania	1	Australia
2	Benin	2	Cameroon	2	Algeria	2	Austria
3	Congo, Dem. Rep.	3	Congo, Rep.	3	Angola	3	Bahrain
4	Ethiopia	4	Cote d'Ivoire	4	Argentina	4	Belgium
5	Haiti	5	Egypt, Arab Rep.	5	Brazil	5	Brunei Darussalam
6	Kenya	6	El Salvador	6	Bulgaria	6	Canada
7	Mozambique	7	Ghana	7	China	7	Chile
8	Myanmar	8	Guatemala	8	Colombia	8	Cyprus
9	Nepal	9	Honduras	9	Costa Rica	9	Denmark
10	Tanzania	10	India	10	Cuba	10	Finland
11	Togo	11	Indonesia	11	Dominican Rep.	11	France
12	Zimbabwe	12	Morocco	12	Ecuador	12	Germany
		13	Nicaragua	13	Gabon	13	Greece
		14	Nigeria	14	Hungary	14	Hong Kong SAR, China
		15	Pakistan	15	Iran, Islamic Rep.	15	Iceland
		16	Paraguay	16	Iraq	16	Ireland
		17	Philippines	17	Jamaica	17	Israel
		18	Senegal	18	Jordan	18	Italy
		19	Sri Lanka	19	Lebanon	19	Japan
		20	Sudan	20	Libya	20	Korea, Rep.
		21	Syrian Arab Rep.	21	Malaysia	21	Kuwait
		22	Vietnam	22	Mexico	22	Luxembourg
		23	Yemen, Rep.	23	Panama	23	Malta
		24	Zambia	24	Peru	24	Netherlands
				25	Romania	25	New Zealand
				26	South Africa	26	Norway
				27	Thailand	27	Oman
				28	Tunisia	28	Poland
				29	Turkey	29	Portugal
				30	Venezuela, RB	30	Qatar
						31	Saudi Arabia
						32	Singapore
						33	Spain
						34	Sweden
						35	Switzerland
						36	Trinidad and Tobago
						37	United Arab Emirates
						38	United Kingdom
						39	United States
						40	Uruguay

Income groups based on World's Bank classification (see, `http://data.worldbank.org/about/country-classifications/country-and-lending-groups`).

Table 3: Descriptive Statistics

	All (106) countries			
	Mean	Std. Dev.	Min	Max
ECpc	1531.481	1799.134	51.9216	11921.3
ELECpc	243.9057	364.0757	.495488	4315.99
OILCpc	702.3392	804.3783	3.72564	5836.37
RECpc	193.3783	234.4822	0.064045	2383.83
GASCpc	311.2041	886.9787	0	10429.4
COALCpc	75.45598	200.8438	0	3085.71
rGDPpc	10973	15081.02	69.2472	143857
CO$_2$pc	5.846479	8.555352	0.016772	87.7236
ΔlECpc	0.0121768	0.0746827	-1.36878	1.173048
ΔlELECpc	0.037479	0.1005172	-1.083343	1.367861
ΔlOILCpc	0.0122061	0.115757	-1.691606	1.510489
ΔlRECpc	.0055689	0.1620123	-1.478541	4.496975
ΔlGASCpc	0.0656589	0.3583766	-5.45392	5.221148
ΔlCOALCpc	-0.0045751	0.4451491	-3.737421	5.108232
ΔlrGDPpc	0.0157345	0.0633426	-0.9515371	0.7404585
ΔlCO$_2$pc	0.0096107	0.1537402	-2.989925	3.438777
	Low income countries			
	Mean	Std. Dev.	Min	Max
ECpc	328.2962	151.9233	79.2725	942.363
ELECpc	11.50485	19.15558	.495488	87.6468
OILCpc	35.59047	26.61454	3.72564	157.589
RECpc	267.1315	107.6806	56.8751	566.646
GASCpc	2.195314	6.772629	0	45.7832
COALCpc	11.87407	34.32951	0	203.786
rGDPpc	357.5438	172.5754	69.2472	782.074
CO$_2$pc	0.2441556	0.3236986	0.016772	1.70522
ΔlECpc	0.0002795	0.0398477	-0.251123	0.2688012
ΔlELECpc	0.0328722	0.1454683	-0.8628395	0.8201807
ΔlOILCpc	0.0102994	0.180874	-1.295665	1.510489
ΔlRECpc	-0.0033291	0.0362055	-0.3048782	.3538866
ΔlGASCpc	0.1438622	0.4879167	-0.4934822	4.208153
ΔlCOALCpc	0.0019321	0.5594509	-2.227083	2.417915
ΔlrGDPpc	0.0061218	0.0512807	-0.1978607	0.1382208
ΔlCO$_2$pc	0.0086734	0.1670622	-0.8109386	1.3321
	Lower middle income countries			
	Mean	Std. Dev.	Min	Max
ECpc	378.2989	148.7149	51.9216	822.09
ELECpc	27.36173	23.65112	1.24373	145.115
OILCpc	132.9541	92.48996	14.6047	565.745
RECpc	199.0532	138.8228	.064045	588.323
GASCpc	10.85986	26.88979	0	193.742
COALCpc	7.696426	16.2862	0	118.353
rGDPpc	1025.895	537.0024	189.758	3036.45
CO$_2$pc	0.7491466	0.57636	0.089386	3.48014
ΔlECpc	0.0084833	0.0499445	-0.2699594	0.3806319
ΔlELECpc	0.0386487	0.1040806	-0.8233216	0.9387753
ΔlOILCpc	0.0141289	0.1042584	-1.150261	0.4609997
ΔlRECpc	-0.0024745	0.1150826	-1.478541	1.279958
ΔlGASCpc	0.0782631	0.3219074	-1.048862	2.647494
ΔlCOALCpc	0.0061369	0.5726546	-2.650032	4.855736
ΔlrGDPpc	0.0150088	0.0464666	-.3372002	0.2650084
ΔlCO$_2$pc	0.0153506	0.1635674	-1.510073	1.209623
	Upper middle income countries			
	Mean	Std. Dev.	Min	Max
ECpc	882.1746	472.6334	140.804	2602.7
ELECpc	111.1888	84.87876	4.21575	389.894
OILCpc	441.8446	232.3345	34.1811	1666.86
RECpc	129.9609	151.7529	.317744	822.733
GASCpc	118.0237	203.9759	0	1239.54
COALCpc	60.42268	121.7945	0	743.792
rGDPpc	3929.305	2459.435	150.522	20663.5
CO$_2$pc	3.537373	2.470163	0.053105	11.3465
ΔlECpc	0.0132976	0.0742199	-0.5711589	0.4810648
ΔlELECpc	0.0414688	0.1125998	-1.083343	1.367861
ΔlOILCpc	0.0136462	0.1075797	-0.628767	0.70468
ΔlRECpc	-0.0021987	0.1571085	-1.18752	3.297458
ΔlGASCpc	0.0531262	0.3930091	-5.45392	4.121325
ΔlCOALCpc	0.0205458	0.4556663	-3.298157	5.108232
ΔlrGDPpc	0.0156424	0.0864707	-0.9515371	0.602406
ΔlCO$_2$pc	0.013931	0.181343	-2.989925	3.438777
	High income countries			
	Mean	Std. Dev.	Min	Max
ECpc	3071.325	2114.572	103.725	11921.3
ELECpc	543.09	445.418	1.14824	4315.99
OILCpc	1439.366	864.2325	101.399	5836.37
RECpc	228.6295	373.9753	0.132152	2383.83
GASCpc	728.9986	1329.849	0	10429.4
COALCpc	146.4613	293.4573	0	3085.71
rGDPpc	25408.66	16100.98	2541.75	143857
CO$_2$pc	12.31741	10.8771	1.04891	87.7236
ΔlECpc	0.0171216	0.092778	-1.36878	1.173048
ΔlELECpc	0.0351667	0.0664658	-0.3538976	0.7059971
ΔlOILCpc	0.0105444	0.1025556	-1.691606	1.183875
ΔlRECpc	0.0268828	0.2280739	-1.281683	4.496975
ΔlGASCpc	0.0645502	0.3294918	-2.315926	5.221148
ΔlCOALCpc	-0.0283794	0.3304565	-3.737421	4.683958
ΔlrGDPpc	0.0191229	0.0539233	-0.4990711	0.7404585
ΔlCO$_2$pc	0.0032077	0.116273	-1.574471	1.087051

Table 4: Panel unit root test results

		H$_0$: All panels contain unit root			
		LLC		IPS	
	Variables	Constant	Constant + Trend	Constant	Constant + Trend
All (106) countries	ECpc	1.0990 [0.8641]	1.5913 [0.9442]	5.1489 [1.0000]	4.7420 [1.0000]
	ELECpc	11.0719 [1.0000]	8.0452 [1.0000]	16.8953 [1.0000]	11.6798 [1.0000]
	OILCpc	2.5259 [0.9942]	1.2861 [0.9008]	3.6243 [0.9999]	2.2606 [0.9881]
	RECpc	-3.7505*** [0.0000]	-0.2951 [0.3839]	4.6403 [1.0000]	1.7755 [0.9621]
	GASCpc	-1.9402** [0.0262]	1.3263 [0.9076]	-11.7075*** [0.0000]	-3.1213*** [0.0009]
	COALCpc	-5.4711*** [0.0000]	-0.5383 [0.2952]	-1.0316 [0.1511]	-1.6746** [0.0470]
	rGDPpc	10.6511 [1.0000]	5.2173 [1.0000]	15.0265 [1.0000]	7.2373 [1.0000]
	CO$_2$pc	0.9244 [0.8224]	-0.2519 [0.4005]	1.9026 [0.9715]	-0.0716 [0.4714]
	ΔlECpc	-44.6320*** [0.0000]	-42.1713*** [0.0000]	-45.0808*** [0.0000]	-46.2669*** [0.0000]
	ΔlELECpc	-42.2563*** [0.0000]	-43.5944*** [0.0000]	-43.2891*** [0.0000]	-47.8868*** [0.0000]
	ΔlOILCpc	-46.3093*** [0.0000]	-40.2124*** [0.0000]	-47.4619*** [0.0000]	-44.9605*** [0.0000]
	ΔlRECpc	-31.1043*** [0.0000]	-28.8895*** [0.0000]	-40.8410*** [0.0000]	-39.8379*** [0.0000]
	ΔlGASCpc	-41.3776*** [0.0000]	-43.4310*** [0.0000]	-34.1739*** [0.0000]	-35.0007*** [0.0000]
	ΔlCOALCpc	-41.2611*** [0.0000]	-43.9608*** [0.0000]	-44.0739*** [0.0000]	-43.8927*** [0.0000]
	ΔlrGDPpc	-31.2442*** [0.0000]	-30.2429*** [0.0000]	-34.7408*** [0.0000]	-34.9379*** [0.0000]
	ΔlCO$_2$pc	-58.8880*** [0.0000]	-52.0750*** [0.0000]	-57.6959*** [0.0000]	-56.7720*** [0.0000]
Low income countries	ECpc	-5.3033 [0.0000]	-1.4024* [0.0804]	0.3308 [0.6296]	2.0629 [0.9804]
	ELECpc	11.7161 [1.0000]	3.8527 [0.9999]	-9.9362 [1.0000]	5.0405 [1.0000]
	OILCpc	1.5202 [0.9358]	0.0384 [0.5153]	1.7871 [0.9630]	-0.0581 [0.4768]
	RECpc	-1.7426** [0.0407]	-1.0922 [0.1374]	1.6619 [0.9517]	1.9968 [0.9771]
	GASCpc	-1.9402** [0.0262]	1.3263 [0.9076]	-11.7075*** [0.0000]	-3.1213*** [0.0009]
	COALCpc	-5.4711*** [0.0000]	-0.5383 [0.2952]	-1.0316 [0.1511]	-1.6746** [0.0470]
	rGDPpc	7.5682 [1.0000]	2.1003 [0.9821]	7.3423 [1.0000]	4.9773 [1.0000]
	CO$_2$pc	1.4106 [0.9208]	-0.2556 [0.3991]	0.7764 [0.7812]	-0.1595 [0.4366]
	ΔlECpc	-14.7776*** [0.0000]	-15.3453*** [0.0000]	-15.1297*** [0.0000]	-15.8718*** [0.0000]
	ΔlELECpc	-20.3469*** [0.0000]	-18.4658*** [0.0000]	-19.7398*** [0.0000]	-19.0703*** [0.0000]
	ΔlOILCpc	-21.7666*** [0.0000]	-18.9207*** [0.0000]	-20.6081*** [0.0000]	-19.9510*** [0.0000]
	ΔlRECpc	-9.0331*** [0.0000]	-9.1908*** [0.0000]	-12.8841*** [0.0000]	-12.3275*** [0.0000]
	ΔlGASCpc	-21.3776*** [0.0000]	-23.4310*** [0.0000]	-34.1739*** [0.0000]	-35.0007*** [0.0000]
	ΔlCOALCpc	-21.2611*** [0.0000]	-23.9608*** [0.0000]	-44.0739*** [0.0000]	-43.8927*** [0.0000]
	ΔlrGDPpc	-23.2517*** [0.0000]	-28.6219*** [0.0000]	-39.5565*** [0.0000]	-13.7539*** [0.0000]
	ΔlCO$_2$pc	-17.5205*** [0.0000]	-15.5644*** [0.0000]	-20.2617*** [0.0000]	-20.3238*** [0.0000]
Lower middle income countries	ECpc	5.4295 [1.0000]	2.6839 [0.9964]	5.8400 [1.0000]	3.9452 [1.0000]
	ELECpc	13.6313 [1.0000]	6.2467 [1.0000]	13.3694 [1.0000]	7.1297 [1.0000]
	OILCpc	2.8216 [0.9976]	1.9768 [0.9760]	3.7750 [0.9999]	3.4602 [0.9997]
	RECpc	-2.6512*** [0.0040]	2.2028 [0.9862]	1.4198 [0.9222]	1.6206 [0.9474]
	GASCpc	-1.9402** [0.0262]	1.3263 [0.9076]	-11.7075*** [0.0000]	-3.1213*** [0.0009]
	COALCpc	-5.4711*** [0.0000]	-0.5383 [0.2952]	-1.0316 [0.1511]	-1.6746** [0.0470]
	rGDPpc	12.6025 [1.0000]	5.3869 [1.0000]	10.1295 [1.0000]	7.9695 [1.0000]
	CO$_2$pc	1.2237 [0.8895]	-1.2539 [0.1049]	1.5390 [0.9381]	-1.2190 [0.1114]
	ΔlECpc	-23.1259*** [0.0000]	-22.3683*** [0.0000]	-22.3714*** [0.0000]	-23.4154*** [0.0000]
	ΔlELECpc	-23.2788*** [0.0000]	-21.1841*** [0.0000]	-23.7809*** [0.0000]	-22.7847*** [0.0000]
	ΔlOILCpc	-24.6545*** [0.0000]	-21.7089*** [0.0000]	-25.5948*** [0.0000]	-23.8857*** [0.0000]
	ΔlRECpc	-10.9597*** [0.0000]	-9.9667*** [0.0000]	-15.3446*** [0.0000]	-14.8495*** [0.0000]
	ΔlGASCpc	-10.3776*** [0.0000]	-3.4310*** [0.0003]	-34.1739*** [0.0000]	-35.0007*** [0.0000]
	ΔlCOALCpc	-10.2611*** [0.0000]	-3.9608*** [0.0000]	-44.0739*** [0.0000]	-43.8927*** [0.0000]
	ΔlrGDPpc	-15.1602*** [0.0000]	-14.0478*** [0.0000]	-17.6763*** [0.0000]	-18.4499*** [0.0000]
	ΔlCO$_2$pc	-33.0406*** [0.0000]	-28.9317*** [0.0000]	-31.8605*** [0.0000]	-31.1170*** [0.0000]
Upper middle income countries	ECpc	2.1590 [0.9846]	1.3489 [0.9113]	3.3383 [0.9996]	2.8841 [0.9980]
	ELECpc	7.9314 [1.0000]	1.8266 [0.9661]	10.0746 [1.0000]	3.2878 [0.9995]
	OILCpc	2.2923 [0.9891]	0.7275 [0.7666]	1.1615 [0.8773]	1.0237 [0.8470]
	RENCpc	-3.3366*** [0.0004]	-0.8591 [0.1951]	2.7098 [0.9966]	0.9272 [0.8231]
	COALCpc	-5.4711*** [0.0000]	-0.5383 [0.2952]	-1.0316 [0.1511]	-1.6746** [0.0470]
	GASCpc	-1.9402** [0.0262]	1.3263 [0.9076]	-11.7075*** [0.0000]	-3.1213*** [0.0009]
	rGDPpc	7.0956 [1.0000]	3.6112 [0.9998]	7.4745 [1.0000]	4.6322 [1.0000]
	CO$_2$pc	2.0946 [0.9819]	0.1453 [0.5578]	1.9552 [0.9747]	-0.0500 [0.4800]
	ΔlECpc	-21.5025*** [0.0000]	-19.7518*** [0.0000]	-22.1471*** [0.0000]	-22.4619*** [0.0000]
	ΔlELECpc	-21.5772*** [0.0000]	-21.6755*** [0.0000]	-21.8008*** [0.0000]	-23.5335*** [0.0000]
	ΔlOILCpc	-22.4546*** [0.0000]	-19.5108*** [0.0000]	-22.9217*** [0.0000]	-22.3254*** [0.0000]
	ΔlRECpc	-16.4339*** [0.0000]	-15.8879*** [0.0000]	-24.2890*** [0.0000]	-24.5463*** [0.0000]
	ΔlGASCpc	-19.3776*** [0.0000]	-3.4310*** [0.0003]	-34.1739*** [0.0000]	-35.0007*** [0.0000]
	ΔlCOALCpc	-19.2611*** [0.0000]	-3.9608*** [0.0000]	-44.0739*** [0.0000]	-43.8927*** [0.0000]
	ΔlrGDPpc	-19.3611*** [0.0000]	-17.1865*** [0.0000]	-19.1238*** [0.0000]	-17.0913*** [0.0000]
	ΔlCO$_2$pc	-26.8398*** [0.0000]	-22.8984*** [0.0000]	-26.0180*** [0.0000]	-24.0138*** [0.0000]
High income countries	ECpc	-0.6751 [0.2498]	0.9522 [0.8295]	0.7994 [0.7880]	1.0416 [0.8512]
	ELECpc	-3.3316*** [0.0004]	4.2096 [1.0000]	2.9869 [0.9986]	7.8852 [1.0000]
	OILCpc	-1.2905* [0.0984]	-0.1044 [0.4584]	1.0078 [0.8432]	0.1552 [0.5617]
	RECpc	2.9939 [0.9986]	-0.1396 [0.4445]	3.3523 [0.9996]	-0.6055 [0.2724]
	GASCpc	-1.9402** [0.0262]	1.3263 [0.9076]	-11.7075 [0.0000]	-3.1213 [0.0009]
	COALCpc	-5.4711*** [0.0000]	-0.5383 [0.2952]	-1.0316 [0.1511]	-1.6746 [0.0470]
	rGDPpc	-0.3924 [0.3474]	-1.3039* [0.0961]	6.1054 [1.0000]	-1.1451 [0.1261]
	CO$_2$pc	-2.4798*** [0.0066]	0.7775 [0.7816]	-0.2209 [0.4126]	0.9624 [0.8321]
	ΔlECpc	-28.1955*** [0.0000]	-26.0464*** [0.0000]	-28.5833*** [0.0000]	-29.0239*** [0.0000]
	ΔlELECpc	-22.0689*** [0.0000]	-26.1523*** [0.0000]	-22.3512*** [0.0000]	-29.4676*** [0.0000]
	ΔlOILCpc	-25.2981*** [0.0000]	-21.6243*** [0.0000]	-26.3052*** [0.0000]	-24.4406*** [0.0000]
	ΔlRECpc	-28.3305*** [0.0000]	-24.0546*** [0.0000]	-27.4093*** [0.0000]	-26.0665*** [0.0000]
	ΔlGASCpc	-21.3776*** [0.0000]	-23.4310*** [0.0000]	-34.1739*** [0.0000]	-35.0007*** [0.0000]
	ΔlCOALCpc	-21.2611*** [0.0000]	-23.9608*** [0.0000]	-44.0739*** [0.0000]	-43.8927*** [0.0000]
	ΔlrGDPpc	-21.1201*** [0.0000]	-18.9197*** [0.0000]	-21.0707*** [0.0000]	-20.2542*** [0.0000]
	ΔlCO$_2$pc	-37.5118*** [0.0000]	-33.9094*** [0.0000]	-35.6259*** [0.0000]	-36.4132*** [0.0000]

The numbers in brackets denote *p*-values. The LLC test is performed using the Newey–West bandwidth selection with Barlett Kernel, and the Schwartz Bayesian Criterion is used to determine to optimal lag length.

Table 5: Panel causality tests, total energy consumption, CO_2 emissions and economic growth

	Null hypothesis								
Panel A: Total Energy consumption	EC $\nRightarrow$ G	$CO_2 \nRightarrow$ G	EC+$CO_2 \nRightarrow$ G	G $\nRightarrow$ EC	$CO_2 \nRightarrow$ EC	G+$CO_2 \nRightarrow$ EC	G $\nRightarrow CO_2$	EC $\nRightarrow CO_2$	G+EC $\nRightarrow CO_2$
All countries	85.147***	3.341	86.058***	5.809*	3.556	10.366**	8.430**	90.123***	134.622***
Low income countries	1.170	0.136	1.289	3.558	2.880	5.126	5.931*	1.394	6.803
Lower middle income countries	3.047	1.211	4.623	1.781	1.272	2.870	4.433	9.530***	18.291***
Upper middle income countries	10.802***	3.798	12.953**	11.964***	1.790	15.204***	5.267*	42.518***	49.660***
High income countries	137.682***	67.276***	219.009***	31.774***	19.527***	66.279***	12.521***	105.360***	152.945***

	Null hypothesis								
Panel B: Electricity consumption	ELEC $\nRightarrow$ G	$CO_2 \nRightarrow$ G	ELEC+$CO_2 \nRightarrow$ G	G $\nRightarrow$ ELEC	$CO_2 \nRightarrow$ ELEC	G+$CO_2 \nRightarrow$ ELEC	G $\nRightarrow CO_2$	ELEC $\nRightarrow CO_2$	G+ELEC $\nRightarrow CO_2$
All countries	7.334**	1.354	8.215*	22.861***	0.6904	25.297***	22.478***	40.166***	83.727***
Low income countries	6.552**	0.080	6.675	1.817	1.685	2.700	5.231*	0.708	6.101
Lower middle income countries	9.554***	1.204	11.149**	13.231***	5.185*	18.868***	2.900	12.167***	20.971***
Upper middle income countries	1.251	2.075	3.371	10.426***	4.036	17.347***	5.624**	17.140***	24.020***
High income countries	1.760	69.472***	71.872***	11.288***	36.470***	49.629***	19.440***	19.488***	62.787***

	Null hypothesis								
Panel C: Oil consumption	OILC $\nRightarrow$ G	$CO_2 \nRightarrow$ G	OILC+$CO_2 \nRightarrow$ G	G $\nRightarrow$ OILC	$CO_2 \nRightarrow$ OILC	G+$CO_2 \nRightarrow$ OILC	G $\nRightarrow CO_2$	OILC $\nRightarrow CO_2$	G+OILC $\nRightarrow CO_2$
All countries	51.297***	1.757	52.196***	9.261***	0.725	11.128**	15.806***	67.960***	112.043***
Low income countries	2.272	0.098	2.392	1.007	2.282	3.390	4.995*	0.489	5.877
Lower middle income countries	9.187**	1.475	10.781**	11.882***	3.597	16.029***	4.574	15.483***	24.342***
Upper middle income countries	6.894**	2.843	9.033**	7.703**	2.237	11.526**	4.641*	23.185***	30.127***
High income countries	213.799***	77.591***	301.406***	55.388***	9.125**	85.278***	23.078***	91.986***	138.904***

	Null hypothesis								
Panel D: Renewable Energy consumption	REC $\nRightarrow$ G	$CO_2 \nRightarrow$ G	REC+$CO_2 \nRightarrow$ G	G $\nRightarrow$ REC	$CO_2 \nRightarrow$ REC	G+$CO_2 \nRightarrow$ REC	G $\nRightarrow CO_2$	REC $\nRightarrow CO_2$	G+REC $\nRightarrow CO_2$
All countries	3.455	0.855	4.364	10.975***	0.652	13.124**	42.763***	2.520	45.071***
Low income countries	0.797	0.074	0.917	0.744	3.207	3.720	5.346*	1.612	7.026
Lower middle income countries	0.861	1.536	2.429	10.484***	0.184	10.584**	8.291**	0.342	8.950*
Upper middle income countries	4.552	2.291	6.683	1.309	0.152	1.669	6.698**	0.473	7.181
High income countries	1.100	96.449***	96.724***	11.156***	1.014	22.138***	70.190***	4.879*	72.908***

	Null hypothesis								
Panel E: Natural Gas consumption	GASC $\nRightarrow$ G	$CO_2 \nRightarrow$ G	GASC+$CO_2 \nRightarrow$ G	G $\nRightarrow$ GASC	$CO_2 \nRightarrow$ GASC	G+$CO_2 \nRightarrow$ GASC	G $\nRightarrow CO_2$	GASC $\nRightarrow CO_2$	G+GASC $\nRightarrow CO_2$
All countries	4.957*	3.567	8.963*	2.292	3.679	5.965	25.261***	30.256***	59.699***
Low income countries	1.236	0.363	1.641	0.164	0.501	0.525	0.793	0.921	2.116
Lower middle income countries	2.032	3.042	4.822	0.826	2.865	4.148	0.202	1.528	1.778
Upper middle income countries	0.722	2.152	2.917	1.774	0.334	1.912	5.348*	20.085***	25.198***
High income countries	15.517***	87.639***	99.681***	3.663	32.755***	50.846***	34.870***	6.078**	51.810***

	Null hypothesis								
Panel F: Coal Energy consumption	COALC $\nRightarrow$ G	$CO_2 \nRightarrow$ G	COALC+$CO_2 \nRightarrow$ G	G $\nRightarrow$ COALC	$CO_2 \nRightarrow$ COALC	G+$CO_2 \nRightarrow$ COALC	G $\nRightarrow CO_2$	COALC $\nRightarrow CO_2$	G+COALC $\nRightarrow CO_2$
All countries	0.301	0.627	1.009	0.078	10.925***	12.295**	48.066***	9.021**	58.466***
Low income countries	0.293	0.849	1.162	0.799	2.508	2.745	3.132	1.507	5.068
Lower middle income countries	7.517***	2.564	10.243**	0.518	5.156*	6.030	3.040	5.577*	8.556*
Upper middle income countries	1.050	3.257	3.976	1.916	5.037*	11.300**	19.532***	8.178**	28.442***
High income countries	3.996	14.625***	19.573***	2.935	22.118***	23.050***	15.5800***	6.150**	22.732***

*, ** and *** indicate rejection of the null hypothesis at the 10, 5 and 1 percent levels of significance, respectively.

Figure 1: Energy consumption, CO_2 emissions and GDP, by income group

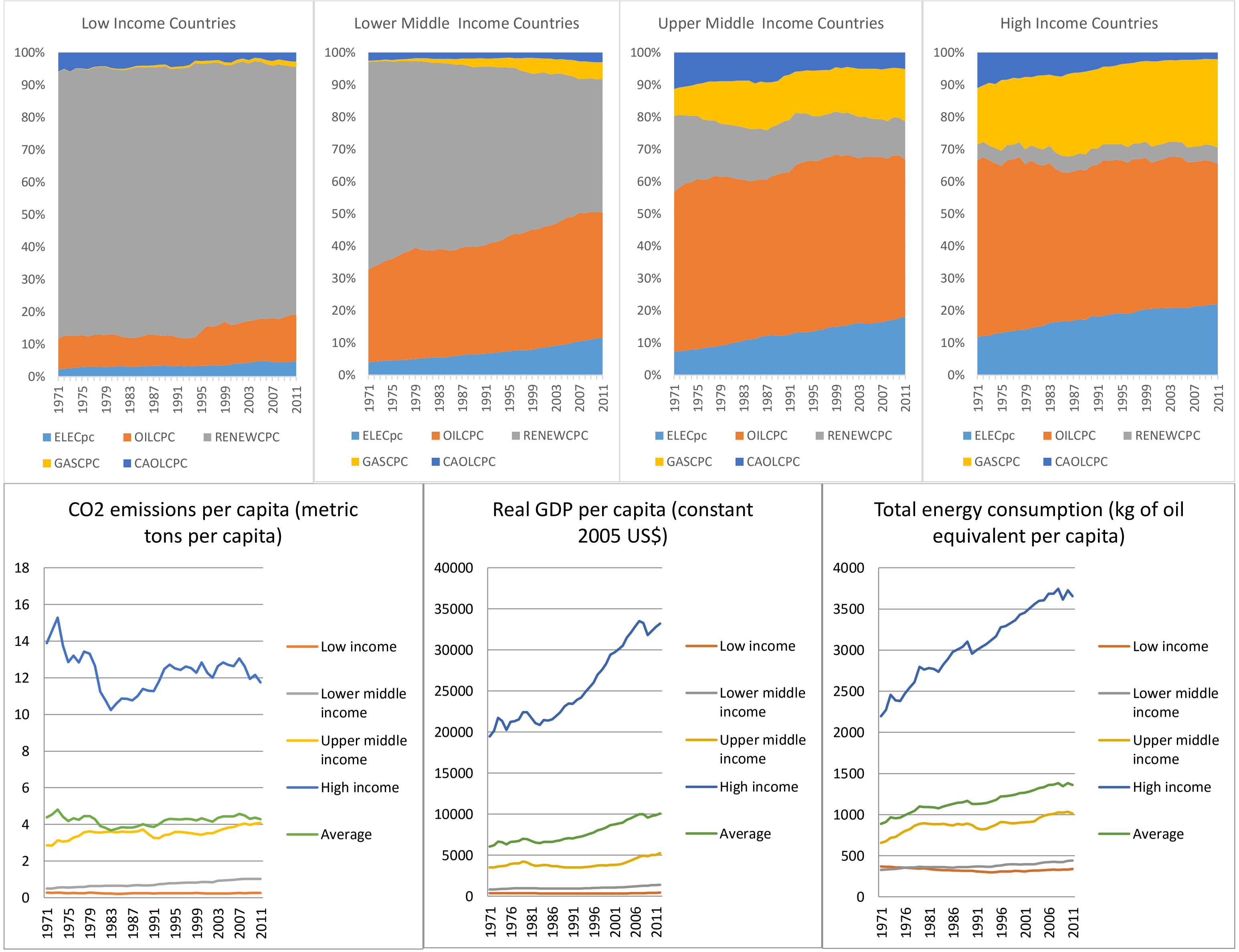
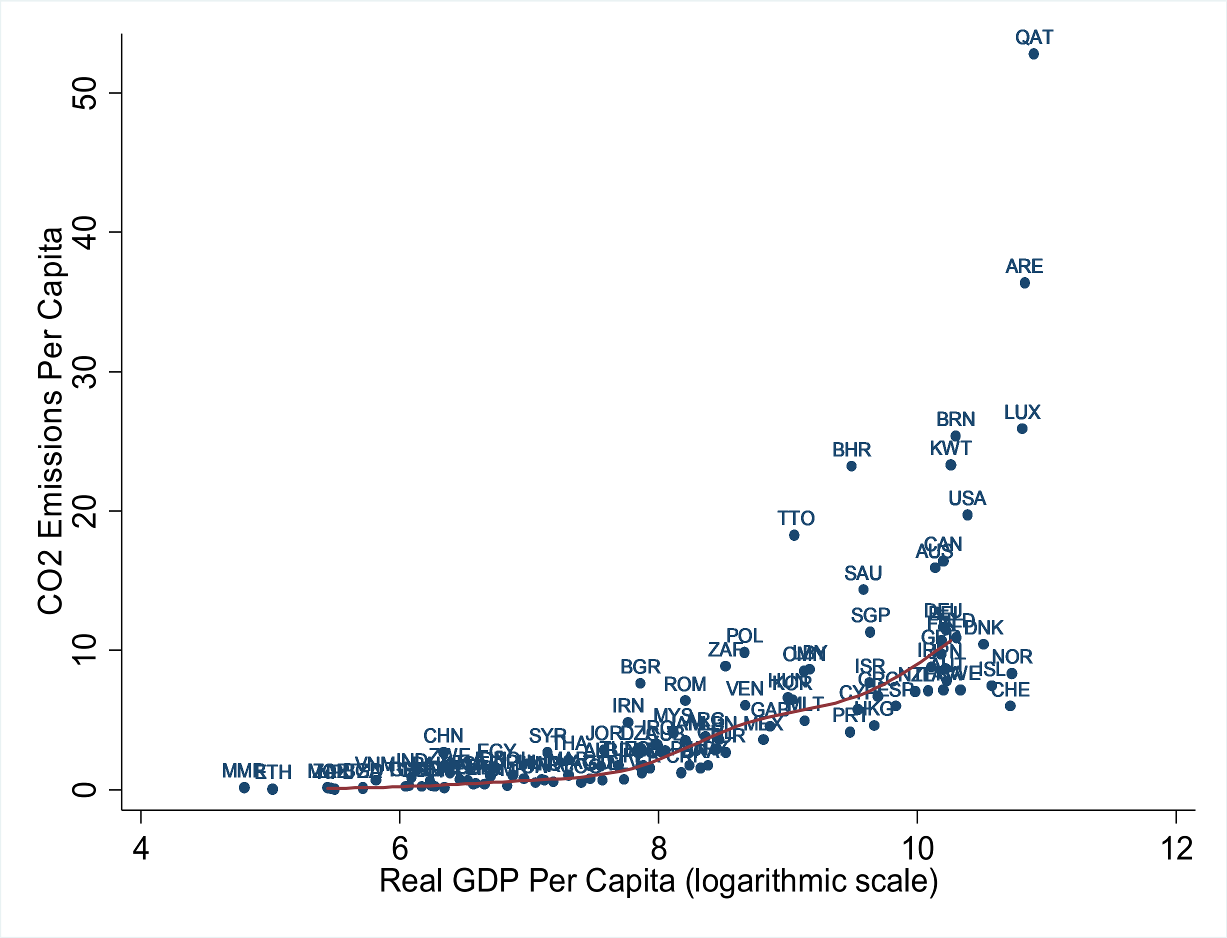
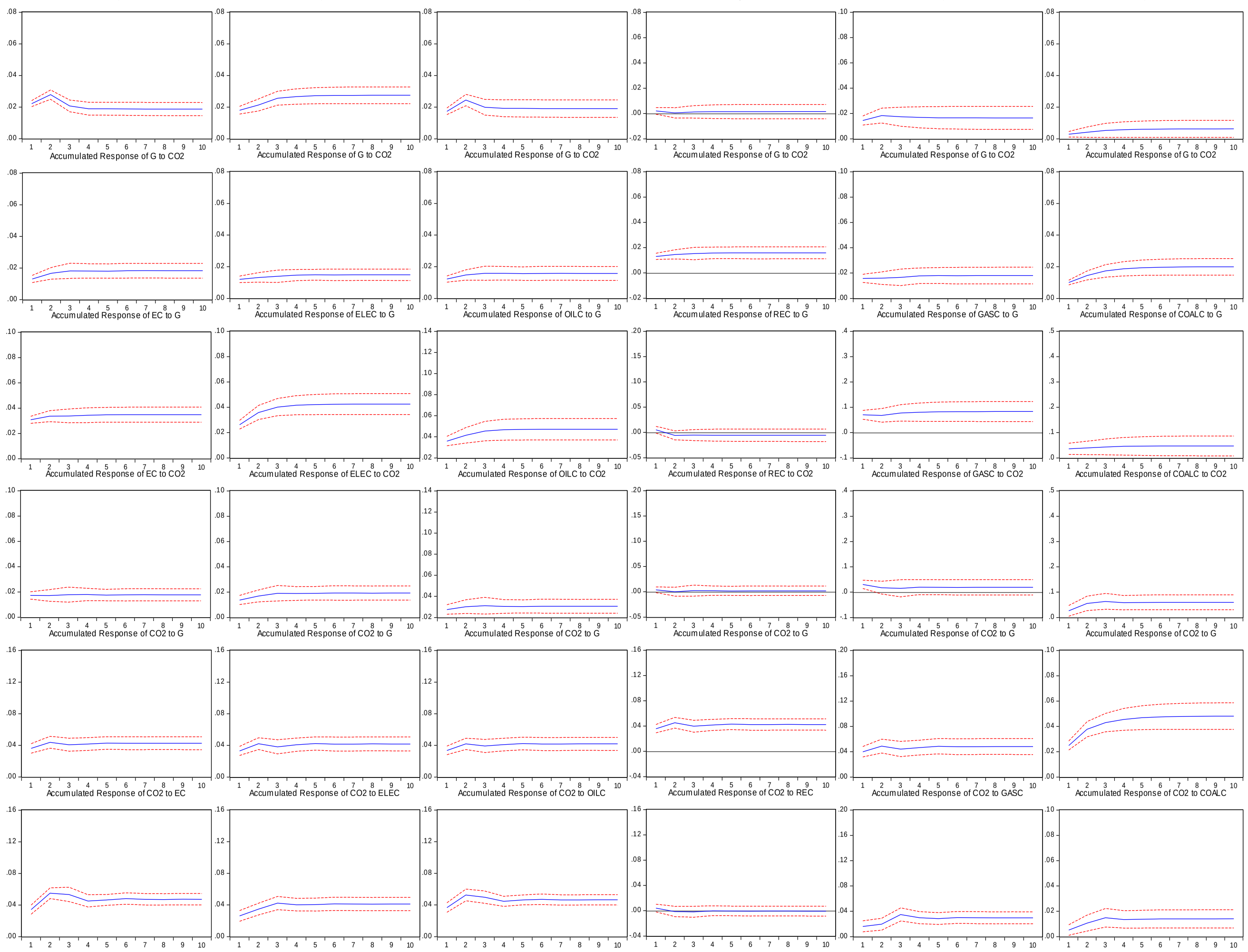


Figure 2: Scatter plot between CO_2 emissions per capita and real GDP per capita (1971-2011 averages)



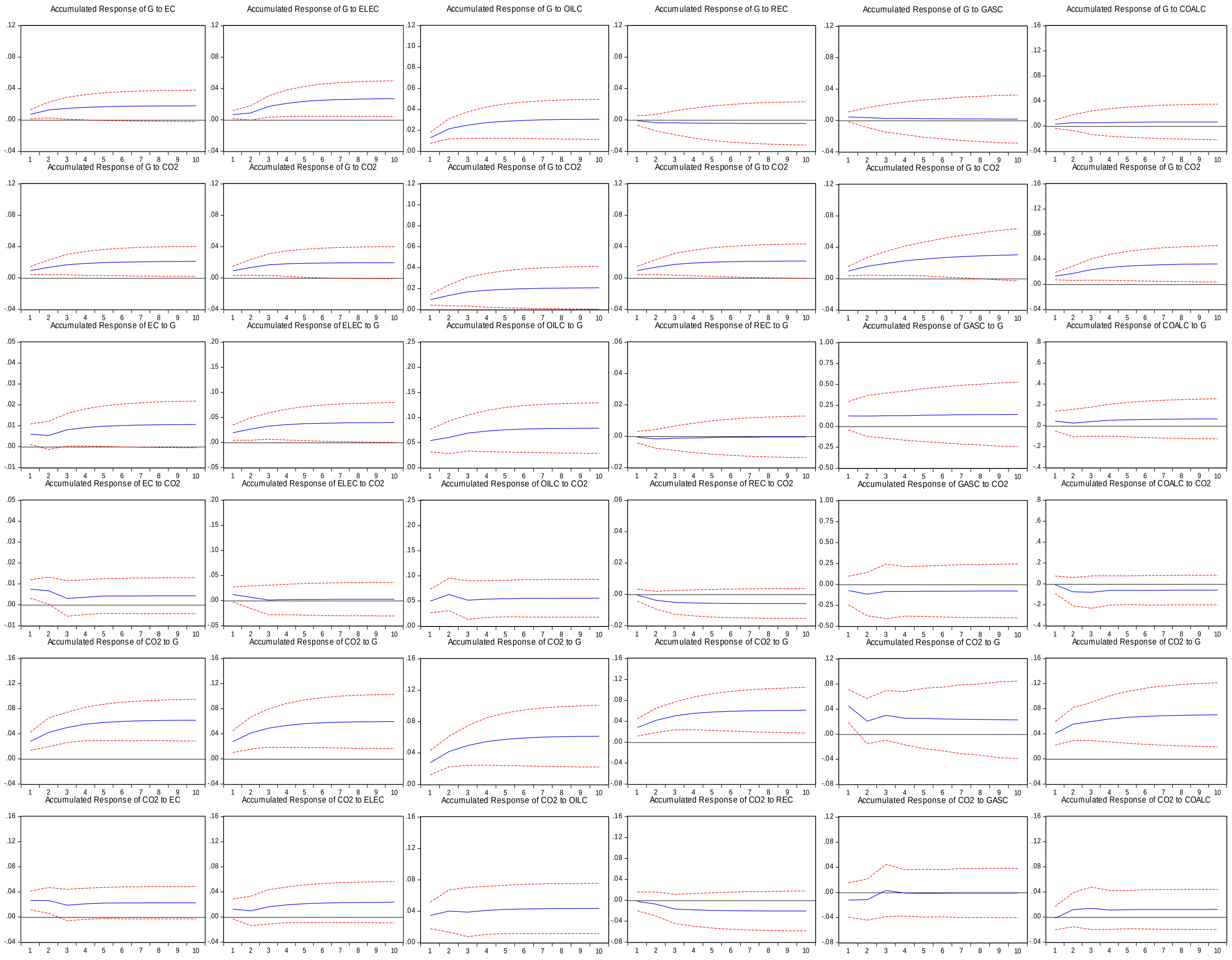
Note: Solid line is a median spline line.

Figure 3: Cumulative generalized impulse responses of energy consumption, CO_2 emissions and economic growth, all countries



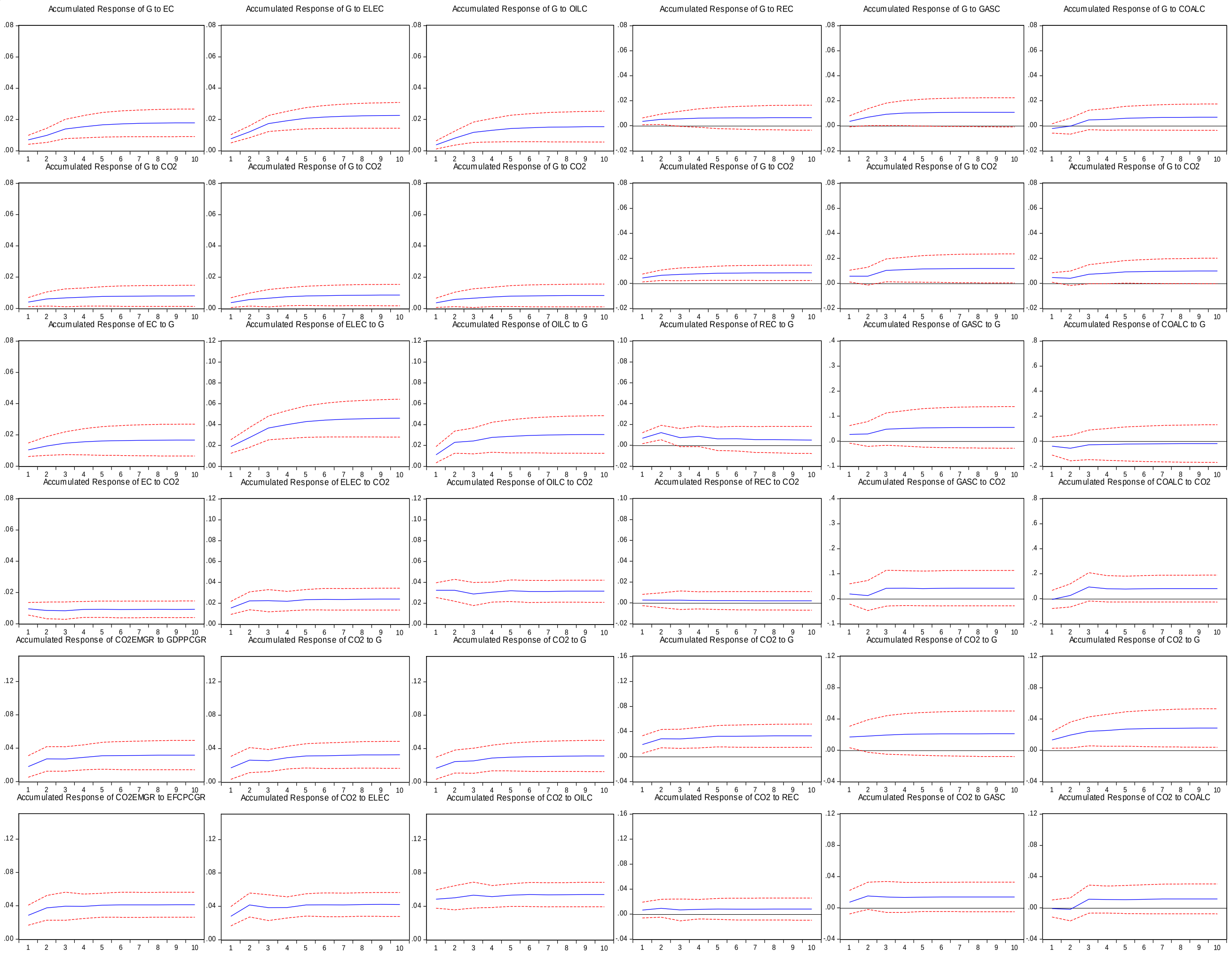
Note: 1st column reports the IRFs based on total energy consumption (EC); 2nd column on electricity consumption ($ELEC$); 3rd column on oil consumption ($OILC$); 4th column on renewable energy consumption (REC); 5th column on natural gas consumption ($GASC$); 6th column on coal consumption ($COALC$). 1st row plots the responses of economic growth (G) to energy consumption shocks; 2nd row the responses of G to CO_2 emission shocks; 3rd row the responses of energy consumption to G shocks; 4th row the responses of energy consumption to CO_2 emission shocks; 5th row the responses of CO_2 emissions to G shocks; 6th row the responses of CO_2 emissions to energy consumption shocks.

Figure 4: Cumulative generalized impulse responses of energy consumption, CO$_2$ emissions and economic growth, low income countries



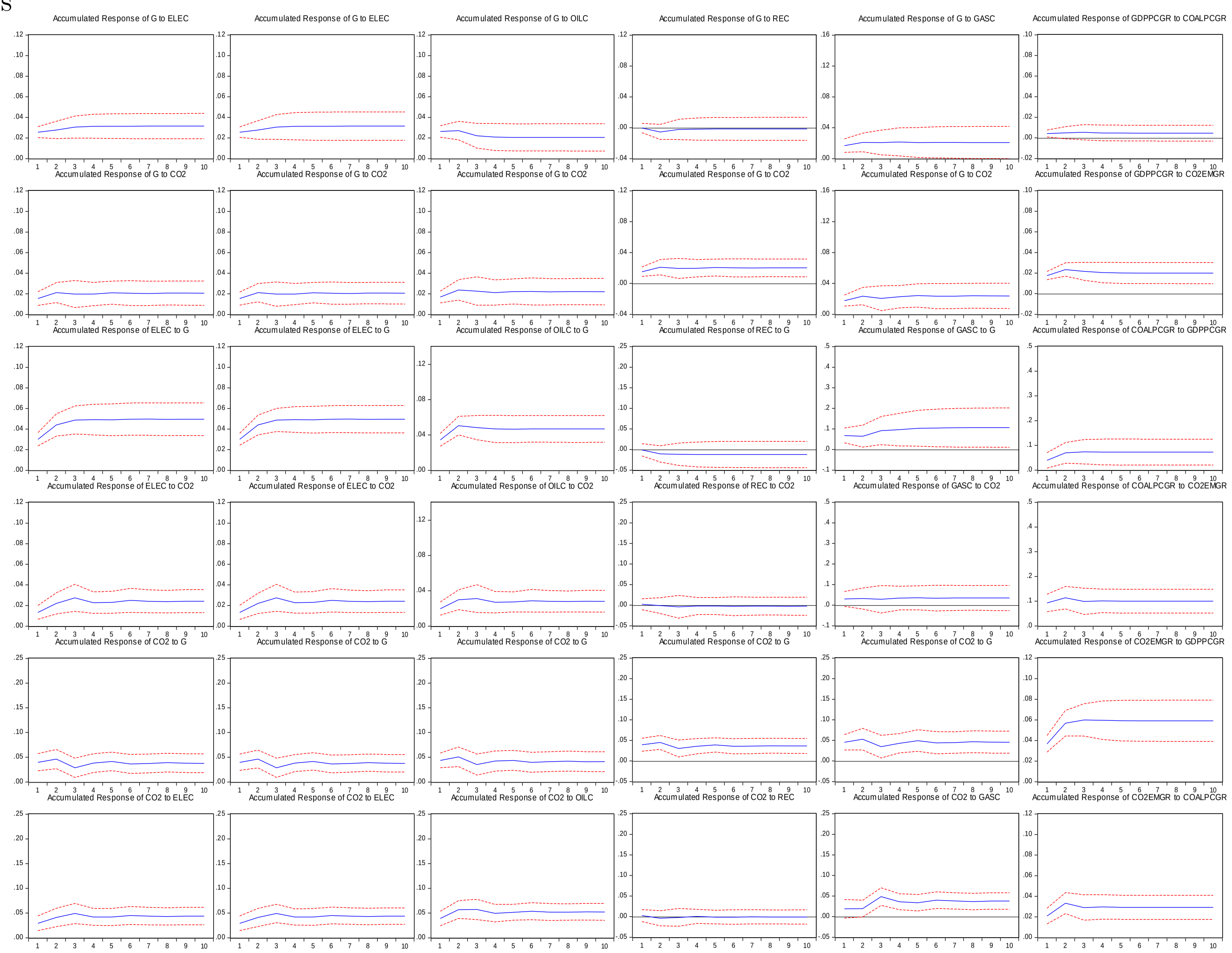
Note: 1st column reports the IRFs based on total energy consumption (EC); 2nd column on electricity consumption ($ELEC$); 3rd column on oil consumption ($OILC$); 4th column on renewable energy consumption (REC); 5th column on natural gas consumption ($GASC$); 6th column on coal consumption ($COALC$). 1st row plots the responses of economic growth (G) to energy consumption shocks; 2nd row the responses of G to CO$_2$ emission shocks; 3rd row the responses of energy consumption to G shocks; 4th row the responses of energy consumption to CO$_2$ emission shocks; 5th row the responses of CO$_2$ emissions to G shocks; 6th row the responses of CO$_2$ emissions to energy consumption shocks.

Figure 5: Cumulative generalized impulse responses of energy consumption, CO$_2$ emissions and economic growth, lower middle income countries



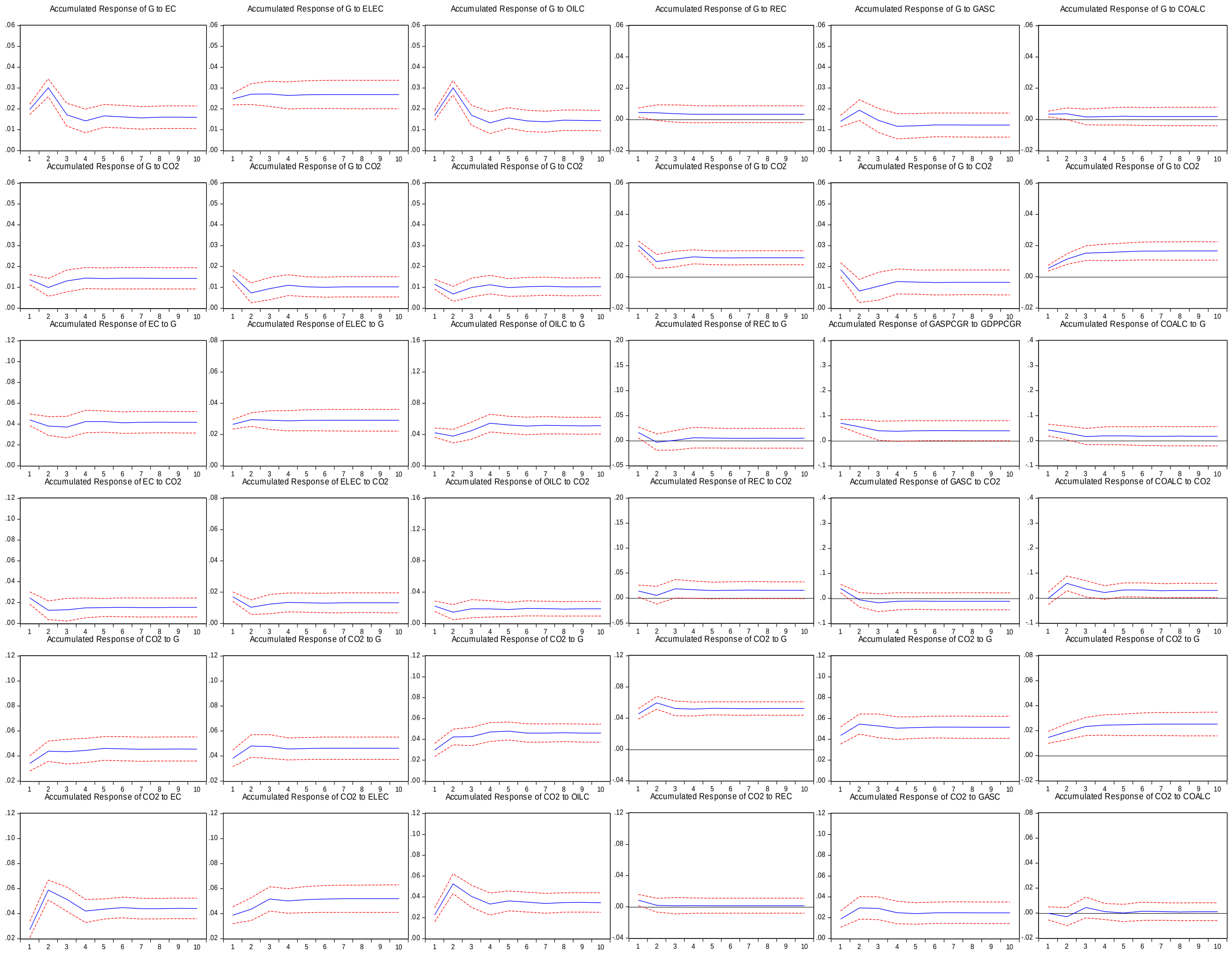
Note: 1st column reports the IRFs based on total energy consumption (EC); 2nd column on electricity consumption ($ELEC$); 3rd column on oil consumption ($OILC$); 4th column on renewable energy consumption (REC); 5th column on natural gas consumption ($GASC$); 6th column on coal consumption ($COALC$). 1st row plots the responses of economic growth (G) to energy consumption shocks; 2nd row the responses of G to CO$_2$ emission shocks; 3rd row the responses of energy consumption to G shocks; 4th row the responses of energy consumption to CO$_2$ emission shocks; 5th row the responses of CO$_2$ emissions to G shocks; 6th row the responses of CO$_2$ emissions to energy consumption shocks.

Figure 6: Cumulative generalized impulse responses of energy consumption, CO_2 emissions and economic growth, upper middle income countries



Note: 1st column reports the IRFs based on total energy consumption (EC); 2nd column on electricity consumption ($ELEC$); 3rd column on oil consumption ($OILC$); 4th column on renewable energy consumption (REC); 5th column on natural gas consumption ($GASC$); 6th column on coal consumption ($COALC$). 1st row plots the responses of economic growth (G) to energy consumption shocks; 2nd row the responses of G to CO_2 emission shocks; 3rd row the responses of energy consumption to G shocks; 4th row the responses of energy consumption to CO_2 emission shocks; 5th row the responses of CO_2 emissions to G shocks; 6th row the responses of CO_2 emissions to energy consumption shocks.

Figure 7: Cumulative generalized impulse responses of energy consumption, CO$_2$ emissions and economic growth, high income countries



Note: 1st column reports the IRFs based on total energy consumption (*EC*); 2nd column on electricity consumption (*ELEC*); 3rd column on oil consumption (*OILC*); 4th column on renewable energy consumption (*REC*); 5th column on natural gas consumption (*GASC*); 6th column on coal consumption (*COALC*). 1st row plots the responses of economic growth (*G*) to energy consumption shocks; 2nd row the responses of *G* to CO$_2$ emission shocks; 3rd row the responses of energy consumption to *G* shocks; 4th row the responses of energy consumption to CO$_2$ emission shocks; 5th row the responses of CO$_2$ emissions to *G* shocks; 6th row the responses of CO$_2$ emissions to energy consumption shocks.