Understanding Energy Consumption Pattern Across the Globe

By

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Dedicated to

My most respected mentor Professor Dr. Eatzaz Ahmed who has always nurtured my intellectual curiosity

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Table of Contents

List of Tables

List of Figures

Abstract

This dissertation explains the pattern of energy consumption across the globe. Chapters 2, 3 and 4, examine respectively the energy-income relationship for developing and developed countries, decomposition analysis of energy consumption, and the relationship of energy-intensity with per capita income to determine the possible existence of threshold levels of per capita income at which the nature of relationship is altered. The findings from chapter 2 confirm the presence of a positive relationship between energy consumption per capita and real GDP per capita for developing and developed countries. However, to what extent energy consumption per capita affects real GDP per capita varies both between and within the two categories of countries. Chapter three findings indicate that efficiency component/effect and activity/effect component are considerably a significant drivers relative to structural component to drive the energy consumption in most of the countries considered in our study. Further, efficiency effect (sectoral energy intensities) as compare to structural effect has a positive contribution in reducing aggregate energy intensity in most of the countries. In addition to that, the determinants of energy efficiency component are investigated. The findings show that the energy efficiency improves due increase in tertiary education and labor productivity. The result of chapter four shows that there exists a non-linear relationship between energy intensity and real GDP per capita in the middle income and high income countries which are considered in the third study. The dissertation concludes with Chapter Five.

Chapter 1
Introduction

1.1. Background

In today's world, energy plays a vital role in expanding the scale of economic activities across both the developing and developed countries, affecting the lives of the planet's eight billion people both directly and indirectly. In recent years, access to affordable energy has been considered as a basic humanitarian need. The 2030 Development Agenda encompassing the 17 Sustainable Development Goals includes one Goal on ensuring "access to affordable, reliable, sustainable and modern energy for all". The per capita energy consumption of a country is considered an important indicator of the level of its economic development. Besides being taken as a basic input in the production process, energy is increasingly being viewed as a strategic commodity that forms the foundations of international relations and influences the global economy IEA (2012c, pp. 37, 50, 272).

The emergence of mass production techniques in the post industrial revolution period has led to a manifold increase in the demand for energy. Consequently, the contribution of energy to the production process has increased substantially, and has become very important to increase in economic activity (IEA 2009). The critical role of energy as a productive input has come into greater debate following the oil crisis of the 1970s, resulting in an increase in theoretical and empirical research on the relationship between energy and output. The seminal work in this regard is the famous article of Kraft & Kraft (1978) on the relationship between energy and GNP. This has spawned a large and growing body of literature that highlights the importance of energy as a basic input consumed in all spheres of production and, thereby, in welfare generation (See, for example, Altinay & Karagol, 2005; Odhiambo, 2009; Apergis & Payne, 2010; Iyke, 2015; Ranjbar et al., 2017; Rathnayaka et al., 2018). The growth hypothesis assumes energy to be one of the major factors determining economic growth. Some researchers disagreeing with this hypothesis consider a little or neutral role in economic growth. (See, for example, Yu & Hwang, 1984; Cheng, 1995; Hondroyiannis et al., 2002; Ozturk et al., 2010; Chang et al., 2017). There are two broad categories of analysis employed in the existing body of empirical evidence to determine the effect of energy on economic activity. The first pre-dominant category attempts to obtain empirical evidence in a broad sense using panel data set of countries or group of countries in order to prescribe general policies applicable to all countries, while the second approach focuses upon a specific country to examine the relationship between energy and output.

Any examination related to the impact of energy consumption on economic activity and development needs to account for the fast changing dynamics of energy consumption during the last few decades all over the world. In this regard, an emerging strand of the literature has employed decomposition analysis techniques to identify the main driving forces causing these changes. According to Nooji et al, (2003), the three major effects /components that play a vital role in determining the pattern of energy consumption in a country overtime are: the output or production (activity effect/component), the composition or structure of the economy (structural effect/component), and the output or activity per unit of energy consumed (efficiency effect/component). IEA (2012c) and Allcott & Greenstone (2012) show that economies have move towards less energy intensive sector as a result of structural changes in the global economy due to changes in the structural composition of the world. Moreover, energy efficiency across various sectors of the globe's economies may also increase in future due to use of more efficient production technologies. The previous studies in this regard have focused mostly on a single country and have conducted energy consumption decomposition at aggregate level. In their review of a large number of studies which used the decomposition method to examine changes in energy consumption in different countries, Liu & Ang, (2007) found that decreases in energy consumption of the industrialized countries over the past three decades were explained mainly by the intensity effect. Reddy & Ray (2011) carried out a decomposition analysis to examine energy consumption in different Indian manufacturing sectors, over the period 1991-2005. Their results indicated that most of the sectors, including cement, textiles, pulp and paper industries, witnessed a reduction in energy consumption, which is explained in some cases on account of efficiency improvements and, in other cases, by a shift to more efficient energy sources. However, in some other sectors, like aluminum, energy consumption increased in the period despite improvements in efficiency, which was attributable to movements towards more energy-intensive products.

In recent times, concerns about environmental degradation and climate change stemming from a more intensive use of energy resources globally has motivated research on the major determinants of energy intensity. According to Malenbaum (1978), it can be postulated that if a country's level of energy intensity is determined by its level of economic development, a higher income can be expected to push upwards the demand for energy and thereby increase in energy intensity. On the other hand, at higher income levels which reflect a more advanced stage of development, energy intensity is likely to decline as both households and industries use more energy-saving technologies. Damette & Seghir (2013) study the relationship between energy intensity and economic growth, across 12 oil exporting countries during the period 1990- 2010. They found a long-run equilibrium relationship between energy intensity and economic growth; while for short run, unidirectional causality from energy intensity to economic growth was observed. Metcalf (2008) investigated determinants of energy intensity in the USA and found rise in per capita income and higher energy prices as major factors in declining energy intensity. Galli (1998), for the first time, applied energy consumption as a quadratic function of income along with energy intensity during 1973-1990 for ten Asian emerging economies and found that this specification explains well change in energy intensity as the level of per capita income rises. The inverted U-shaped patterns in energy intensity with rising levels of income per capita are better explained by this kind of non-monotonic function.

The present study will attempt to fill the gaps with respect to the three dimensions discussed above, i.e., relationship between energy consumption and output; evolving patterns of energy consumption and it's major driving forces; relationship between energy intensity and per capita income using maximum number of countries subject to availability of updated and long spans data. In spite the importance of energy in economic activity, the energy-economy relationship is not well understood. This analysis will extend the existing body of evidence in various ways. It will carry out an in-depth examination of the link of energy consumption per capita with real GDP per capita, as there is little consensus on the strength of this relationship in the existing literature related to developing and developed countries. The study uses a sample of panel data for 18 developed and 26 developing countries over the period 1980-2014 to revisit the relationship between energy consumption per capita and real GDP per capita, by using time-series as well as panel ARDL approaches to co-integration. For policy makers of energy sector, it is imperative to properly understand the link between energy consumption per capita and GDP per capita, as it will help them in designing energy policy for maximizing the output potential of an economy.

The second part of the study seeks to explain the contribution of three main components in explaining the pattern of aggregate energy consumption across 60 countries assuming three main economic sectors[1] using logarithmic mean Divisia index (LMDI) decomposition analysis for the period 1990–2015. Most previous studies decompose energy intensity into two components, i.e., structural and efficiency components. The present study decomposes energy consumption rather than energy intensity, into three components, i.e., activity, structural and efficiency components. Furthermore, the present study considers a large number of developing countries which are mostly ignored in the previous literature. In addition to that, a cross-sectional regression analysis is carried out to investigate the determinants of energy efficiency. Understanding the factors that play an important role in sectoral dynamics of energy consumption and the interaction of structural changes and improvement in sectoral efficiency will generate key policy recommendations for the design of effective energy policy regimes.

The third part of the study will help to uncover the true nature of relationship between energy intensity and per capita income and locate the threshold level of per capita income at which the nature of relationship changes, by the application of spline function.

1.2. Research Objectives

The present study seeks to answer the following research questions:

- What is the role of energy consumption in promoting economic activity?
- Is the changing composition of output, especially towards service sector, a source of increased energy consumption or energy conservation?
- Has there been sufficient improvements in energy efficiency to result in conservation of energy?
- What factors drive energy efficiency (sectoral energy intensities)?
- Do such critical (threshold) levels of per capita income exist at which the nature of relationship between income and energy intensity changes in a fundamental way?
- If answer to previous question in the affirmative, what are such critical levels of per capita income?

[1] Agriculture sector, Industrial sector and Services sector

- To what extent such critical levels of per capita income differ between high-income and middle-income countries?

1.3. Outline

The study is divided into 5 chapters. Following this introductory section, Chapter 2 examines the first two research objectives, i.e., whether increase in energy consumption a necessary condition to increase in GDP and the extent to which increase in energy consumption affects output. Chapter 3 discusses whether the changing composition of output, especially towards service sector, a source of increased energy consumption or energy conservation. It also examines if there been sufficient improvements in energy efficiency to result in energy conservation. Moreover, the determinants of energy efficiency are investigated. Chapter 4 investigates whether there exists a specific level (threshold level) of per capita income exists beyond which increase in income results in reduced energy intensity and also computes that threshold level of per capita income. The chapter further examines if there is a single specific level of per capita income or there are multiple levels.

The main conclusions with respect to all three aspects are given in Chapter 5, which also presents policy implications emerging from the analysis.

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Chapter 2
Energy–Output Relationship: Evidence from Developed and Developing Countries

Abstract

The paper explores the relationship between energy use per capita and GDP per capita for 44 developed and developing countries over the period: 1980-2014. The study has made extensive use of time series and panel data analysis. ARDL co-integration approach has been applied in pure time-series setting for each country in the sample as well as in panel data setting separately for the group of developed and developing countries. The results confirm the presence of a positive relationship between per capita energy use and GDP per capita, controlling for other potential determinants, across both the categories of countries. However, to what extent energy consumption affects output level varies both between and within the two categories of countries. Specifically, the contribution of energy use to GDP is higher in developed countries as compared to the developing countries. The study concludes that energy use has a significant role in raising real GDP per capita in both developed and developing economies. The analysis prescribes that energy conservation is not necessarily desirable because it will hinder economic activity. However, the serious efforts should be taken to formulate energy use promoting policies keeping in view the environment issues for sustainable economic development.

Key Words: *Per Capita Energy Use, GDP Per Capita, Developing Countries, Developed, Countries, ARDL*

2.1. Introduction

Greater use of energy is expected to stimulate economic activity/output level of an economy and this proposition has invited extensive deliberations in literature, especially after publication of the famous article of Kraft & Kraft (1978) on the relationship between energy and GNP. Subsequently, a vast literature has emerged that highlights the importance of energy as a basic input consumed in all spheres of production and, thereby, in welfare generation (See, for example, Altinay & Karagol, 2005; Odhiambo, 2009; Apergis & Payne, 2010; Iyke, 2015; Ranjbar et al., 2017; Rathnayaka et al., 2018). This strand of literature referred to growth hypothesis in the literature assuming energy as one of the major factors determining the economic activity. However, researchers disagree with this hypothesis and consider a limited or neutral role of energy in stimulating economic activites (See, for example, Yu & Hwang, 1984; Cheng, 1995; Hondroyiannis et al., 2002; Ozturk et al., 2010; Chang et al., 2017).

For policy makers in the energy sector, it is imperative to understand the link between energy consumption and economic activity because this understanding would help them in designing/devising an appropriate and effective energy policy The government should encourage energy consumption to increase GDP as it is linked to many factors such as unemployment, investment, savings and economic development (See, for example, Ozturk *et al.,* 2010; Apergis & Payne, 2011).

Although an extensive literature has evolved over the past 40 years on the study of how energy consumption affects output, yet there is still no consensus on the extent or direction of this effect. There are two broad categories of econometric approaches in this context. One category attempts to obtain empirical evidence in a broad sense using panel data of a set of countries over a certain time period to prescribe major policies applicable to all countries as a whole. The benefits of this approach is that it is backed by a large data set and is considered to give more robust and reliable results, while the disadvantage is that it does not distinguish between countries at different stages of development. The second approach makes use of time-series econometric techniques for each country in the category of developed and developing countries to study over the period of time. This approach does not normally lead to one standard policy prescription applicable to all countries. Rather varying policies are likely to emerge for different countries. This approach is beneficial in terms of gaining better insight into the energy-output relationship at the country level but at the cost of relatively low reliability due to country-wise small samples.

The present study adopts an approach that can take advantage of both the panel and country-wise time-series data to determine the linkages between energy consumption and output. The study employs data for 18 developed and 26 developing countries with 35 annual observations from 1980 to 2014.[2] The number of time series observations for each country is also sufficient to carry out separate time-series analysis for each country. Thus, we use time-series as well as panel ARDL approaches to co-integration. The results from time-series ARDL estimation are used as a stepping stone for Panel ARDL estimation. At the panel level, separate analyses are conducted for the set of developed and developing countries[3].

The study uses financial development, trade openness and investment as control variables. The study also applies important diagnostic tests for time series analysis namely normality test, and autocorrelation test for residuals etc. Test applied to panel analysis include cross-sectional dependency and structural break unit tests etc. to prevent misleading inference and inconsistent estimates in the models.

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[2] Initially 33 developed and 45 developing countries were selected. However, some of the countries are dropped from analysis due to abnormal patterns observed in data, especially in the capital stock series on which no actual data are available and the series are constructed using perpetual inventory method under certain assumptions.

[3] Developed countries are high income countries, and developing countries are upper and lower middle income countries.

The rest of the study is organized as follows. Sections 2, 3, 4 & 5 present the literature review, model, data and econometric procedure respectively. Section 6 presents results of estimation and section 7 concludes the paper.

2.2. Literature Review

There exists a significant body of empirical evidence examining the causal relationship between energy consumption and level of economic activity, using different time series econometric methodologies. This line of research which was initially motivated by the oil crisis of the 1970s has evolved over time to encompass issues related to energy pricing and energy security that help to conserve energy and reduce environmental degradation.

The seminal work in this regard has been the study by Kraft & Kraft (1978) which employed annual U.S. data from the year 1947-1974 to analyze the relationship between GNP and gross energy input. The study using the Sims causality test procedure found that increase in energy consumption led to higher GNP. Akarca & Long (1979) used employment as substitute to economic activity and found that increased energy consumption was associated with higher levels of employment. Erol & Yu (1987a) also utilized employment as substitute to GDP/GNP and made use of Sims causality technique to U.S. data (1973 – 84). The study, however, found no relationship between energy consumption and employment. Erol & Yu (1987b) used Sims and Granger causality approaches to analyze the linkages between energy consumption and GNP for three countries, i.e., Canada, France and the U.K. Their findings indicated that increase in energy use led to increase in GNP in Canada, but no causal relationship has observed in case of France and U.K.

The earlier strand of empirical research was based on bivariate causality test between energy consumption and output/employment. However, the issue of omitted variable bias is likely to be a problem in case of bivariate analysis and can lead to misleading results.

Subsequent studies by Yu & Hwang (1984) and Stern (1993) included other variables in case of U.S. Yu & Hwang (1984) used employment, while Stern (1993) included employment and capital and used both the Sims and Granger causality tests, to examine the energy consumption and output nexus and observed that increase in energy consumption led to increase in real GDP.

This line of research made use of the traditional regression model to estimate parameters and to carry out statistical tests. However, a shortcoming of these estimation methods is that they do not adequately address issues like endogeneity and non-stationarity, which could lead to spurious regressions and misleading results (Granger & Newbold, 1974). The linkages of energy consumption with economic output have been re-examined in light of emergence of new econometric approaches in time series econometrics, like Engle-Granger (1987) or Johansen-Juselius (1990) co-integration and error-correction models.

Subsequently, a new strand of research studies has emerged that have employed the Engle-Granger co-integration and error-correction model (ECM). The majority of studies employing co-integration and ECM are bivariate in nature, using only energy and output / employment (Masih & Masih, 1997; Soytas & Sari, 2003; Yoo & Jung 2005; Chen et al., 2007; and Zachariadis, 2007). Some studies such as Stern (2000), Paul & Bhattacharya (2004), Soytas & Sari (2006a, 2007) and Yuan et. al. (2008) employed capital and/or labor and consumer prices Masih & Masih (1997, 1998; Asafu-Adjaye, 2000). Glasure (2002) included various other variables, such as real government expenditure, real money supply, real oil prices and dummy variable for oil price shocks.

It has been argued that the use of aggregate data on energy consumption hides the different effects of the use of different types of energy, as well as on the sector of end use. To account for this issue, some studies (Yang, 2000a, 2000b; Yoo & Kim, 2006; Jinke et al., 2008; Pirlogea & Cicea, 2012) investigated the effect of different types of energy consumption, like coal, natural gas, electricity, oil; on economic activity. Other studies that have employed different measures of energy consumption which include Hondroyiannis et al. (2002), Ghosh (2002), Shiu & Lam (2004), Yoo & Jung (2005), Soytas & Sari (2007), Chen et al. (2007), Zachariadis (2007) and Yuan et al. (2008). However, the studies did not provide any conclusive evidence on the relationship between energy consumption and economic activity within and across countries.

The Engle-Granger, Johansen-Juselius co-integration techniques and ECM have been employed to investigate the linkages between energy consumption and Gross Domestic Product. However, these techniques have been criticized by Harris & Sollis (2003) on account of having low explanatory power due to small number of observations common to unit root and co-integration tests. In order to overcome this shortcoming, latest research has used the autoregressive distributed lag (ARDL) model and bounds testing methodology, along with the Toda & Yamamoto (1995) and Dolado-Lütkepohl (1996) long-run causality tests. ltinay & Karagol (2005) making use of Dolado-Lütkepohl test, found that increased electricity consumption led to higher GDP in Turkey. Using the Toda-Yamamoto causality test, Lee (2006) did not find any causality between energy consumption and GDP per capita in Germany, Sweden and the United Kingdom; while increased energy consumption was seen to result in higher real GDP per capita in Belgium, Canada and Switzerland.

Soytas & Sari (2006b) also used Toda-Yamamoto causality test to analyze the relationship between energy consumption and output in China, but the study did not find any causality between the two. Zachariadis (2007) examined the relationship between different types of energy consumption and output in six highly developed countries by using the ARDL bounds test and the Toda-Yamamoto causality test. However, the study's results were diverse across countries under consideration. Bowden & Payne (2010) also investigated the relationship between the sector-wise measure of energy consumption and output in the U.S employing the Toda-Yamamoto causality test. However, the study did not find any causal relationship between industrial / commercial energy consumption and real GDP; while increase in residential renewable/industrial non-renewable energy consumption was found to lead to an increase in real GDP. Sari et al. (2008) examined the causal relationship between disaggregated measure of energy consumption by sector and industrial production in the United States using the ARDL bounds test approach. The findings indicated that higher industrial production lead to increased energy consumption, with the exception of coal consumption.

Despite the use of new and more sophisticated econometric methods for determining the linkage between energy consumption and economic output, the increasing body of empirical research still yields inconsistent results. These divergent findings can be attributed to a number of factors, including different data sets (i.e. variable selection and time periods of the studies), model specification, alternative econometric techniques and different countries' characteristics such as different indigenous energy supplies, different political and economic histories, different political arrangements, different institutional arrangements, different cultures and different energy policies (Ozturk et al., 2010; Payne, 2010). In addition, Karanfil (2009) emphasized that the examination of the relationship between energy consumption and economic activity in developing countries may not give reliable results primarily due to the unrecorded economic activities that make it difficult to correctly measure the official GDP.

Most of the studies that we have observed, yielded diverse and contradictory findings for underlying energy-output nexus. In view of these limitations, the relationship between energy consumption and activity warrants is needed further attention. The underlying relationship can be re-examined by using the new econometric estimation techniques along with up dated data. Further, most of the studies that we have observed do not examine the intensity of the link between energy consumption and GDP.

The present study attempts to fill in these gaps by adopting an approach that takes advantage of both the panel and country-wise time-series data. The study incorporates additional control variables, such as trade openness and financial development. Furthermore, unlike many of the previous studies, the present study focuses on strength the relationship between per capita energy consumption and real GDP per capita in developing countries relative to developed one.

2.3 Analytical Model

The aggregate production function considering technology endogenously takes following form:

$$y = f(A, k, \mathrm{l}) \tag{2.1}$$

Wherein y is aggregate real output, k and l relates with stock of capital and labor, while 'A' assumed to be a technological factor.

Romer (1986) is of the view; technology progress ensures the acquisition of knowledge that maximizes the profit of the firms in the country. Technological progress has been explained by a number of factors in literature. Trade liberalization and openness have introduced the innovative ideas in the economy inducing technological progress. (Barro & Sala-i-Martin, 1997; Rivera-Batiz & Romer, 1991). Whereas, Arrow (1971) advocated that "learning by doing" induces the technological advancement that depends upon the volume of investment in the country. McKinnon (1973), Shaw (1973), Fry (1998), Ghura & Goodwin (2000), and Almasaied (2010) argued that investment could be boosted up by financial development. In the view of these arguments, we can say that technological progress depends upon international trade and financial development i.e.

$$A = f(op, fd) \quad (2.2)$$

Wherein, op stands for trade openness[4] and fd attributes to the financial development.

The equation 2.1 can be written by incorporating the determinants of technological progress as follows:

$$y = f(\mathrm{k}, \mathrm{l}, \mathrm{op}, \mathrm{fd}) \quad (2.3)$$

Furthermore, the possible contribution of energy use as an input in aggregate production function was underestimated before 1970. However, after the emergence of oil crises in the 1970s, energy was recognized as an important factor of production in output generation. Unless, the energy is properly consumed, the presence of technology alone cannot ensure the maximum potential output. Considering the prominent role of energy use in economic activity, Berndt (1975), Rasche (1977) and Renshaw (1981) recognized energy as an input in production function. Thus, by incorporating energy as a factor of production, equation 2.3 can be written as follows:

$$y = f(k, l, e, op, fd) \quad (2.4)$$

Where e, stands for energy use.

Following Lean and Smyth (2010), Shahbaz and Lean (2012), Shahbaz et al (2013), we divide both sides by population and get each series in per capita terms; but leave the impact of labor constant[5]. In the light of above considerations and assuming Cobb-Douglas technology, we propose the following econometric model in the log form for estimation.

$$LY = \alpha + \beta LK + \gamma\, LE + \delta LOP + \theta LFD + u \quad (2.5)$$

[4] Trade openness is measured by summation of import and export as a percentage of GDP
[5] Labor force proportion to population is assumed to be constant over the long-run.

where LY, LK, LE, LOP and LFD stand for log of per capita output, log of per capita capital stock, log of per capita energy consumption, log of trade openness (trade to GDP ratio) and log of financial development respectively. The term μ is a random error term.

2.4. Data

As mentioned earlier, the study is carried out for panels of 18 developed and 26 developing countries[6] using time-series annual data over the period 1980-2014. Selection of these countries is based mainly on the availability of consistent time series data. Data on all the variables are either directly available or extractable from the information available in *World Development Indicators* (*WDI*). Thus, following the standard practice, the available data on gross capital formation are used to construct capital stock series using perpetual inventory method by setting capital depreciation equal to 0.05. The data on GDP and gross capital formation are measured in constant US$ prices of the year 2010. Energy consumption includes the consumption of all types of energy by all types of users. Data on energy consumption are measured in term of kg of oil equivalent per capita (Kgoe). Trade openness is measured as total trade as ratio to GDP. Data on real GDP, capital stock, trade openness and financial development variable are transformed into per capita terms. All the variables are taken in natural logarithmic scale for estimation of equation (2.5).

2.5. Econometric Methodology

Empirical analysis in this study follows two rounds. In the first round equation (2.5) is extended to ARDL format and estimated for each country in the sample using time series data. The country-wise analysis is carried out to gain basic insights into the relationship, whereas the panel estimation of the model separately for developed and developing countries allows to

[6] For list of countries see table 1 & table 2.

capture the average behavior of each set of countries to have a broad understanding about the relationship.

2.5.1 Time Series Modeling

For time series data standard ARDL model is used that in the present context takes the form:

$$\Delta L\ (Y_t) = \alpha + \sum_{i=1}^{p1} a_i \Delta\ L\ (Y_{t-i}) + \sum_{i=0}^{p2} b_i \Delta\ L\ (E_{t-i}) + \sum_{i=0}^{p3} c_i \Delta\ L(K_{t-i}) + \sum_{i=0}^{p4} d_i \Delta\ L\ (FD_{t-i})$$

$$+ \sum_{i=0}^{p5} e_i \Delta L\ (OP_{t-i}) + \beta_1 L\ (Y_{t-1}) + \beta_2 L\ (E_{t-1}) + \beta_3 L\ (K_{t-1}) + \beta_4 L\ (FD_{t-1})$$

$$+ \beta_5 L\ (OP_{t-1)} + v_t \qquad (2.6)$$

Note that parameters associated with the level variables indicate long-run relationship, while those associated with the variables in first differences represent short-run relationships. The parameter β_1 is the error correction coefficient. The existence of co-integrating relationship is verified if the null hypothesis: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$ is rejected against the alternative that at least one of these parameters is non-zero. All the variables are tested for unit root before estimation of this equation. The number of I (0) and I (1) variables will determine the critical value of F-statistic in Bounds testing for co-integration.

2.5.2. Panel Modeling

For the panel estimation also ARDL approach is adopted. However, the testing and estimation procedure is not straightforward as it depends on the possible existence of cross-sectional dependence in various time-series data sets. Thus the first step is to apply Cross-Sectional Dependence (CD) test[7]. In the presence of cross-sectional dependence, as in our case,

[7] See appendix 2a

the second generation CIPS unit root test of Pesaran (2007) based on the following test equation is applied."

$$\Delta L(X_{it}) = \alpha_i + \beta_i L(X_{i,t-1}) + \gamma_i \Delta L(\overline{X}_{t-1}) + \sum_{j=0}^{p} \theta_{ij} \Delta L(\overline{X}_{t-j}) + \sum_{j=1}^{p} \vartheta_{ij} L(\Delta X_{i,t-j}) + \mu_{it} \qquad (2.7)$$

Here α_i is the drift term and p is the lag length to be determined by some criteria like AIC or SBC. Pesaran used individual Cross-sectional Augmented Dickey-Fuller (CADF), and developed CIPS statistic by taking the average of these individual CADF statistics.

$$\text{CIPS} = \sum_{i=1}^{N} t_i \Big/ N$$

where t_i is the t-statistic of the estimate of β_i. The null hypothesis is that all individuals series follow unit root process i.e. all $\beta_i = 0$.

For penal ARDL[8] analysis Mean Group (hereafter MG) model proposed by Pesaran & Smith (1995) and Pooled MG (hereafter PMG) model developed by Pesaran *et al.* (1999) are employed. There is no requirement for order of integration to be same for the application of MG and Pooled PMG models. The two models are given by:

MG Model:

$$\Delta L\,(Y_{it}) = \theta_i\big(L\,(Y_{i,t-1}) - \delta_i L\,(X_{i,t-1})\big) + \sum_{j=1}^{p-1} \rho_y^i \Delta L\,(Y_{i,t-j}) + \sum_{j=0}^{q-1} \gamma_y^i \Delta L\,(X_{i,t-j}) + \mu_i + \epsilon_{it} \qquad (2.8)$$

[8] See appendix 2b

PMG Model:

$$\Delta L\,(Y_{it}) = \theta_i\big(L\,(Y_{i,t-1}) - \delta L\,(X_{i,t-1})\big) + \sum_{j=1}^{p-1} \rho_y^i \Delta L\,(Y_{i,t-j}) + \sum_{j=0}^{q-1} \gamma_y^i \Delta L\,(X_{i,t-j}) + \mu_i + \epsilon_{it} \quad (2.9)$$

Here, $Y_{i,t}$ is GDP and $X_{i,t-j}$ is the vector of explanatory variables of group i and μ_i stands for fixed effect. Principally, p and q can differ across countries and thus the panel can be unbalanced. Further, δ_i and δ represent long-run parameters, while ρ_y^i, γ_y^i and θ_i are short-run parameters, The error correction parameters θ_i measure the proportion of error corrected with one period lag. The main difference between MG and PMG models is that the latter restricts long-run parameters to be common across time series. So, the PMG estimators will be inconsistent if this restriction does not hold. Hausman test will be applied to select between the two models.

2.6. Results and Discussion

This section has three subsections. Descriptive analysis is provided in Section 2.6.1 using (average) GDP per capita and (average) energy consumption per capita. Time series analysis is provided in section 2.6.2, whereas, panel data analysis is presented in 2.6.3.

2.6.1. Trends in Real GDP Per Capita and Energy Consumption Per Capita

Trends in the per capita GDP and per capita energy consumption over the period 1980-2014 are shown in Tables 2.1 and 2.2 for the entire period as well as for seven five year sub-periods, for sample of developed and developing countries, respectively. The tables show that there is overwhelming evidence of positive trend in both the per capita GDP and per capita energy consumption over the sample period even though variations beside the trend are also present. In addition, there are also a few countries for which the relationship between the two series is not positive. Among the developed countries a notable exception is UK where the relationship follows inverted U-shaped profile. That is, in long run the UK has been able to conserve energy consumption despite experiencing rising higher per capita GDP. One possible reason for this pattern is that the UK has shifted a significant portion of its manufacturing activity to China and other countries (Bailey & Propris, 2014).

Similar rising trend in per capita GDP and per capita energy consumption is observed in Table 2.2 with a few exceptions of small countries like Cote d'Ivoire, Gabon and Togo.

Average trends in both the sets of series are also illustrated in Figure 2.1 and Figure 2.2 for the same set of countries. Figure 2.1 shows a persistently rising trend in GDP per capita and energy use per capita across the developed countries over all the seven five-year sub-periods. The average per capita GDP (in real terms) for the developed countries is observed to rise from close to US $ 19725 over the period 1980-84 to reach around US $ 34008 by 2005-09. On the other hand, per capita energy use increased from 3,430 kilogram of oil equivalent (hereafter kgoe) in the base sub-period (1980-84) to 5,764 Kgoe in end period of 2010-14.

For the sample of developing countries, the average real GDP per capita is seen to increase consistently from US$ 2,890 during the initial five sub-periods of 1980-84 to US$ 4,185 in 2010-14 (Figure 2.2). On the other hand, energy use per capita also shows increasing trends, rising from an average of 665 Kgoe in the base sub-period of 1980-84 to reach 1,026 Kgoe by 2010-14. The trends in energy use per capita further show a relatively higher increase in the latter sub-period starting from 1995-99 and onwards.

Table 2.1: Average of Real GDP Per Capita and Energy Consumption/Use Per Capita in Developed Countries

Country	GDP Per Capita and Energy Use Per Capita	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14	1980-14
Australia	GDP Per Capita	30273.05	33429.38	35808.75	40335.50	45670.96	50461.49	53091.70	41295.83
	Energy Use Per Capita	4691.30	4740.60	5037.17	5431.28	5565.51	5793.80	5584.79	5263.49
Austria	GDP Per Capita	28099.38	30899.78	34742.26	38346.65	42785.52	46234.37	47564.91	38381.84
	Energy Use Per Capita	2918.27	3126.30	3278.23	3540.57	3816.76	4002.85	3908.91	3513.13
Canada	GDP Per Capita	31990.22	35707.70	35872.96	39256.76	44777.94	47763.01	48808.40	40596.71
	Energy Use Per Capita	7375.53	7672.26	7660.73	8008.50	8210.11	8170.09	7805.27	7843.21
Chile	GDP Per Capita	4666.02	5291.82	7035.56	9291.45	10264.86	12014.71	13795.55	8908.57
	Energy Use Per Capita	806.94	873.11	1130.62	1505.15	1656.62	1802.38	2028.14	1400.42
Cyprus	GDP Per Capita	10668.70	13655.89	16505.42	18579.84	20705.91	22922.95	21702.21	17820.13
	Energy Use Per Capita	1271.83	1544.16	1974.55	2107.07	2227.52	2271.91	1941.36	1905.49
Finland	GDP Per Capita	26640.59	30818.04	31127.75	35057.04	42172.69	47209.52	46123.95	37021.37
	Energy Use Per Capita	4924.22	5611.45	5681.02	6122.47	6722.66	6717.25	6394.36	6024.77
Greece	GDP Per Capita	18509.66	18855.00	19552.90	21179.20	25264.73	29065.60	23796.27	22317.62
	Energy Use Per Capita	1569.63	1845.69	2111.24	2283.05	2612.08	2725.12	2309.00	2207.97
Iceland	GDP Per Capita	27218.25	30515.72	30265.97	32863.87	38003.67	44575.50	43063.56	35215.22
	Energy Use Per Capita	7120.33	7732.69	8252.10	8952.52	10748.25	14253.97	17781.02	10691.55
Ireland	GDP Per Capita	17449.07	19693.14	24622.75	34073.61	46779.91	51620.53	48934.86	34739.12
	Energy Use Per Capita	2369.07	2559.77	2835.76	3258.34	3614.95	3357.46	2895.32	2984.38
Korea, Rep.	GDP Per Capita	4523.80	6930.51	10042.62	13105.08	16517.74	20041.30	23285.03	13492.30
	Energy Use Per Capita	1130.04	1595.48	2556.18	3495.50	4156.50	4532.31	5227.77	3241.97
Netherlands	GDP Per Capita	29778.32	32456.23	36405.18	41296.86	46607.58	50261.10	50394.17	41028.49
	Energy Use Per Capita	4137.40	4306.87	4504.64	4840.76	4911.61	4878.72	4646.80	4603.83

Table 2.1: Continued

Country	GDP Per Capita and Energy Use Per Capita	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14	1980-14
New Zealand	GDP Per Capita	23683.59	25640.12	24948.03	27747.96	31305.39	34099.23	34930.39	28907.82
	Energy Use Per Capita	3015.41	3564.34	3889.95	4182.90	4322.49	4070.58	4336.03	3911.67
Oman	GDP Per Capita	11893.62	14928.81	15531.42	17373.43	18565.24	18972.81	17765.85	16433.03
	Energy Use Per Capita	1105.55	1376.10	2773.00	2970.62	3487.43	5689.17	6378.24	3397.16
Saudi Arabia	GDP Per Capita	22099.92	14880.09	15573.64	15004.34	14899.39	17525.10	20271.29	17179.11
	Energy Use Per Capita	3860.00	3714.83	4200.27	4507.66	4769.25	5521.49	6571.77	4735.04
Trinidad and Tobago	GDP Per Capita	9138.13	6989.18	6543.12	7901.22	11323.02	15969.29	16763.57	10661.07
	Energy Use Per Capita	3745.05	4396.62	5018.38	5954.07	9408.53	13830.71	14646.39	8142.82
United Kingdom	GDP Per Capita	22385.53	26455.28	28781.28	32263.32	36919.14	39832.15	39449.72	32298.06
	Energy Use Per Capita	3416.92	3607.42	3687.09	3788.14	3736.53	3446.88	3002.03	3526.43
United States	GDP Per Capita	29392.83	34106.70	36773.10	41077.37	45890.05	49050.16	49459.85	40821.44
	Energy Use Per Capita	7498.26	7638.91	7689.59	7832.75	7880.78	7569.44	6980.37	7584.30
Uruguay	GDP Per Capita	6636.36	6562.57	7493.31	8842.65	8416.12	10063.67	12937.82	8707.50
	Energy Use Per Capita	783.66	721.50	780.34	885.92	826.08	1052.03	1322.03	910.22

- GDP per capita is measured in US dollar constant 2010 prices
- Energy use per capita is measured in kg of oil equivalent

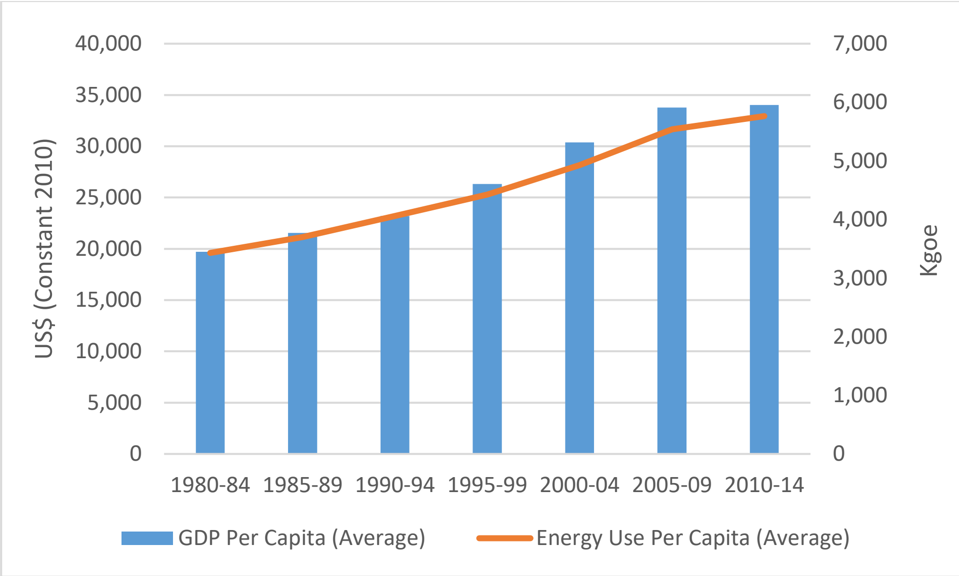

Figure 2.1: Trends of Real GDP Per Capita and Energy Consumption Per Capita for Developed Countries

Table 2.2: GDP Per Capita (Real) and Energy Consumption Per Capita in Developing Countries

Country	GDP Per Capita and Energy Use Per Capita	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14	1980-14
Algeria	GDP Per Capita	3735.33	3722.01	3360.26	3331.41	3792.27	4338.31	4560.97	3834.37
	Energy Use Per Capita	709.14	829.26	862.09	825.24	904.68	1058.84	1206.27	913.65
Argentina	GDP Per Capita	7376.18	6701.76	7077.86	8230.99	7597.29	9403.79	10527.31	8130.74
	Energy Use Per Capita	1440.47	1441.11	1466.31	1610.15	1606.61	1833.82	1945.70	1620.60
Benin	GDP Per Capita	612.72	616.83	614.60	652.02	715.78	747.17	785.80	677.84
	Energy Use Per Capita	356.48	349.38	324.41	341.14	307.06	362.51	403.33	349.19
Brazil	GDP Per Capita	7689.16	8257.53	8019.22	8619.10	8939.85	10140.11	11646.62	9044.51
	Energy Use Per Capita	896.71	981.64	945.92	1047.77	1091.25	1217.07	1410.20	1084.37
Cameroon	GDP Per Capita	1451.33	1578.29	1114.47	1056.42	1151.02	1180.94	1229.99	1251.78
	Energy Use Per Capita	434.98	435.04	415.85	410.77	410.42	363.84	336.47	401.05
Congo, Dem. Rep.	GDP Per Capita	789.83	774.70	515.99	343.46	269.99	298.86	344.78	476.80
	Energy Use Per Capita	329.16	334.46	322.71	307.65	298.72	306.33	355.54	322.08
Congo, Rep.	GDP Per Capita	2871.61	2868.51	2621.70	2377.44	2392.38	2523.32	2800.14	2636.44
	Energy Use Per Capita	350.80	338.04	306.58	252.37	248.80	333.57	504.27	333.49
Cote d'Ivoire	GDP Per Capita	1849.71	1575.92	1351.69	1375.45	1270.81	1213.82	1255.76	1413.31
	Energy Use Per Capita	391.58	375.08	362.84	384.97	416.39	511.78	575.45	431.16
Ecuador	GDP Per Capita	3689.87	3678.16	3781.75	3854.15	3862.90	4461.34	5098.32	4060.93
	Energy Use Per Capita	632.07	603.32	611.70	697.58	696.77	713.48	829.06	683.43
Egypt, Arab Rep.	GDP Per Capita	1288.83	1467.47	1576.44	1768.18	1999.80	2328.90	2597.75	1861.05
	Energy Use Per Capita	416.15	525.08	550.28	589.98	645.60	859.24	858.09	634.92
Gabon	GDP Per Capita	12220.20	10836.20	11098.02	11427.44	9888.83	9046.00	9188.64	10529.33
	Energy Use Per Capita	1994.15	1516.87	1255.74	1245.86	1502.05	2509.78	2638.68	1809.02

Table 2.2: Continued

Country	GDP Per Capita and Energy Use Per Capita	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14	1980-14
Honduras	GDP Per Capita	1566.36	1544.95	1579.80	1612.21	1658.95	1902.14	2001.69	1695.16
	Energy Use Per Capita	497.82	477.08	476.04	497.70	498.77	568.18	594.75	515.76
India	GDP Per Capita	412.91	477.96	553.88	679.19	820.47	1108.10	1486.81	791.33
	Energy Use Per Capita	297.92	328.08	362.56	398.66	425.08	490.89	597.46	414.38
Indonesia	GDP Per Capita	1305.59	1492.41	1886.34	2233.38	2268.37	2747.80	3408.93	2191.83
	Energy Use Per Capita	387.08	432.73	582.22	677.68	755.88	802.74	860.96	642.76
Kenya	GDP Per Capita	872.84	887.46	884.73	858.01	833.01	906.82	1021.41	894.90
	Energy Use Per Capita	442.62	459.88	448.12	443.88	437.60	451.44	478.49	451.72
Malaysia	GDP Per Capita	3598.22	3914.48	5172.34	6599.20	7224.17	8560.55	9707.49	6396.63
	Energy Use Per Capita	934.64	1080.05	1494.47	1875.35	2223.62	2640.41	2774.98	1860.50
Mauritius	GDP Per Capita	2415.45	3127.47	4008.25	4831.39	5813.40	7046.49	8581.25	5117.67
	Energy Use Per Capita	430.84	502.22	651.61	727.53	888.01	997.29	1076.18	753.38
Mexico	GDP Per Capita	7535.41	7040.65	7557.48	7899.36	8527.97	9012.00	9292.07	8123.56
	Energy Use Per Capita	1398.86	1379.53	1471.57	1446.84	1520.78	1613.46	1539.81	1481.55
Morocco	GDP Per Capita	1369.57	1601.86	1780.33	1899.37	2173.70	2614.76	3034.76	2067.76
	Energy Use Per Capita	270.42	284.13	327.97	363.23	409.06	498.92	550.86	386.37
Nepal	GDP Per Capita	296.68	333.38	376.17	422.87	473.12	532.60	629.20	437.72
	Energy Use Per Capita	306.63	306.18	310.00	318.48	346.15	359.60	388.81	333.69
Pakistan	GDP Per Capita	596.24	691.67	775.74	825.18	870.63	1022.48	1068.46	835.77
	Energy Use Per Capita	333.95	370.88	411.46	447.80	466.55	506.90	490.03	432.51
Senegal	GDP Per Capita	897.01	881.59	823.41	826.66	899.61	979.73	1004.40	901.77
	Energy Use Per Capita	263.52	238.93	216.16	221.40	248.17	259.91	286.06	247.74

Table 2.2: Continued

Country	GDP Per Capita and Energy Use Per Capita	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14	1980-14
South Africa	GDP Per Capita	6540.46	6162.77	5716.38	5742.72	6204.01	7174.31	7529.91	6438.65
	Energy Use Per Capita	2486.70	2666.35	2420.16	2497.04	2514.19	2790.14	2700.32	2582.13
Thailand	GDP Per Capita	1510.00	1920.23	2888.00	3469.10	3778.55	4630.25	5351.42	3363.94
	Energy Use Per Capita	447.78	549.98	842.89	1111.52	1292.90	1574.30	1863.53	1097.56
Togo	GDP Per Capita	602.00	553.34	488.30	528.17	490.94	480.13	508.16	521.58
	Energy Use Per Capita	318.32	320.19	335.51	396.24	419.88	428.06	463.08	383.04
Tunisia	GDP Per Capita	2056.51	2129.83	2337.29	2665.56	3166.86	3798.82	4148.87	2900.53
	Energy Use Per Capita	525.16	551.05	611.92	682.25	797.16	867.04	941.64	710.89

- GDP per capita is measured in US dollar constant 2010 prices
- Energy use per capita is measured in kg of oil equivalent

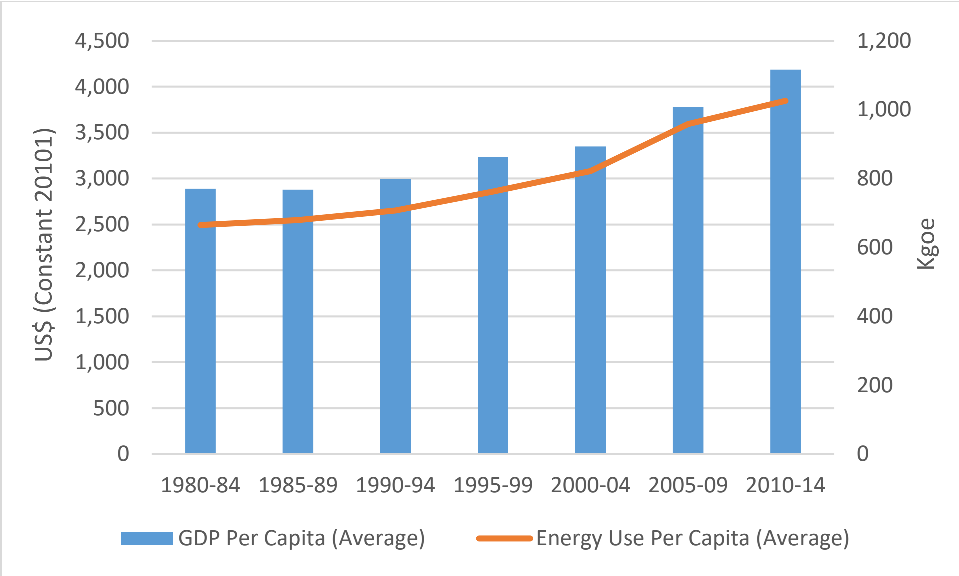

Figure 2.2: Trends of Real GDP Per Capita and Energy Consumption Per Capita for Developing Countries

2.6.2. Results from Time Series Analysis

The results of time series data are reported and discussed in this section. The structural-break unit-root test results in appendix 2c show that the series of the variables in the study have differing order of integration. For example, the series of trade openness (OP) is stationary at level [I (0)] whereas all other variables are not stationary at level and integrated of order one [I (1)]. ARDL approach for all the countries is, therefore, justified. For appropriate lag selection in respective ARDL model, Schwarz Bayesian Criterion (SBC) and Akaike Information Criterion (AIC) are used. The selected lag lengths based on SBC and AIC criteria for each country are provided in Table 2.3 and 2.4. The reliability and efficiency of the model and coefficients depend upon diagnostic tests. Therefore, the results of diagnostics (i.e. Adj R^2, LM test (Auto correlation) and Jarque-Bera Normality test) of ARDL model estimation are given in appendix 2d. The values of Adj R^2 ranges from 0.69 to 0.96 which shows that ARDL models explain high variation in the dependent variable in most of the countries. On the other hand, LM and normality tests reveals that errors have no serious econometric problems. Finally, the existence of long run relationship is tested by Bounds test. Moreover, the long run and short run relationship can also be confirmed through coefficient of error correction term. The results of Bound test and error correction term are reported in Table 2.3 and 2.4. It is important to note that for a stable error correction process, it is necessary that the error correction term lies between 0 and -2 (Rafindadi and Yosuf 2013).

The parameter estimates of ARDL models are presented in Tables 2.3 and 2.4 for the two sets of countries. Table 2.3 shows that out of the 18 developed countries, 14 show positive and statistically significant contribution of energy use to output in long run. The developed countries are dependent on energy because of high technology and capital-intensive industries and this implies positive relationship between energy use and output i.e. GDP (per capita)

(Apergis and Tang, 2013). The effect of energy use per capita on GDP per capita is relatively more pronounced in Austria, Finland, Greece, Iceland, Ireland, Oman, Trinidad. On the other hand, the effect of energy uses on GDP per capita in Australia, Chile and Saudi Arabia is found to be statistically insignificant. The results are in line with Menegaki (2011). But in case of Canada, the sign of coefficient (elasticity) of energy use is significantly negative and contrary to established relationship between energy use and GDP (per capita). The possible reason of the inverse sign in a developed country like Canada may be the energy conservation measures taken for sustainable development and transformation of new energy consumption to combat global warming (Xie et al., 2018).

Further, the results of other explanatory variables included in the study i.e. capital stock (K), financial development (FD), and trade openness (OP) are interpreted briefly. The findings reveal that the coefficient (elasticity) of capital per capita for majority of countries is positive and significant. The increase in the country's capital stock is a key determining factor of production i.e. GDP. Increase in capital stock enhances the productive capacity and, hence, raises the output level (Badawi, 2003; Michaelides et al., 2005). The other determining factor of GDP per capita, in this analysis, is financial development measured by domestic credit to private sector. The long-run estimated coefficients (elasticity) of financial development (FD) are positive and statistically significant for Australia, Austria, Greece, Iceland, Netherland, Oman, and United States. The financial development boosts investment and economic activities by reducing the financial constraints that lead to increase the output level in the economy (Fry, 1998, Ghura and Goodwin, 2000). However, for five developed countries the impact of financial development on GDP per capita is also found to be positive but statistically insignificant. In case of remaining six countries the effect of financial development is negative but statistically insignificant except for Trinidad where it is marginally significant.

Next, the empirical results of trade openness (OP) demonstrate positive and statistically significant effect on GDP per capita for the eight countries in the list. The justification of positive sign of OP is that liberalization reduces the trade barriers and creates an advantage to the export-oriented sector and results in improving the current account balance and investment incentives which lead to increase in output (Asante, 2000; Naa-Idar *et al.*, 2012). On the other hand, in case of only two countries namely Greece and Oman the impact of trade openness on GDP per capita is negative and significant. The possible reason of this inverse relationship may be due to trade policy practices impeding and adversely affecting the economic activities i.e. investment through high cost of imports (Busari and Omoke, 2008). The relationship between trade openness and GDP per capita is found to be insignificant for remaining half of the countries in the sample of developed countries.

Table 2.3: Estimates of ARDL Models from Time-Series Data for Developed Countries

Country	Long Run					Short Run					Lag length	Bounds test
	Intercept	LE	LK	LFD	LOP	LE	LK	LFD	LOP	ECM		
Australia	7.76*	-0.015	0.151	0.189*	0.301***	-0.002	0.177*	0.031**	0.049***	-0.162*	1,0,1,0,0	1.55
Austria	2.14*	0.588*	0.235*	0.146*	0.149*	0.094***	0.115**	-0.045	0.165*	-0.764*	3,3,1,3,3	11.81*
Canada	13.15*	-0.807**	0.478*	0.060	0.487*	0.179**	0.184*	0.011	0.087*	-0.179*	1,1,1,0,0	4.75**
Chile	2.64*	0.552	0.477	-0.098	0.248	0.069	0.170*	-0.012	0.031	-0.124	1,0,1,0,0	5.25*
Cyprus	3.30*	0.593**	0.217***	0.022	0.199	0.017	0.120*	0.095***	0.047	-0.31**	2,4,2,4,3	7.00*
Finland	0.26	0.996*	0.287*	-0.078	0.325*	0.136*	0.246*	-0.011	0.044**	-0.136*	1,0,1,0,0	5.11*
Greece	5.86*	0.267*	0.021	0.198*	-0.115**	0.030	0.159*	0.132*	-0.092**	-0.794*	4,4,3,2,0	6.29*
Iceland	6.30*	0.324*	0.003	0.109*	-0.100	0.205**	0.079**	0.069*	-0.215**	-0.632*	2,0,1,0,1	2.97*
Ireland	4.99*	0.201*	0.025	-0.084	0.722*	0.334*	0.196*	-0.014	0.120*	-0.166*	3,0,3,0,0	5.94*
Korea, Rep	3.56*	0.299**	0.353***	0.088	0.062	0.052	0.216*	0.015	0.011	-0.2***	1,0,2,0,0	7.83*
Netherland	2.22	0.626**	0.100	0.209*	0.204**	0.040	0.229*	0.015	0.136*	-0.341*	4,3,1,2,3	9.42*
New Zealand	-1.46	0.543***	0.769*	0.038	-0.311	-0.068	0.200*	0.052*	-0.053**	-0.260*	3,3,0,4,4	0.50
Oman	6.98*	0.075*	0.030***	0.217*	-0.269*	0.025	0.005	0.231*	-0.052	-1.316*	3,1,4,3,4	10.72*
Saudi Arabia	6.53*	0.134	0.116	0.142	0.273***	0.052	0.045	0.032	0.106**	-0.388*	1,0,0,2,0	20.57*
Trinidad	4.56*	0.762*	0.538*	-0.725**	0.564	0.147*	0.033	-0.140**	0.108**	-0.192*	1,0,1,0,0	17.68*
U.K	5.72*	0.451**	0.376*	-0.023	-0.089	0.037	0.248*	-0.011	-0.006	-0.485*	1,0,2,0,0	3.37
United states	6.02*	0.060***	0.077***	0.323*	0.102*	0.113**	0.188*	0.105*	0.019	-0.766*	4,3,4,4,3	9.23*
Uruguay	3.41*	0.451**	0.376*	-0.023	-0.088	0.036	0.248*	-0.011	-0.005	-0.484*	1,1,1,0,4	5.24*

Note that *, ** and *** represents significance at 1%, 5% and 10% level of significance respectively.

The results of 26 developing countries are reported in Table 2.4. The findings reveal that in case of 16 countries, increase in per capita energy use significantly enhances real GDP per capita and thus supports energy-led-growth hypothesis (Lee, 2005; Narayan and Smyth, 2008; Apergis and Tang, 2013). Notably, the relationship is found to be robust for the ten countries namely Brazil, Congo Rep, Honduras, India, Indonesia, Kenya, Malaysia, Pakistan, Senegal, Tunisia. However, the effect of per capita energy use on per capita GDP is found to be statistically insignificant for Benin, Congo Dem R, Cote d'lovior, Gabon, Egypt, Mexico and South Africa. The findings do not support the view that energy consumption per capita contributes to increase in real GDP per capita. More precisely unidirectional causality from (per capita) energy use to GDP (Huang et al., 2008; Belloumi, 2009). Surprisingly, in three countries the link between energy use per capita and GDP per capita is found to be significant but negative. The probable reasons of inverse relationship may be the energy waste, poor energy consumption technology, poor energy efficiency, and high economic cost of adoption the new energy consumption substituting traditional energy based on fossil fuel (Xie et al., 2018; Liu, 2020).

It is pertinent to note that country-wise variation in results pertaining to relationship between energy use per capita and GDP per capita may likely occur due to energy use with stage of economic development (Masih and Masih 1997; Ozturk, 2010; Apergis and Tang, 2013).

Likewise, the category of developed countries, the brief interpretation of findings on other explanatory variables included in the model i.e. capital stock (K), financial development (FD), and trade openness (OP) for the set of developing countries is provided as follows. The effect of capital stock on real output (GDP per capita) is consistent with theory and observed to be positive and significant for the two-third representative developing countries. Pertinently, accumulation or growth of capital raises productivity in the economy and creates economies of scale which plays an integral role in accelerating GDP (Ghani and Din, 2006; Ajaz and Nazima, 2012). The capital stock is observed to be causing real GDP per capita insignificantly in Algeria, Cameron, Egypt, Gabon, Mexico, Morocco, Nepal, South Africa, and Thailand. Further, the role of financial development in real GDP per capita is observed to be positive and statistically significant for Cameron, Congo Dem R, Cote d'lovior, Ecuador, Honduras, Kenya, Mauritius, Mexico, Morocco, Nepal, Pakistan, South Africa, Thailand. The results are in line with the findings of other related studies (Ajidi 2013; Akanbi, 2016). The possible reason of this direct relationship may be due to heavy reliance of private (domestic) sector on financial intermediaries i.e. banking because of limited loanable funds in the developing countries which are necessary to encourage the economic activates/stimulate or boost the output (Ajidi, 2013). On the other hand, for the rest of other half set of the influence of financial development is insignificant. It is important to note that in the developing countries, financial sector is underdeveloped and faces structural and institutional issues. Moreover, insignificant effect of domestic credit (financial development) may be due to providing credit to sick units for repaying loans (i.e. putting good money after bad money) which may discourage productive economic/investment activities and hinder economic progress (Ghani and Din, 2006).

In the end, trade openness is positively and significantly influencing real GDP per capita in Algeria, Cameron, Ecuador, Kenya, Pakistan, South Africa. Importantly, more open economies attract more capital and financial flows than protected economies and provide access to the latest technology which support resource lacking economies to uplift the output on sustained basis (Hamuda *et al*., 2013). In addition to that the trade reforms (i.e. trade openness) stimulate the investment activates thereby overall output (GDP) (Aysan *et al*., 2006). However, trade openness exerts negative and significant effect on real GDP per capita for a limited number of countries, namely Congo Dem R, Congo Rep, Mauritius, and Senegal. The possible reasons may include shifting of demand towards foreign goods and services, chronic current account deficits, heavy reliance on imported machinery and equipment, exchange rate misalignment/uncertainty, and low competitiveness. Moreover, for thirteen countries, the relationship between trade openness and real GDP per capita is found to be statistically insignificant. It implies that the trade is not the major catalyst to stimulate output in these countries.

Table 2.4: Estimates of ARDL Models from Time-Series Data for Developing Countries

Country	Long Run					Short Run					Lag order	Bounds test
	Intercept	LE	LK	LFD	LOP	LE	LK	LFD	LOP	ECM		
Algeria	5.29*	0.372***	0.055	0.032	0.280***	-0.050	-0.002	0.016	0.047	-0.442**	3,3,3,3,3	1.55
Argentina	1.23	0.757**	0.351**	-0.039	0.030	-0.178	0.385*	0.006	-0.043**	-0.256**	2,3,1,4,1	1.35
Benin	6.11*	-0.185	0.303*	0.049	0.313	-0.055	0.05***	0.015	0.092*	0.295**	1,0,3,0,0	3.57***
Brazil	2.70*	0.796*	0.123*	-0.002	0.035	0.730*	0.076*	-0.001	-0.060*	-0.615*	1,1,0,0,1	4.94**
Cameroon	5.34*	0.169**	0.149	0.075*	0.537**	0.083**	0.104***	0.050***	0.136*	-0.491*	2,0,4,3,4	4.75**
Congo Dem R	0.06	0.747	0.197***	0.226**	-0.550**	0.049	0.013	0.015***	0.041**	-0.066*	2,0,0,0,1	1.38
Congo Rep	5.77*	0.237*	0.110*	0.008	-0.06***	0.236*	-0.028	0.008	-0.071	-0.996*	3,0,2,0,4	4.18**
Cote d’lovior	6.35	-0.099	0.188*	0.092*	0.017	-0.037	0.072*	0.087*	0.006	-0.38*	1,0,0,1,0	1.94
Ecuador	7.13*	-0.398**	0.396*	0.168*	0.071***	-0.177	0.190*	0.052	-0.036	-1.415*	4,4,4,4,3	4.22**
Egypt	-0.33	1.270	0.055	0.325	2.280	0.021	0.046**	0.082*	0.037*	-0.016	1,0,3,1,0	4.81**
Gabon	6.00*	-0.069	0.576	-0.122	-0.562	-0.024	0.208*	-0.042	-0.012	-0.34***	2,0,3,0,2	2.34
Honduras	3.10*	0.353*	0.097*	0.244*	0.012	0.225**	0.062*	0.104**	0.008	-0.637*	1,0,0,3,0	3.98***
India	-2.78*	1.392*	0.163**	0.037	0.004	0.390	0.139*	0.148**	0.004	-0.856*	1,4,0,3,0	3.67***
Indonesia	1.23*	0.605*	0.380*	0.035	0.013	-0.086	0.193*	0.018	-0.068**	-0.509*	2,4,0,0,1	4.31**
Kenya	0.203	0.817*	0.166*	0.159*	0.172*	0.117	0.113*	0.014	0.004	-0.680*	4,1,0,1,2	4.85**
Malaysia	1.54*	0.723*	0.176***	0.069	-0.073	0.149**	0.185*	0.014	-0.015	-0.206**	1,01,0,0	4.33**
Mauritius	5.38*	-0.327**	0.228*	0.481*	-0.306*	0.261*	0.138*	0.033	-0.186*	-0.608*	2,3,0,3,0	0.90
Mexico	3.89	0.201	0.299	0.199***	0.009	0.036	0.236*	0.035*	-0.077**	-0.17***	1,0,1,0,1	1.78
Morocco	3.21*	0.374**	0.168	0.136***	0.001	0.141	0.178**	0.052	-0.166**	-0.378**	2,4,3,0,1	3.99**
Nepal	2.14	0.443***	0.104	0.214*	-0.094	0.111	0.026	0.054*	0.031	-0.250*	4,0,0,0,1	7.29*

Table 2.4: continued

Country	Long Run					Short Run					Lag order	Bounds test
	Intercept	LE	LK	LFD	LOP	LE	LK	LFD	LOP	ECM		
Pakistan	-0.94	0.421*	0.250*	0.099*	0.122**	0.293**	0.229*	0.026	0.013	-0.916*	3,1,1,4,4	2.74
Senegal	3.69*	0.386*	0.224*	-0.056	-0.362*	0.067	0.098*	-0.025	-0.159*	-0.441*	1,3,0,0,0	2.80
South Africa	5.14*	0.288	0.070	0.131*	0.442*	0.096	0.084*	0.044*	0.119*	-0.335*	1,01,0,3	3.42
Thailand	3.25*	0.490**	0.076	0.123***	0.148	0.149	0.152*	0.122**	-0.050	-0.304**	1,0,1,1,1	3.57***
Togo	8.26*	-0.433*	0.146**	-0.014	0.115***	0.029	0.097*	-0.009	0.261*	-0.669*	4,1,0,0,2	4.89**
Tunisia	-0.67*	1.109*	0.169**	0.041	-0.086	0.132	0.207*	-0.083**	-0.038	-0.446*	2,2,2,2,0	9.00*

Note that *, ** and *** represents significance at 1%, 5% and 10% level of significance respectively.

To move further, we need to consolidate our results through panel estimation. However, the above results mean that substantial gain in information is possible if panel models are estimated separately for the sets of developed and developing countries.

2.6.3. Results from Panel Estimation

Starting with the issue of cross sectional dependence, the results given in the appendix 2e (for the whole period) strongly reject the null hypothesis of cross-sectional independence among developed as well as among developing countries at the 1% level of significance for all the variables. This result exposes the presence of shared dynamics in all the variables across countries within the sets of developing and developed countries.

The results of CIPS test reported in appendix 2f suggest that the variables under consideration have mixed orders of integration. Gross capital formation is integrated of order zero, i.e., I (0) in developing countries group whereas trade openness is I (0) in developed countries group. Other variables are integrated of order one, i.e., I (1) in the two groups of countries. Since the variables under consideration have mixed orders of integration, Panel ARDL approach appears appropriate here. Further, the results of Hausman test reported in appendix 2g suggest that MG estimation in developing countries and PMG estimation in developed countries should be preferred to PMG estimation and MG estimation respectively.

Results of MG estimation for developing countries and PMG estimation for developed countries presented in Table 2.5 show statistically significant negative value of the estimated error-correction coefficient, confirming the existence of long-run equilibrium relationship among the variables within the groups of developed as well as developing countries. The coefficient of energy consumption per capita is highly significant and positive in the long-run relationships in developed as well as developing countries. This finding implies that energy consumption per capita has a stimulating effect on the real GDP per capita for both groups of countries. This inference is also supported by Lee (2005), Mahadevan & Asafu-djaye (2007), Narayan & Smyth (2008) and Apergis & Payne (2009). Moreover, the long-run coefficient of energy consumption per capita in developed countries is higher than that in the developing countries, that is, the contribution of energy consumption to real GDP per capita is higher in developed countries than in developing countries. It follows that the cost of conserving energy in terms of lost output has been relatively higher in developed countries. In spite of this observation, energy intensity has declined in many developed countries (Mahmood & Eatzaz 2018). This means that better environment is highly valued in developed countries. On average, citizens in developed world have gained sufficient consumption and they are now more inclined to improve their living standards on qualitative grounds by spending more on the luxury of better environment.

Table 2.5: Results of MG and PMG Model (Dependent Variable is log of GDP Per-Capita (LY))

	Mean Group Estimates		Pooled Mean Group Estimates	
Variables	**Developing Countries**		**Developed Countries**	
	Short run	**Long run**	**Short run**	**Long run**
ECM	-0.254* (0.000)		-0.095* (0.000)	
Log of Energy (LE)	0.0332 (0.319)	0.318** (0.022)	0.069* (0.006)	0.512* (0.000)
Log of Openness (LOP)	-0.0245*** (0.076)	0.183** (0.017)	-0.013 (0.473)	0.357* (0.000)
Log of Capital (LK)	0.066* (0.000)	0.229* (0.000)	0.129* (0.006)	0.370* (0.000)
Log of Financial Development (LFD)	0.017*** (0.064)	0.090** (0.024)	0.026** (0.025)	-0.031 (0.225)
Constant (C)	0.814* (0.000)		0.293* (0.000)	

Note that, *, ** and *** represents significance at 1%, 5% and 10% level of significance respectively, P-values are reported in square brackets.

As expected, the per capita capital stock has significant and positive impact on GDP per capita in short run as well as long- run. The estimated long-run coefficients of capital are consistent with the generally held presumption that the share of capital in output is about 30% in developing countries and a bit higher in developed counties. The respective coefficients are much smaller in short run.

The role of trade is not statistically significant in short-run in developed countries, but in developing countries trade hurts real GDP per capita in short run. However, in the long-run this effect is significantly positive in both cases of developing and developed countries. The reason is that developed countries are well equipped with resources of capital, entrepreneurial ability, advance technology and skilled labor and their terms of trade remain favorable. These countries also provide economic incentives and flourish environment of large scale production for earning the returns of economies of scale. Eventually, all these factors contribute to the enhancement of real GDP per capita through trade.

Financial development (real domestic credit to private sector) has statistically significant positive long-run effect on real GDP per capita in developing countries but insignificant in case of developed countries. It means financial development does not contribute to real GDP per capita remarkably especially after the 1980 due to attaining the potential level of output and widening income inequity gap because of financial liberalization.

2.7. Summary and Conclusions

This paper has attempted to empirically analyze the relationship between energy consumption per capita and real GDP per capita with a focus on the possible differences in the relationship across developed and developing countries. The relationship is examined with the consideration of three complementary explanatory variables i.e. real domestic credit to private sector as a proxy for financial development, real gross capital formation and trade openness. The study employs country wise time-series as well as panel estimation for 26 developing and 18 developed countries over the period 1980 to

2014. Based on preliminary diagnostic tests, all the estimation is carried out in ARDL framework.

The results of time series analysis reveals that the parameter estimates of ARDL models in case of developed countries, 14 show positive and statistically significant contribution of energy use to output in long run. On the other hand, for the developing countries, increase in per capita energy use significantly enhances GDP per capita is in sixteen countries. The empirical findings validate the energy –led growth hypothesis at large and accentuate the role of energy use in economic progress.

The findings from panel analysis show that energy consumption contributes to GDP per capita in both the developed and developing countries in the short and long run. The evidence also indicates that the long-run contribution of energy use per capita to GDP per capita is higher in both categories of the countries.

Additionally, the study also signifies the role of capital stock in boosting an economic activity. Moreover, the trade is more conducive for economic progress in developed countries than developing one. However, the role of financial development is crucial in increasing the output level in case of developing countries.

There are two important implications of the above results. First, the cost of energy conservation in terms of lost output growth is higher in developed countries. Therefore, their efforts to reduce energy intensity during the past few decades may be regarded as a significant contribution to global environment. Second, since the contribution of energy use to increase per capita income is relatively less in developing countries; these countries could also be encouraged to conserve energy through technology transfer and other incentives such as energy-use sensitive trade policies in developed countries. That is, the products with lower energy content may be treated favorably in trade policies of developed countries

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Appendices

Appendix 2a: Cross-Sectional Dependence

Pesaran (2004) allowed cross-sectional dependence for panel unit root testing. The Cross-Sectional (CD) statistic is based on pair-wise correlation coefficients across all panels and is given by:

$$\mathrm{CD} = \sqrt{\frac{2\mathrm{T}}{\mathrm{N}(\mathrm{N}-1)}}\left(\sum_{\mathrm{i}=1}^{\mathrm{N}-1}\sum_{\mathrm{j}=\mathrm{i}+1}^{\mathrm{N}}\widehat{\rho_{\mathrm{ij}}}\right) \tag{2.10}$$

where N, T and $\widehat{\rho_{ij}}$ are respectively the number of cross-sectional units (countries in our case), number of periods and sample correlation coefficient between counties i and j. CD is follows Chi-square distribution. Rejection of the null hypothesis that correlation coefficient across all pairs are equal to zero would imply presence of cross-sectional dependence.

Appendix 2b: Panel Co-integration

Westerlund (2007) developed the panel co-integration test allowing for cross sectional dependence. However, Westerlund panel co-integration test requires that the order of integration for all the variables under consideration should be equal to one. Whereas such condition is not required in Mean Group (MG) and Pooled Mean Group (PMG) estimators (panel ARDL models). The existence and strength of relationship among variables in the long run are ensured by PMG and MG estimators. These estimators of dynamic panels for large number of periods and large number of cross-sectional units were proposed by Pesaran and Smith (1995). The proposed ARDL model can be derived from the following econometric model:

$$\mathrm{L}\,(\mathrm{Y}_{\mathrm{it}}) = \alpha_{\mathrm{i}} + \beta_{\mathrm{i}}\mathrm{L}\,(\mathrm{Y}_{\mathrm{it}-1}) + \gamma_{\mathrm{i}}\mathrm{L}\,(\mathrm{X}_{\mathrm{it}}) + \epsilon_{\mathrm{it}} \tag{2.11}$$

long-run parameters are $\delta_{\mathrm{i}} = \frac{\gamma_{\mathrm{i}}}{1-\beta_{\mathrm{i}}}$.

MG estimators proposed by Pesaran & Smith (1995) and PMG estimators developed by Pesaran et al. (1999) are employed for the analysis of dynamic panel data. MG model is as follows:

$$\Delta L\,(Y_{it}) = \theta_i\big(L\,(Y_{i,t-1}) - \delta_i L\,(X_{i,t-1})\big) + \sum_{j=1}^{p-1} \rho_y^i \Delta L\,(Y_{i,t-j}) + \sum_{j=0}^{q-1} \gamma_y^i \Delta L\,(X_{i,t-j}) + \mu_i + \epsilon_{it} \tag{2.12}$$

Here, δ_i represents long-run parameters, while ρ_y^i, γ_y^i and θ_i and are short-run parameters. In particular θ_i are the error correction parameters that measure the proportion of past error which is corrected with a lag of one period. The restriction in PMG estimation is that the elements of δ are common across the countries so that the above equation modifies as:

$$\Delta L\,(Y_{it}) = \theta_i\big(L\,(Y_{i,t-1}) - \delta L\,(X_{i,t-1})\big) + \sum_{j=1}^{p-1} \rho_y^i \Delta L\,(Y_{i,t-j}) + \sum_{j=0}^{q-1} \gamma_y^i \Delta L\,(X_{i,t-j}) + \mu_i + \epsilon_{it} \tag{2.13}$$

In this model long-run slope coefficient is restricted to be common across all countries, while all the short-run are allowed to vary across countries. So, the PMG estimator will be inconsistent, if we fail to fulfill these conditions. While selecting between from MG and PMG estimators, we will apply the Hausman test to select the preferable estimator. The PMG estimator will be recommended on account of its efficiency if the Null Hypothesis is accepted.

Appendix 2c: Results of Break Point Unit Root Tests

Country	Break point unit root at level					Break point unit root at first difference				
	LY	LE	LK	LOP	LFD	LY	LE	LK	LOP	LFD
	Developing Countries									
Algeria	(0.00)	(0.00)	(0.81)	(0.17)	(0.00)	-	-	(0.00)	(0.01)	-
Argentina	(0.01)	(0.20)	(0.00)	(0.06)	(0.07)	-	(0.00)	-	(0.00)	(0.00)
Benin	(0.14)	(0.32)	(0.03)	(0.68)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	-
Brazil	(0.45)	(0.99)	(0.52)	(0.17)	(0.30)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)
Cameroon	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.06)
Congo, Dem, Rep.	(0.96)	(0.40)	(0.87)	(0.28)	(0.94)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)
Congo, Rep	(0.89)	(0.36)	(0.82)	(0.41)	(0.83)	(0.04)	(0.00)	(0.00)	(0.00)	(0.00)
Cote d'Ivoire	(0.68)	(0.00)	(0.71)	(0.13)	(0.99)	(0.03)	(0.00)	(0.00)	(0.00)	(0.00)
Ecuador	(0.98)	(0.62)	(0.92)	(0.12)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.07)
Egypt,	(0.00)	(0.06)	(0.09)	(0.00)	(0.15)	(0.01)	(0.00)	(0.01)	(0.01)	(0.00)
Gabon	(0.84)	(0.00)	(0.71)	(0.01)	(0.76)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Honduras	(0.28)	(0.22)	(0.00)	(0.65)	(0.98)	(0.02)	(0.00)	(0.02)	(0.00)	(0.00)
India	(0.98)	(0.77)	(0.01)	(0.03)	(0.09)	(0.09)	(0.00)	(0.00)	(0.00)	(0.00)
Indonesia	(0.00)	(0.99)	(0.00)	(0.35)	(0.00)	(0.00)	(0.00)	(0.00)	(0.04)	(0.00)
Kenya	(0.69)	(0.99)	(0.91)	(0.01)	(0.18)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)
Malaysia	(0.19)	(0.55)	(0.48)	(0.99)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)
Mauritius	(0.98)	(0.81)	(0.49)	(0.30)	(0.91)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Mexico	(0.40)	(0.40)	(0.08)	(0.27)	(0.20)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Morocco	(0.25)	(0.00)	(0.08)	(0.51)	(0.28)	(0.00)	(0.00)	(0.00)	(0.00)	0.07)
Nepal	(0.04)	(0.96)	(0.40)	(0.46)	(0.09)	(0.00)	(0.01)	(0.00)	(0.00)	0.00)
Pakistan	(0.24)	(0.96)	(0.28)	(0.00)	(0.71)	(0.00)	(0.00)	(0.00)	(0.00)	(0.04)
Senegal	(0.83)	(0.97)	(0.17)	(0.01)	(0.19)	(0.00)	(0.00)	(0.01)	(0.00)	(0.01)
South Africa	(0.96)	(0.21)	(0.16)	(0.90)	(0.36)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Thailand	(0.99)	(0.94)	(0.08)	(0.63)	(0.48)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Togo	(0.36)	(0.27)	(0.01)	(0.98)	(0.92)	(0.00)	(0.02)	(0.00)	(0.00)	(0.00)
Tunisia	(0.93)	(0.87)	(0.00)	(0.00)	(0.98)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Developed Countries										
Country	**Break point unit root at level**					**Break point unit root at first difference**				
	LY	**LE**	**LK**	**LOP**	**LFD**	**LY**	**LE**	**LK**	**LOP**	**LFD**
Australia	(0.78)	(0.86)	(0.30)	(0.27)	(0.10)	(0.00)	(0.84)	(0.00)	(0.00)	(0.02)
Austria	(0.99)	(0.50)	(0.43)	(0.55)	(0.99)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Canada	(0.13)	(0.97)	(0.00)	(0.11)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)
Chile	(0.42)	(0.83)	(0.16)	(0.08)	(0.01)	(0.00)	(0.53)	(0.03)	(0.00)	(0.00)
Cyprus	(0.99)	(0.99)	(0.00)	(0.00)	(0.69)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Finland	(0.83)	(0.59)	(0.57)	(0.21)	(0.00)	(0.83)	(0.00)	(0.02)	(0.00)	(0.57)
Greece	(0.51)	(0.99)	(0.05)	(0.45)	(0.22)	(0.00)	(0.00)	(0.00)	(0.00)	(0.04)
Iceland	(0.05)	(0.01)	(0.58)	(0.63)	(0.29)	(0.01)	(0.08)	(0.00)	(0.00)	(0.01)
Ireland	(0.113)	(0.97)	(0.32)	(0.22)	(0.94)	(0.00)	(0.00)	(0.44)	(0.00)	(0.20)
Korea, Rep	(0.99)	(0.99)	(0.00)	(0.81)	(0.73)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Netherland	(0.80)	(0.76)	(0.70)	(0.54)	(0.99)	(0.04)	(0.00)	(0.04)	(0.00)	(0.00)
New Zealand	(0.49)	(0.05)	(0.61)	(0.82)	(0.99)	(0.00)	(0.00)	(0.02)	(0.00)	(0.00)
Oman	(0.89)	(0.98)	(0.09)	(0.64)	(0.09)	(0.04)	(0.00)	(0.00)	(0.00)	(0.01)
Saudi Arabia	(0.55)	(0.10)	(0.37)	(0.39)	(0.12)	(0.00)	(0.00)	(0.04)	(0.00)	(0.00)
Trinidad and Tobago	(0.69)	(0.09)	(0.54)	(0.45)	(0.84)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)
United Kingdom	(0.78)	(0.99)	(0.02)	(0.09)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)
United States	(0.86)	(0.08)	(0.56)	(0.00)	(0.42)	(0.00)	(0.00)	(0.04)	(0.00)	(0.00)
Uruguay	(0.03)	(0.66)	(0.21)	(0.00)	(0.69)	(0.00)	(0.01)	(0.03)	(0.00)	(0.00)

Appendix 2d: Diagnostics of ARDL for Each Country

Country	Diagnostics			Country	Diagnostics		
	Adj R^2	LM Test	Normality		Adj R^2	LM Test	Normality
Developing Countries				**Developed Countries**			
Algeria	0.78	0.92	0.61	**Australia**	0.87	0.9	0.23
Argentina	0.81	0.72	0.78	**Austria**	0.91	0.44	0.51
Benin	0.9	0.6	0.18	**Canada**	0.93	0.5	0.09
Brazil	0.81	0.05	0.7.2	**Chile**	0.75	0.33	0.8
Cameroon	0.91	0.73	0.33	**Cyprus**	0.78	0.71	0.31
Congo Dem Rep	0.85	0.82	0.12	**Finland**	0.82	0.52	0.15
Congo Rep	0.9	0.9	0.32	**Greece**	0.92	0.05	0.46
Cote d'lovior	0.96	0.88	0.21	**Iceland**	0.88	0.75	0.23
Ecuador	0.92	0.17	0.83	**Ireland**	0.89	0.38	0.77
Egypt	0.73	0.72	0.51	**Korea, Rep**	0.72	0.01	0.42
Gabon	0.69	0.91	0.6	**Netherland**	0.81	0.36	0.13
Honduras	0.88	0.8	0.68	**New Zealand**	0.83	0.83	0.04
India	0.83	0.91	0.22	**Oman**	0.81	0.9	0.62
Indonesia	0.85	0.35	0.41	**Saudi Arabia**	0.73	0.81	0.79
Kenya	0.92	0.43	0.41	**Trinidad**	0.92	0.41	0.17
Malaysia	0.89	0.7	0.6	**U.K**	0.86	0.81	0.87
Mauritius	0.94	0.01	0.43	**United states**	0.93	0.73	0.92
Mexico	0.84	0.4	0.14	**Uruguay**	0.83	0.7	0.09
Morocco	0.85	0.76	0.66				

Appendix 2d: Continued

Country	Diagnostics		
	Adj R^2	LM Test	Normality
Developing Countries			
Nepal	0.79	0.11	0.81
Pakistan	0.86	0.62	0.43
Senegal	0.94	0.35	0.55
South Africa	0.87	0.3	0.5
Thailand	0.86	0.51	0.63
Togo	0.91	0.42	0.07
Tunisia	0.86	0.3	0.02

Appendix 2e: Cross Section Dependence (CD) Test Results

Variables	Developed Countries		Developing Countries	
	CD – Stats	P – value	CD – Stats	P - value
LY	58.34	0.00	43.27	0.00
LK	17.6	0.00	33.67	0.00
LE	43.12	0.00	62.18	0.00
LOP	37.60	0.00	46.8	0.00
LFD	57.25	0.00	19.57	0.00

Notes: Under the null hypothesis of cross-section independence CD ~ N(0,1)

Appendix 2f: CIPS Unit Root Test Results

Variables	Developed Countries					Developing Countries				
	Level		First Difference			Level		First Difference		
	Constant	Constant & Trend	Constant	Constant & Trend	Remarks	Constant	Constant & Trend	Constant	Constant & Trend	Remarks
LY	0.02	0.99	0.00	0.02	I(1)	0.99	0.99	0.00	0.01	I(1)
LK	0.98	0.98	0.00	0.00	I(1)	0.13	0.27	0.00	0.00	I(1)
LE	0.97	0.31	0.00	0.00	I(1)	0.99	0.45	0.04	0.02	I(1)
LOP	0.98	0.38	0.00	0.00	I(1)	0.09	0.09			I(0)
LFD	0.55	0.99	0.00	0.02	I(1)	0.85	0.99	0.00	0.01	I(1)

Appendix 2g: Hausman Test Results

Groups	Null hypothesis	Chi-stat	P-value	Conclusion
Developing Countries	PMG is consistent and efficient	37.24	0.000	MG is preferred
Developed Countries	PMG is consistent and efficient	2.25	0.690	PMG is preferred

Chapter 3
Energy Consumption Trend Across Countries: A Decomposition Analysis

Abstract

The present study analysis the trend of energy consumption over time by decomposing it in to three main factors (components): activity effect, structural effect, and efficiency effect across sixty countries. The study employs the logarithmic mean Divisia index method (LMDI), a widely-used index decomposition analysis (IDA) method, to analyze both aggregate and sectoral energy consumption patterns over the period 1990–2015. The study considers the change in activity, efficiency and structural effects as vital factors that cause changes in energy consumption across countries. Of these effects, activity effect is the major cause in escalating the energy consumption in selected the countries with the exception of two countries. In fifty-two countries, energy efficiency effect contributes to reduce the energy consumption, but its contribution is far less than the opposite effect of activity. In twenty-eight countries, structural effect boosts up the energy consumption whereas the activity effect is very strong as compared to the rest of the countries. Further, study finds that, in most of the countries, aggregate energy intensity is following the energy efficiency (sectoral energy intensities) pattern. The main contributing factor is energy efficiency in reducing the energy consumption. A lot of shifts in economic structure have so far affected energy intensity modestly. Yet, the countries where the structural changes scaled down the energy consumption have also very meager activity effect. Thus, there is considerable scope to reduce the energy consumption through the structural transformation. The results of a cross-sectional analysis of main determinants of energy efficiency shows that energy efficiency improves with higher education and labor productivity while a U –shape relationship is observed in case of capital labor ratio.

Key words*: Energy consumption, LMDI, Structural change, Energy Efficiency*

3.1. Introduction

The recent dynamics of environmental and energy consumption highlight energy related concerns as a key challenge in upcoming years. The fast growing population, increasing trends of GDP per-capita and energy use especially in developing countries put forward a huge pressure on existing energy and natural resources in the coming decades. This pressure will continue to keep the levels of anthropogenic emissions higher and higher until the world economy shifts from Non-renewable energy to renewable energy sources, access to use of efficient technologies, changing the composition of GDP through transition of industrial sector to services sectors or using energy mix in industrial sector or pay the price in the form of tax for a clean environment.

According to Nooji et al. (2003) energy consumption is driven by three main factors in an economy. These are: activity effect, structural effect, and efficiency effect. Activity effect explains how energy consumption change as output change in an economy, structural effect explains how energy consumption change when an economy shifts from agriculture sector to industrial sector or industrial sector to services sector where as efficiency effect means how energy consumption change when efficient technologies are used in various sectors of the economy. It is imperative to learn from the previous empirical studies and their contribution to the energy analysis for various countries in order to develop proper understanding about how the decomposition analysis of energy consumption[9] could help in designing energy efficiency policies. The study of Allcott & Greenstone (2012), and IEA (2012) demonstrated that the changes in structural composition[10] of the world economy as well as usage of efficient

[9] After the world oil crisis, decomposition analysis was used in the late 1970s for comprehending the mechanisms of changes in energy consumption.
[10] Structural composition means the division of economy into its sectors i.e. agriculture, industry and services.

technologies in various sectors of the economy have altered the ongoing trends of energy consumption globally. In the phase of change in structural decomposition, economy move from more energy-intensive sector to less energy-intensive sector and at the same time, the use of energy efficient technologies in all sectors of the economy is likely to increase and consequently, aggregate energy intensity declines in an economy. Reddy & Ray (2011) examine energy consumption in different Indian manufacturing sectors. The decomposition analysis explained an improvement in energy efficiency as shown by a negative intensity effect in the period 1991-2005. Most of the sectors including cement, textiles, pulp and paper industries, observed reduction in energy consumption. This reduction is explained in some cases on account of efficiency improvements and, in other cases, by a shift to more efficient energy sources. But, in some other sectors, like aluminum, energy consumption increased in the period despite improvements in efficiency, this was explained by movements towards more energy-intensive products.

Balezentis et al., (2011) analyzed the pattern of energy efficiency in Lithuania during the time period of 1995-2009. They analyzed the policy measures regarding the energy efficiency and studied the behavior of energy intensity under those measures before and during economic downturn period of 2006-2010. The study found that energy efficiency related measures played a significant role to reduce energy intensity before downturn period. However, they found that energy intensity worsened during economic downturn phase. Liu & Ang, (2007) reviewed a large number of studies wherein the decomposition method was used to explain the changes in energy consumption in different countries. They found that decreases in energy consumption of industrialized countries were explained largely by efficiency effect during the past three decades.

All these studies explained, how the energy consumption pattern change over the time due to change in efficiency effect. Understanding the factors that change the energy consumption pattern at aggregate and sectoral level and the interaction between the change in structural decomposition and sectoral efficiency has importance while making energy related polices.

The objective of present study is to perform decomposition analysis of aggregate energy consumption. First energy consumption is decomposed into three components, namely activity, structural and efficiency components that explain changes in energy consumption at country as well as aggregate levels considering a large sample of countries[11] having diverse economic, geographic and social structure. Since the activity and structural components are mostly driven by driven by market forces, at second stage of analysis efficiency component is focused to explore what factors determine its magnitude. The study uses data for the period 1990-2015. To decompose energy consumption in to its three components, the aggregation technique based on logarithmic mean Divisia index (LMDI) recommended by Ang (2005) and Ang et al. (2010) is used.

Mostly, previous studies decompose energy intensity into two components, i.e., structural and efficiency components. However, the present study decomposes energy consumption rather than energy intensity, into three components, i.e., activity, structural and efficiency components. Furthermore, the present study considers a large number of developing countries which are mostly ignored in the previous literature. In addition to that, an econometric analysis is employed to investigate the determinants of energy efficiency. Understanding the factors that play an important role in sectoral dynamics of energy consumption and the

[11] The countries are selected subject to the availability of data.

interaction of structural changes and improvement in sectoral efficiency will generate key policy recommendations for the design of effective energy policy regimes.

The paper is divided into six sections. Section 2 presents a review of the relevant literature. The analytical model, data and empirical methodology are explained in section 3, while Results and discussions are given in section 4. Section 5 carries out a cross-sectional analysis of the determinants of the component that mainly explain the variation in energy consumption over time. Finally, conclusion and relevant policy implication are outlined in section 6.

3.2. Literature Review

The energy related issues like energy efficiency and energy security were much studied empirically after the development of index decomposition analysis[12] since 1980s (Xu & Ang, 2013). However, in the post 1990 period marked by increased awareness of climate change impacts, the scope of IDA has been extended to encompass environmental dimensions of energy consumption, mainly CO2 emissions related to energy use (Xu & Ang, 2013; Ang & Zhang, 2000). Because of energy's high carbon content and growing consumption of energy at global level, the issue of climate change is an important to consider (Gonzalez et al., 2015). Thus, the index decomposition analysis was extended from its beginning usage to study the factors that change the trend of energy consumption and contribute in CO2 emission due to energy use which are helpful for policy makers to chalk out energy related policies.

During the resent years, a large body of empirical literature have examined the factors (components) of aggregate energy intensity and energy consumption, using the index

12 The IDA helps to study the changes in energy consumption due to change in three components: activity effect (changes in output), structural effect (changes in structural composition) and efficiency effect (changes in sectoral energy intensities) in an economy (Ang et al., 2010).

decomposition analysis (IDA) (Ang & Zhang, 2000; Ang, 2004; Liu & Ang, 2007; Song & Zheng, 2012; Wu, 2012). The real effect of energy efficient policies can be analyzed through decomposing the energy intensity into two main effects i.e. structural effect and efficiency effect (IEA, 2014). A large number of comprehensive studies have been carried out in different countries such as Lithuania (Balezentis et al., 2011), India (Reddy & Ray, 2011), China (Zhang, 2003; Ma et al., 2010; Zhao etal., 2010) and the United States (Hasanbeigi et al., 2012) using the IDA technique. Liu & Ang (2007) reviewed 69 studies over the period 1976–2005 and found that aggregate energy intensity has decreased in industrialized countries over the period of analysis, due to efficiency effect that was mainly attributed towards the usage of efficient technologies and energy mix; while this steady decrease was not observed for developing countries. They also found that the effect of changes in industrial structure on the aggregate energy intensity tends to be country-specific, depending on natural resources endowment and national policies. Ang (2004) decomposed the energy intensity change during 1973-2013, using LMDI.

Few studies examined the trend of energy consumption by using the decomposition analysis. Wang et al. (2014) decomposed energy consumption into five effects: investment, energy intensity, economic structure, energy mix, and labor effects over the period from 1991-2011 using a new LMDI method. Their findings indicated that energy intensity effect had a central role in reducing energy consumption.

González et al. (2014) investigated the determining factors responsible for changes in aggregate energy consumption in EU-27 countries during 2001-08 using LMDI. The study's findings showed that improvements in energy efficiency were insufficient to offset the increased activity effect on aggregate energy consumption in European economies.

Baležentis et al. (2011) analyzed overall energy intensity trends in Lithuania from 1995-2009 by decomposing energy consumption using LMDI into three components—production, structure, and intensity effects. They found that energy efficiency fell in period of economic downturn and suggested policy measures to improve energy intensity in Lithuania. Lin & Long (2014) used factor decomposition and the Engle–Granger co-integration techniques to explore drivers of non-renewable energy consumption in chemical industry of china and measured the saving potential of fossil fuel. The findings indicated that the factors could be divided into negative driving factors (energy intensity and structure).and positive driving factors (labor productivity and sector scale).

Zhang et al. (2011) examined the factors that contributed in energy consumption of transportation sector in china. They observed that the output effect is the main contributor in increasing the energy use, while the intensity effect reduces it. Ocaña et al. (2009) found that the energy consumption increases in Spain economy due to its structural shift from less energy intensive sector to more energy intensive sector like construction, transportation and residential sector during the period 1995-2006.

3.3. Analytical Model, Data and Methodology for Decomposition

3.3.1. Decomposition Model

The decomposition analysis derived from index number theory has been in widespread use to decompose energy consumption into its various components. The two main types of decomposition analyses include index decomposition analysis (IDA) and structural decomposition analysis (SDA). The IDA makes use of aggregated time series data that are published annually in official statistics[13] On the other hand, SDA employs disaggregated

[13]. https://www.iea.org/statistics. http://databank.worldbank.org/data/reports.aspx?source=WDI-Archives.

sectoral data from input-output tables which are usually not published on a regular yearly basis in official statistics (Hoekstra & van den Bergh, 2003; Ang 2004; Wang et al., 2017).

The IDA methods is widely used by researchers and can be grouped into two categories. One is based on the Laspeyres index whereas the other is based on Divisia index. Although a few earlier studies, such as Jenne & Cattell (1983) and Marlay (1984) used Laspeyres or Passche in decomposition, it was Boyd et al. (1988) who showed that decomposition analysis problem in the energy literature was similar to the index number problem in economics. In an earlier paper, Boyd et al. (1987) made use of the Divisia index for decomposition. Liu et al. (1992) enhanced Divisia index method for decomposing industrial energy consumption by altering the Divisia integral path problem into a parameter estimation problem and put forward the adaptive weighting Divisia method. On the basis of this method, Ang (1995) brought previous decomposition into a framework referred to as the general parametric Divisia method.

An extensive literature documented the usage of various index decomposition techniques[14]for the decomposition of energy consumption in to activity, structural and efficiency effects but the logarithmic mean Divisia index (LMDI) is considered to be an appropriate aggregate suitable for decomposition (Ang, 1995; Ang et al. 2003; Liu & Ang, 2007). In the 2000′s, the most popular IDA approach was based on the LMDI (Ang, 2015). Various new studies have employed LMDI to decompose the total energy consumption in its components – activity effect, structural effect, and efficiency effect in order to find components that can change the energy consumption trend over time. These studies include Baležentis et al. (2011), Zhang et al. (2011), Lin & Long (2014), González et al. (2014), Wang et al. (2014), Obadi et al. (2015) and Kim (2017). The factors influencing the energy consumption shifts

[14]See Ang (2004) for detail on various methods of decomposition

have been studied through decomposition analysis for which the multiplicative version of LMDI decomposition has been preferred (Ang & Liu, 2001).

LMDI is preferred in the literature[15] on account of four key cited reasons. Firstly, the Laspeyres index considers the ordinary percentage change which is the source of asymmetric of relative change bearing the characteristics of asymmetric and non-additive whereas the Divisia index considers the logarithmic change that uses the concept of the percentage change bearing the characteristics of symmetric and additive in nature (Tornqvist et al. 1985). Secondly, LMDI is preferred over the arithmetic mean Divisia index (AMDI) method because AMDI doesn't satisfy the properties of factor reversal test that leads to residual[16]. Thirdly, LMDI accepts even the decomposition of incomplete datasets (Xu et al., 2016). Lastly, LMDI has sound adaptability, reliable theoretical base as well as the capacity to establish perfect decompositions (Jung et al. 2012).

The LMDI method disaggregates changes in final energy consumption into changes in activity effect, structure effect and efficiency effect (Ang et al. 2010). The Activity effect studies changes in the level of output of the economy, under the premise that energy consumption increases as the level of output increases. This effect is assessed at the aggregate level by indicators such as gross domestic product (GDP) and at the sectoral level cross value added (GVA) (Liu & Ang 2007). The structural effect indicates the proportional share of output of individual sectors to the total output (e.g. GVAi /GVA). It measures the change in energy consumption due to change in the relative importance of sectors regarding their shifts from less energy-intensive sector to more energy-intensive sector and vice versa. Hasanbeigi et al. (2012)

[15] See Ang et al. (2009) for other desirable properties of LMDI.

[16] Satisfying the time-reversal test requires that for each estimated effect, the estimated value from year 0 to year T is the reciprocal of the estimated value from year T to year 0 in the multiplicative case, and the two estimated values are the same in absolute terms but differ only in sign in the additive case Ang & Choi (1997).

stipulates that this effect is positive when sectors of high energy intensity grow more compared to less intensive sectors. The efficiency effect is used to measure the changes in energy consumption through change in sectoral energy intensities. Changes in sectoral energy intensities improve the efficiency due to the use of efficient technologies or replacing the non-renewable energy with renewable energy sources in production (Sun,1998).

Owing to the above mentioned stances, the LMDI has been used in place of other methods in our study[17].

The decomposition based on LMDI can be categorized into either additive or multiplicative forms. The additive form, put forward in Ang et al. (1998), decomposes the difference in the amount yielded at two points in time, while the latter, suggested in Ang & Liu (2001), decomposes the ratio of change with respect to the base year. Multiplicative version of LMDI[18] is derived and used for analyzing the components or driving factors of energy consumption in this study.

To describe decomposition of final energy consumption into its factors i.e. activity, structural and efficiency effects. We use subscripts 'i' to show activity of a sector whereas 't' refers to the time. The symbol E is used to present the final energy use and Y denotes the GVA of the economy whereas E_i and Y_i denote the energy consumption and gross value added of sector i. The energy intensity of sector 'i' is measured by $EI_i = E_i/Y_i$ whereas the proportion of value added of a sector to total gross value added is calculated by $S_i = Y_i/Y$ (share of sector's output in total output). The total energy consumption is the sum of the final energy consumed in all sectors considered in an economy and can be written as;

[17] See Ang (2015) for a detailed comparison of different decomposition methods

[18] There are two versions of LMDI that are used in decomposing the energy use or energy intensity. These are LMDI-I and LMDI-II. In practice, both yield the same results however, LMDI-1 results are easy to interpret. (see Ang, 2004; Ang et al., 2010; Ang, 2015).

$$E_t = \sum_{i=1}^{n} EI_{it}S_{it}Y_t \tag{3.1}$$

where $\sum_{i=1}^{n} S_{it} = 1$

To find the dynamics of total energy consumption due to activity effect, structural effect, and efficiency effect over time in an economy, taking the derivative of the equation 3.1 with respect to time

$$\frac{d(E_t)}{dt} = \sum_{i=1}^{n}\left[\frac{d(EI_{it})}{dt}S_{it}Y_t + \frac{d(S_{it})}{dt}EI_{it}Y_t + \frac{d(Y_t)}{dt}EI_{it}S_{it}\right] \tag{3.2}$$

Dividing both sides by E_t yields:

$$\frac{d(E_t)}{E_t\,dt} = \frac{1}{E_t}\sum_{i=1}^{n}\left[\frac{d(EI_{it})}{EI_{it}dt}EI_{it}S_{it}Y_t + \frac{d(S_{it})}{S_{it}dt}EI_{it}S_{it}Y_t + \frac{d(Y_t)}{Y_t dt}EI_{it}S_{it}Y_t\right] \tag{3.3}$$

Since $\frac{d(x_t)}{x_t\,dt} = \frac{d(\ln x_t)}{dt}$

$$\frac{d(\ln E_t)}{dt} = \frac{1}{E_t}\sum_{i=1}^{n}\left[\frac{d(\ln E_{it})}{dt}EI_{it}S_{it}Y_t + \frac{d(\ln S_{it})}{dt}S_{it}EI_{it}Y_t + \frac{d(\ln Y_t)}{dt}EI_{it}S_{it}Y_t\right] \tag{3.4}$$

$$= \sum_{i=1}^{n}\left[\frac{d(\ln EI_{it})}{dt} + \frac{d(\ln S_{it})}{dt} + \frac{d(\ln Y_t)}{dt}\right] * \left(\frac{EI_{it}S_{it}Y_t}{E_t}\right) \tag{3.5}$$

Or devoting $\frac{EI_{it}S_{it}Y_t}{E_t} = \frac{E_{it}}{E_t}$ by W_{it}, we obtain;

$$= \sum_{i=1}^{n} \left[\frac{d(\ln EI_{it})}{dt} + \frac{d(\ln S_{it})}{dt} + \frac{d(\ln Y_t)}{dt} \right] * W_{it} \tag{3.6}$$

The Divisia terms in equation 3.6 can be used for the data that are continuous in nature. To apply LMDI in discrete data, we take definite integral of equation 3.6. In real application the weight Wit has to be fixed in a way to preserve the time reversal property of the index. The weight function can be approximated by using the simple average of weights of the time period 0 and T. The use of arithmetic average (simple average) leaves a small residual in decomposition. To avoid the residual problem, logarithmic mean scheme of weights Wi0 and Wit proposed by Ang & Choi (1997) was used. The convention is to modify W_{it} as $W_{it}^{*} = (w_{i0} - w_{i,t}) / \ln\left(\frac{w_{i0}}{w_{i,t}}\right)$ [19].

$$\ln\left(\frac{E_T}{E_0}\right) = \sum_{i=1}^{n} \ln\left(\frac{EI_{iT}}{EI_{i0}}\right) * W_{it}^{*} + \sum_{i=1}^{n} \ln\left(\frac{S_{iT}}{S_{i0}}\right) * W_{it}^{*} + \sum_{i=1}^{n} \ln\left(\frac{Y_T}{Y_0}\right) * W_{it}^{*} \tag{3.7}$$

The above equation can also be written as:

$$\frac{E_T}{E_0} = e^{\sum_{i=1}^{n} \ln\left(\frac{EI_{iT}}{EI_{i0}}\right) * W_{it}^{*} + \sum_{i=1}^{n} \ln\left(\frac{S_{iT}}{S_{i0}}\right) * W_{it}^{*} + \sum_{i=1}^{n} \ln\left(\frac{Y_T}{Y_0}\right) * W_{it}^{*}} \tag{3.8}$$

$$\frac{E_T}{E_0} = e^{\sum_{i=1}^{n} \ln\left(\frac{EI_{iT}}{EI_{i0}}\right) * W_{it}^{*}} \; e^{\sum_{i=1}^{n} \ln\left(\frac{S_{iT}}{S_{i0}}\right) * W_{it}^{*}} e^{\sum_{i=1}^{n} \ln\left(\frac{Y_T}{Y_0}\right) * W_{it}^{*}} \tag{3.9}$$

$$D_{tot} = D_{int} D_{st} D_{act} \tag{3.10}$$

Where

$$D_{act} = e^{\sum_{i=1}^{n} \ln\left(\frac{Y_T}{Y_0}\right) * W_{it}^{*}} \tag{3.11}$$

$$D_{st} = e^{\sum_{i=1}^{n} \ln\left(\frac{S_{iT}}{S_{i0}}\right) * W_{it}^{*}} \tag{3.12}$$

[19] Logarithmic mean scheme was introduced by Vartia (1976) and Sato (1976).

$$D_{int} = e^{\sum_{i=1}^{n} \ln\left(\frac{EI_{iT}}{EI_{i0}}\right) * W_{it}^{*}} \quad (3.13)$$

The formula given in equation 3.10 is the multiplicative version of log mean Divisia index. It shows that total effect (D_{tot}) is equal to the total product of the three individual effects (efficiency effect D_{int}, activity effect D_{act} , and structural effect D_{st}).

In equation 3.11, activity effect D_{act} measures the change in energy consumption owed to a change in output in each sector. The structure effect D_{st}, represented in equation 3.12 shows the share of output of each sector (Yi/Y), and observe the changes in energy consumption that would have been perceived due to a change in the relative share of output of each sector having different energy intensities. The efficiency effect D_{int} in equation 3.13 accounts for improvements in energy efficiency. In our study, LMDI is calculated for 1991 to 2015 using 1990 as base period.

3.3.2. Data and Variables

For the purpose of decomposition, total energy consumption is distributed into three sectors agriculture sector, industrial sector and services sector.[20] Data on energy consumption in each sector are taken from *International Energy Agency* (*IEA*)[21]. According to IEA, final energy consumption covers all energy supplied to the final consumer for all energy uses. It is measured in thousand tonnes of oil equivalent (ktoe). Final output can be measured in terms of GVA or GDP. However, GDP is equal to the GVA in which taxes are added but subsidies are subtracted on the products. Because, the data on taxes and subsidies on products are available for an entire economy, GVA is used for measuring final output for each country as well as for

[20] Energy consumed in commercial, public and transport sectors are counted energy consumption in services sector.
[21] https://www.iea.org/statistics

the three sectors namely agriculture, industry and service sectors. GVA is measured in dollar (constant 2010 prices) and data are taken from *World Development Indicators* (*WDI*).[22]

Although the aim of present study is to analyze energy decomposition world over, yet due to limited availability of data the analysis has to be confined to 60 countries including developed as well as developing countries.

3.4. Results of Decomposition and Discussion

The results of energy consumption decomposition into its effects i.e. activity effect, efficiency effect and structural effect are presented in this section. In order to understand the contributions of main driving forces behind the changing trend of energy consumption overtime, we used a criterion that is same as a proposed by Henriques & Kander (2010) in the present study. This criterion comprises of three categories; that indicates "no change" if components (i.e. D_{act}, D_{st}, D_{int}) equals 1.00, a negative impact on contributing to increase aggregate energy consumption, if it exceeds 1.00 and a positive impact contributing to decrease aggregate energy consumption, if it is below 1.00 (Henriques & Kander, 2010). The decomposition is primarily done at two levels i.e. aggregate level and disaggregate (country) level.

3.4.1. Analysis at Aggregate Level (for 60 Countries)

The decomposition results of energy consumption into activity, efficiency and structural effects at aggregate level by employing the LMDI using data for the period of 1990 to 2015. The results in Fig. 3.1 reflect the relevance of intensity and activity effects regarding the explanation of changes in aggregate energy consumption. Whereas, the structure effect (D_{st}) has no prominent relevance. Effectively, according to Fig. 3.1, the contribution from this

[22] http://databank.worldbank.org/data/reports.aspx?source=WDI-Archives

last effect is considered marginal, being close to unity i.e. “no change”. It can be concluded that the trend in energy consumption (or total decomposition D_{tot}) closely follows activity (D_{act}) effect. Further, it can be observed that the aggregate energy intensity[23] follows the trend of efficiency effect.

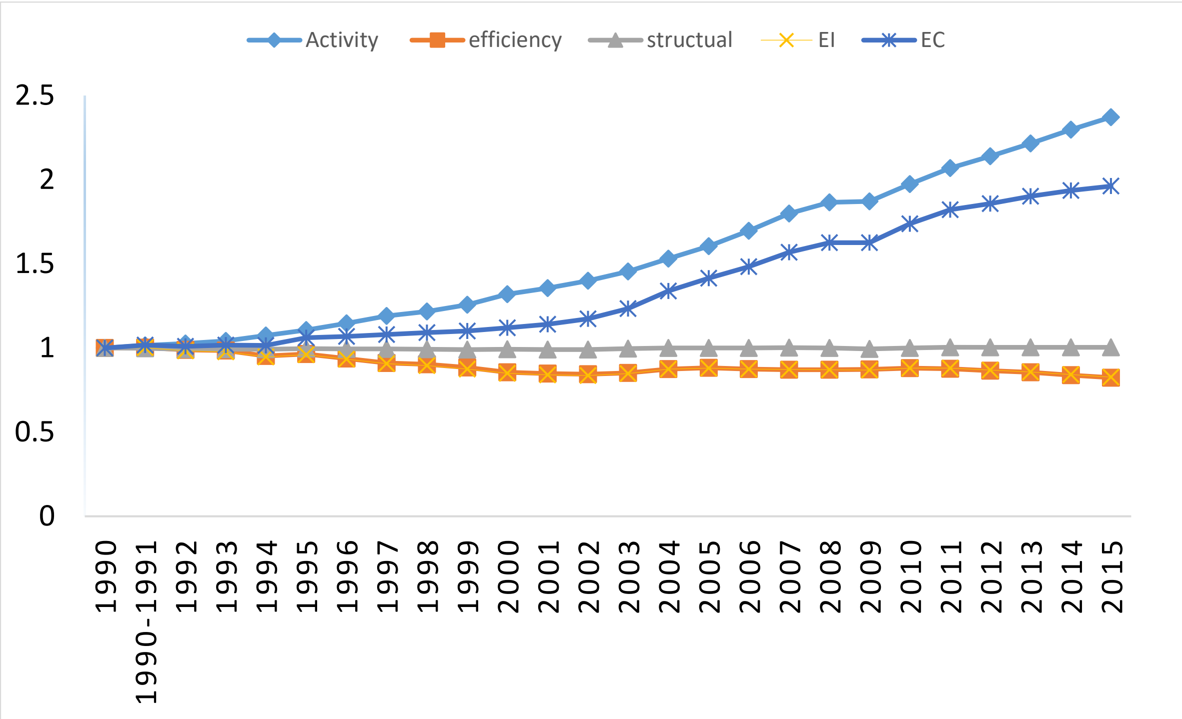

Figure 3.1: Time Path of Activity, Efficiency, Structural Effects, Energy Consumption and Aggregate Energy Intensity

Table 3.1 shows the Growth dynamics of activity, efficiency, structural effects and energy use in sixty countries for five-year windows from 1990 till 2015. During the period of 1990 to 2015, the energy consumption is increased 137% due to increase in activity effect. On the other hand, efficiency improvement has offset the increased activity effect by 17.61%, whereas the role of structural effect is negligible. Finally, aggregate energy consumption is increased by 119% during the 1990 to 2015. Although the role of structural changes to alter

[23] Ratio of total energy-consumption to total GDP.

the energy consumption pattern is very small relative to efficiency effect, yet it is a source of increasing energy consumption. The role of activity in increasing the energy consumption is increasing over the time. However, due to efficiency effect this increased effect of energy consumption is offsetting to some extent, and the effect of efficiency is stronger in periods of 1996 to 2000 and 2011 to 2015. Similar dynamics are also revealed in Figure 3.1 as well as in Table 3.1.[24] One additional information can be analyzed i.e. the behavior of aggregate energy intensity[25] is similar to energy efficiency effect[26] over the time considered in this study. Alike behavior of aggregate energy intensity and energy efficiency is due to the fact that the structural effect is negligible relative to efficiency effect. These all trends can also be observed in Figure 3.1. In all countries energy consumption is decreasing due to improvement in energy efficiency factor. Energy efficiency improves due to use of energy efficient technologies and modern capital equipment while making production in the various sectors of the country (Liu & Ang, 2007).

Table 3.1: Growth Dynamics of Activity, Efficiency, Structural Effects and Energy Use for the Case of Aggregate Level

Years	Percentage Changes LMDI Index				Shares (in percentage)			
	Activity Effect	Efficiency Effect	Structural Effect	Energy Use	Activity Effect	Efficiency Effect	Structural Effect	Energy Use
1990-95	10.57	-3.58	-0.40	6.59	160.50	-54.41	-6.09	100
1996-00	21.35	-10.87	-0.29	10.19	209.59	-106.70	-2.89	100
2001-05	28.61	2.63	0.63	31.86	89.79	8.24	1.97	100
2006-10	36.83	-0.18	0.16	36.82	100.04	-0.48	0.44	100
2011-15	39.79	-5.60	0.29	34.48	115.41	-16.25	0.84	100
1990-15	**137.16**	**-17.61**	**0.38**	**119.9**	**114.36**	**-14.68**	**0.32**	**100**

[24] Results shown in table 1 is based on author's calculations applied on the results of LMDI.
[25] Aggregate energy intensity of an economy is the energy consumed in creation of one unit of gross domestic product (GDP). Trend of aggregate energy intensity at aggregate level is based on author's own calculation and is shown in appendix 3.
[26] Efficiency effect explains the behavior of sectoral energy intensities over time. See (Sun,1998).

3.4.2. Analysis at Country Level:

The decomposition of energy consumption in to activity effect, structural effect, and efficiency effect provided in the previous subsection highlights the detrimental but negligible pattern of structural effect towards energy consumption trend for all the countries included in our sample. In contrast, the efficiency effect contributes positively in offsetting the increased effect of activity effect towards the energy consumption with an exception of period from 2002 to 2005. whereas the activity effect of energy consumption is increasing during the entire period. The aggregate trends presented in the previous subsection are likely to be the result of very heterogeneous country performances in terms of structural and efficiency effect. In the following, the decomposition exercise will be carried out at the country level. The country-level decomposition allows to compare the impact on aggregate energy intensity of structural effect and efficiency effect in each country. Based on the results of LMDI, the countries can be categorized into three groups, arranged by their behavior profiles regarding activity, structural and efficiency effects. Behavior of these three effects of energy consumption of these countries are presented in following tables and graphs in each group respectively.

Group A) Countries with Improved Aggregate Energy Intensity due to Efficiency and Structural Effects:

Figs. 3.2 show changes in total energy consumption according to variations in activity, structure & intensity effects. The value of (D_{tot}) increases and always above1.00. This shows that total energy use is increasing overtime. This result shows the trend like activity (output) effect that is the main component in contributing the energy consumption to increase, which can be observed by the values of the activity effect (D_{act}) that has the value above 1.00 for the entire time period in all the countries in the group. However, with most yearly variations in most of the countries, the value of (D_{int}) is bellow1.00 which means intensity effect is contributing in decreasing the energy uses .

The above outcomes of the research indicated that, adopting the energy efficient capital in the various sectors of the country improves the energy efficiency thereby reduces the energy use (Wang et al. 2014). Meanwhile, the structural effect (D_{st}) contributed with marginal decrease reflected by its value that remains close to 1.00 but less than 1.00 in most of the countries for entire time period) in energy consumption. This fact could be recognized as a consequence of sectoral shift[27] (Tanaka, 2011). Aggregate energy intensity follow the pattern energy efficiency as shown in the Figure 3.2. Aggregate energy intensity is decreasing.

For all the countries analyzed in this group, the main variations in energy consumption are due to activity and efficiency components over the structural component. Both the efficiency and structural effect offset the increasing effect of energy consumption due to strong activity effect to some extent.

[27] Shifting from more intensive energy sector (Industrial sector) to less energy intensive sector (Services sector)

In all the following graphs, —— Activity Effect, — — — Energy Intensity, - - - - Structural Effect, ······ Efficiency Effect and ···— Energy Consumption.

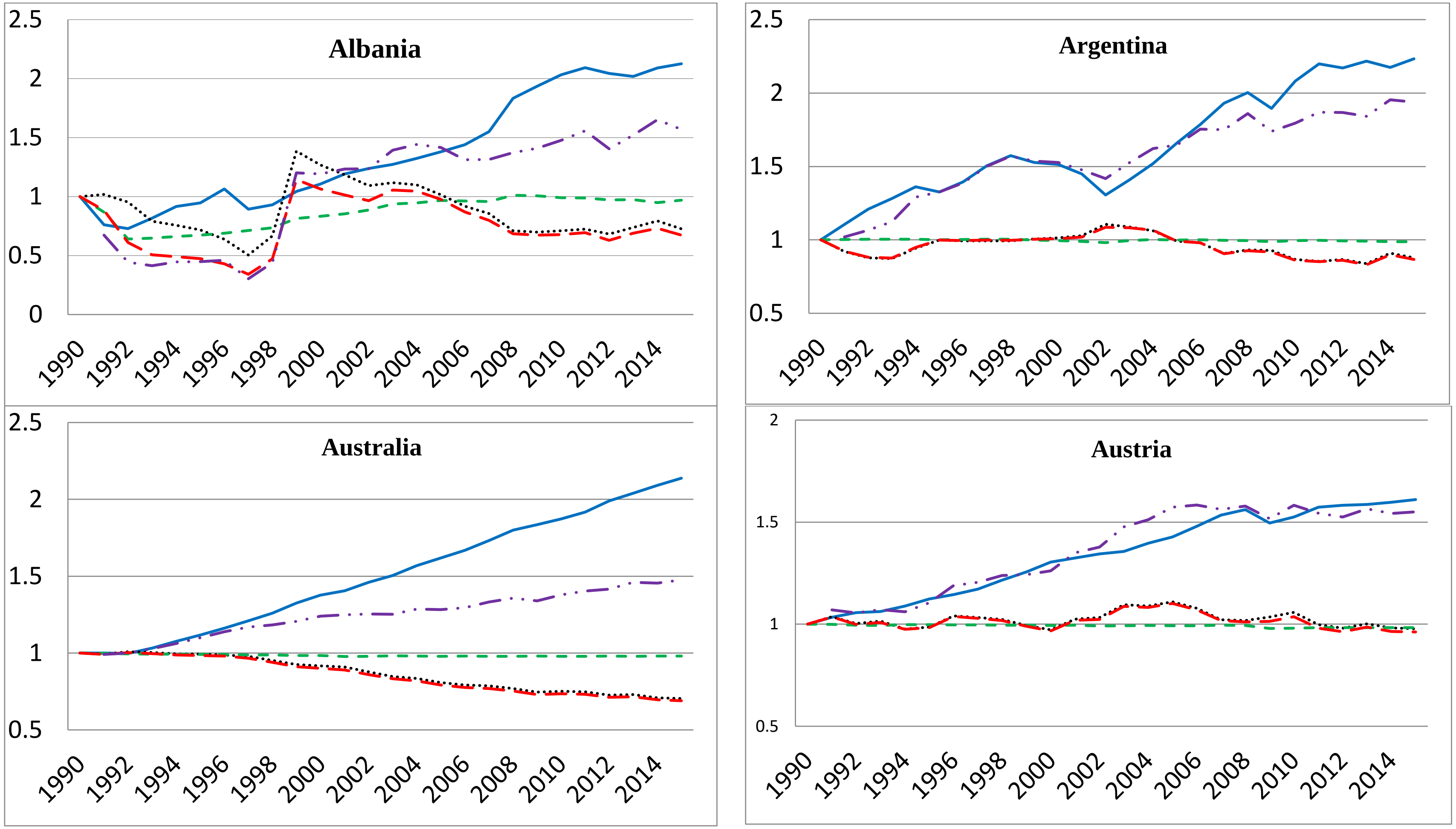

Figure 3.2: Graphical Presentation of Energy Consumption, Energy Intensity, Activity Effect, Efficiency Effect and Structural Effect; for the Case of Group 'A' Countries

In the following graphs, —— Activity Effect, — — — Energy Intensity, - - - - Structural Effect, •••••• Efficiency Effect and •••—— Energy Consumption.

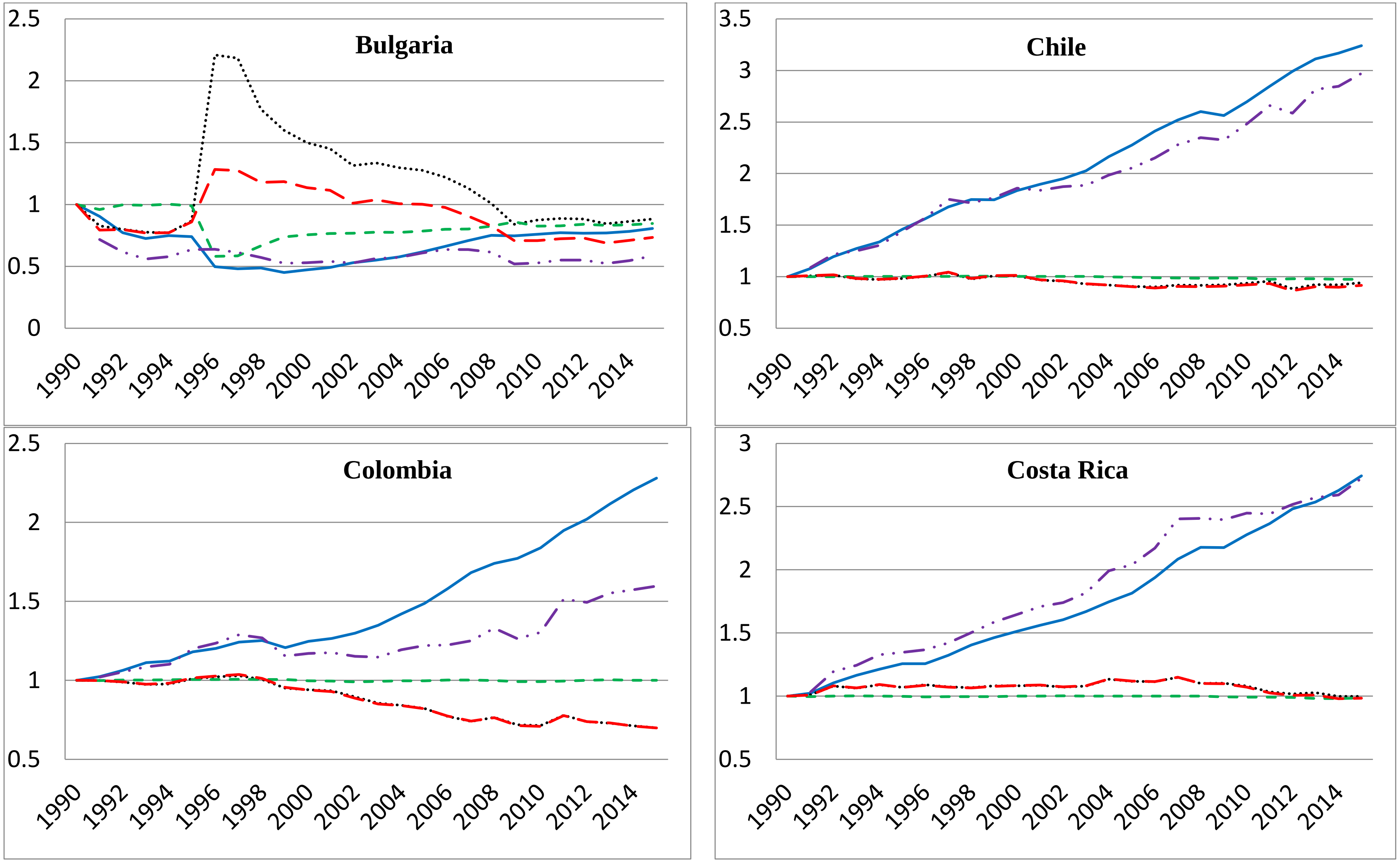

Figure 3.2 Continued

In all the following graphs, —— Activity Effect, — — — Energy Intensity, - - - - Structural Effect, ······ Efficiency Effect and ···— Energy Consumption.

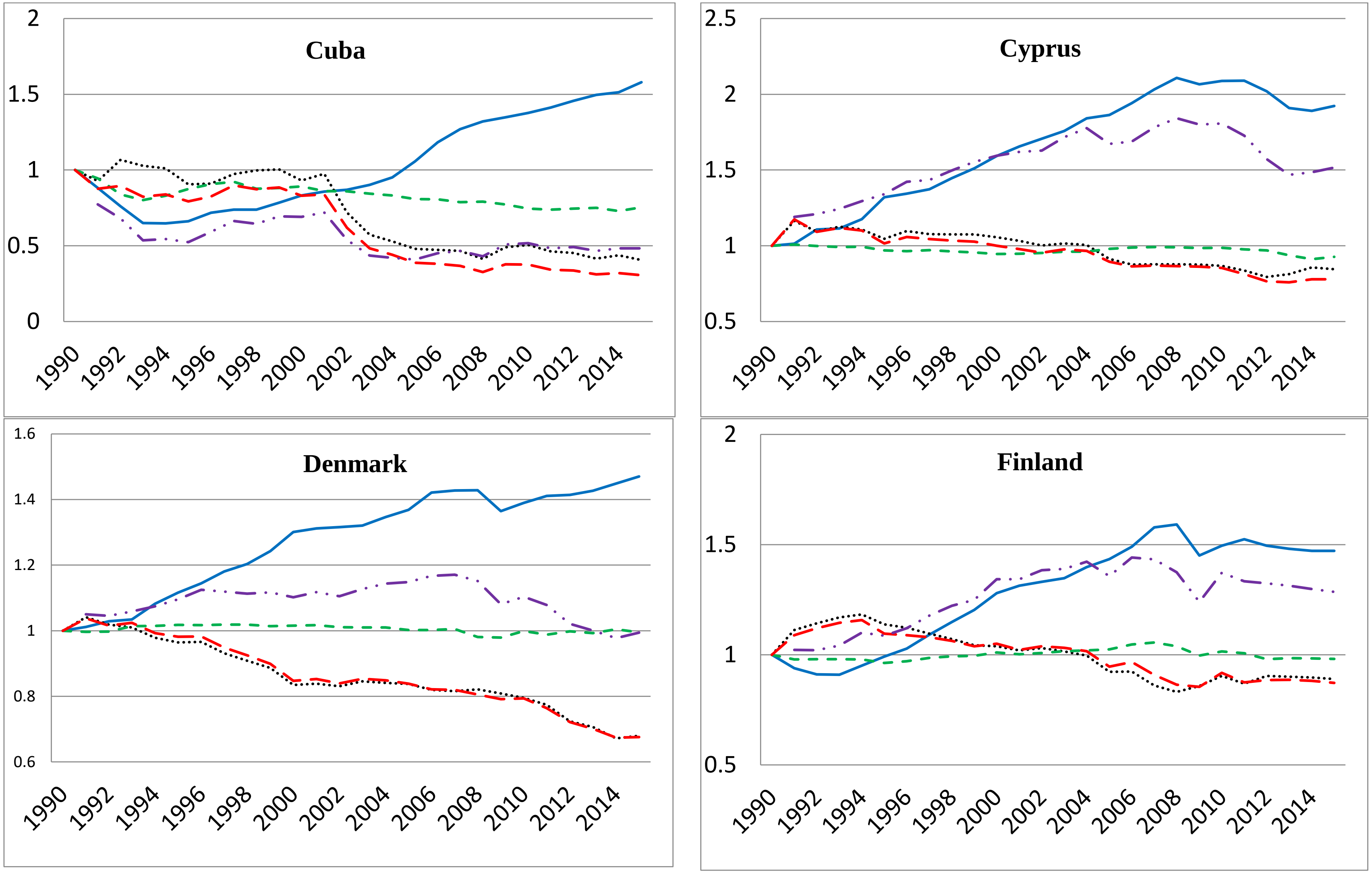

Figure 3.2 Continued

In the following graphs, —— Activity Effect, — — — Energy Intensity, - - - Structural Effect, ······ Efficiency Effect and ··–– Energy Consumption.

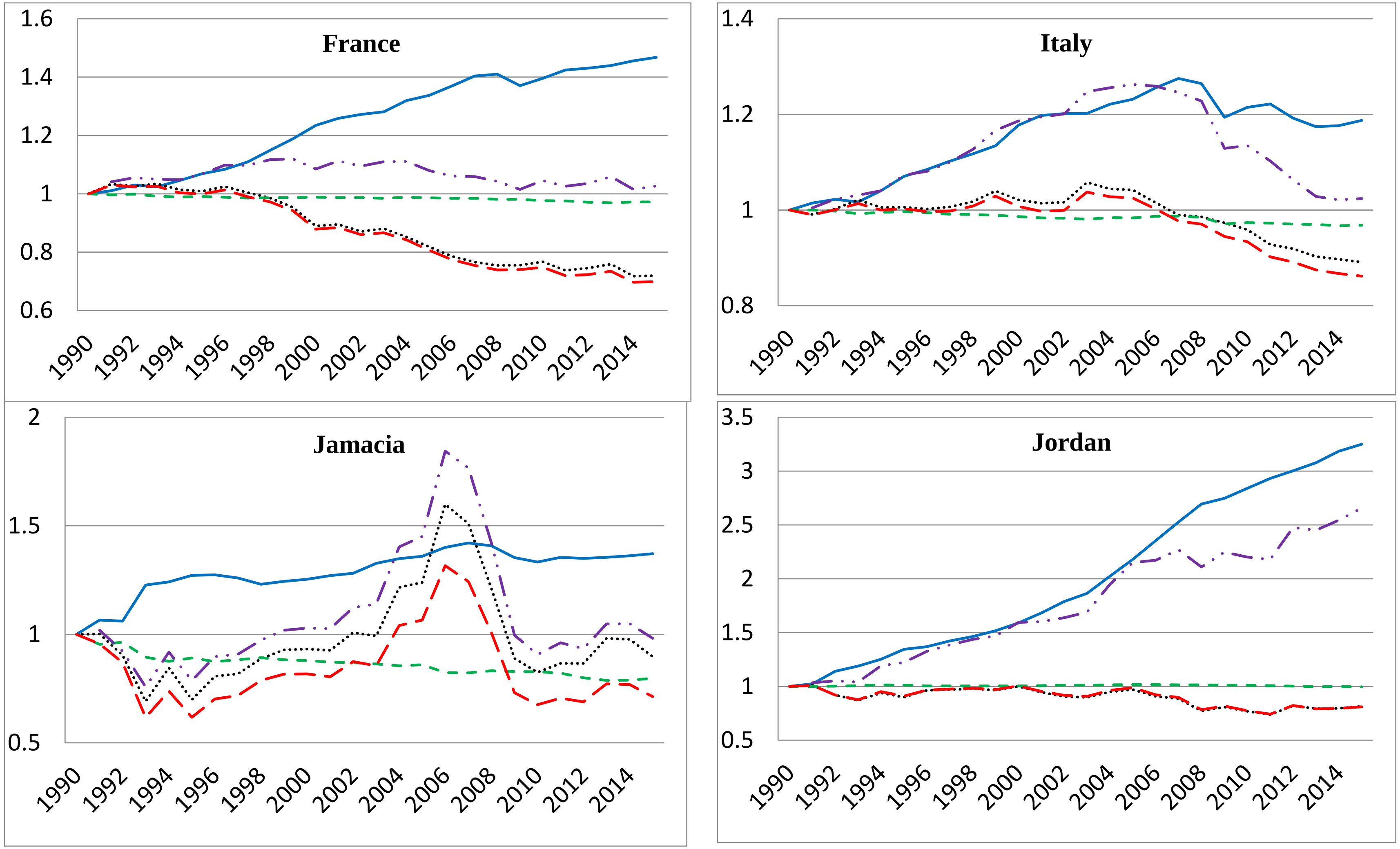

Figure 3.2 Continued

In the following graphs, —— Activity Effect, — — — Energy Intensity, - - - - Structural Effect, ······ Efficiency Effect and ··–— Energy Consumption.

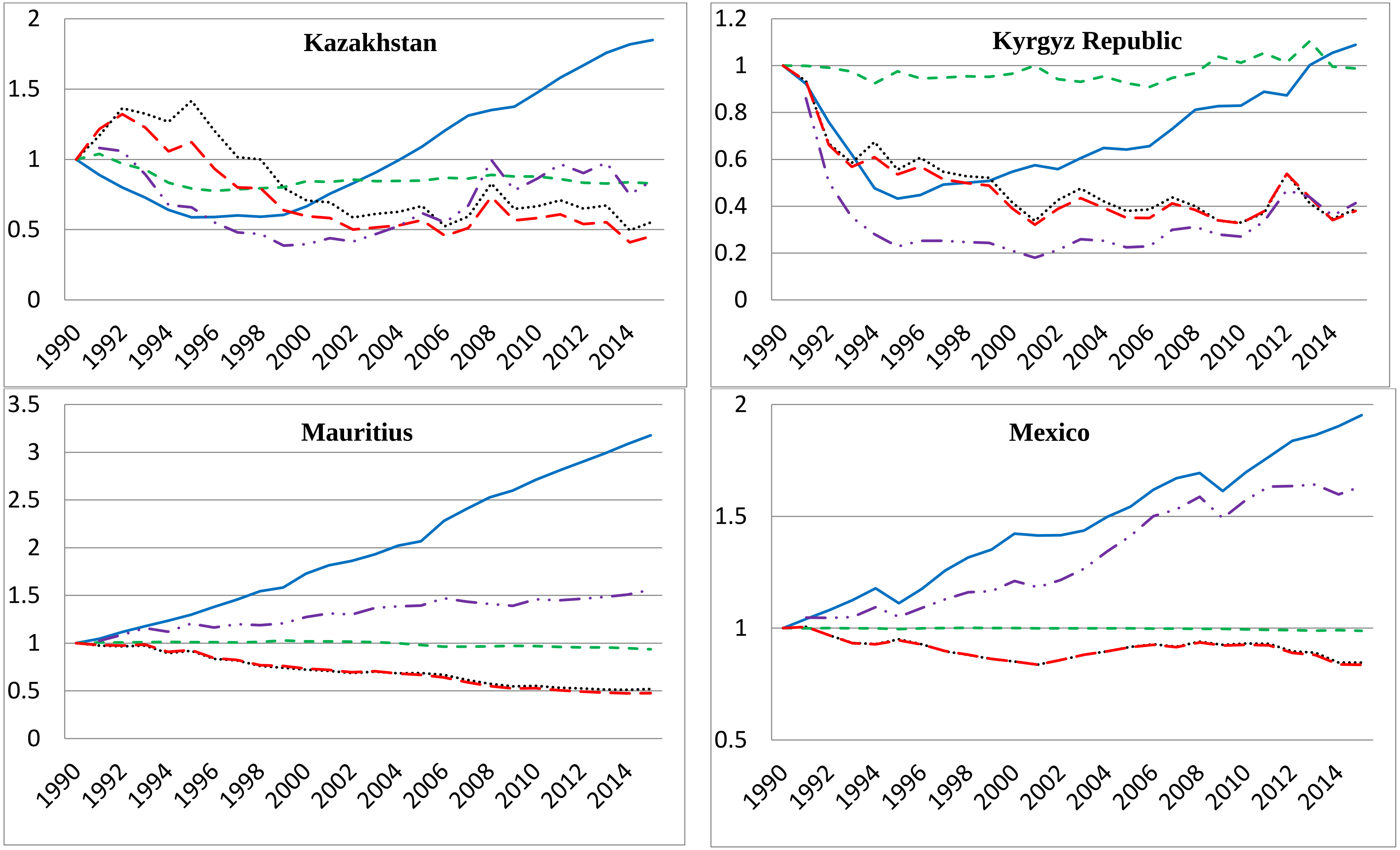

Figure 3.2 Continued

In the following graphs, —— Activity Effect, — — — Energy Intensity, - - - - Structural Effect, ······ Efficiency Effect and ···— Energy Consumption.

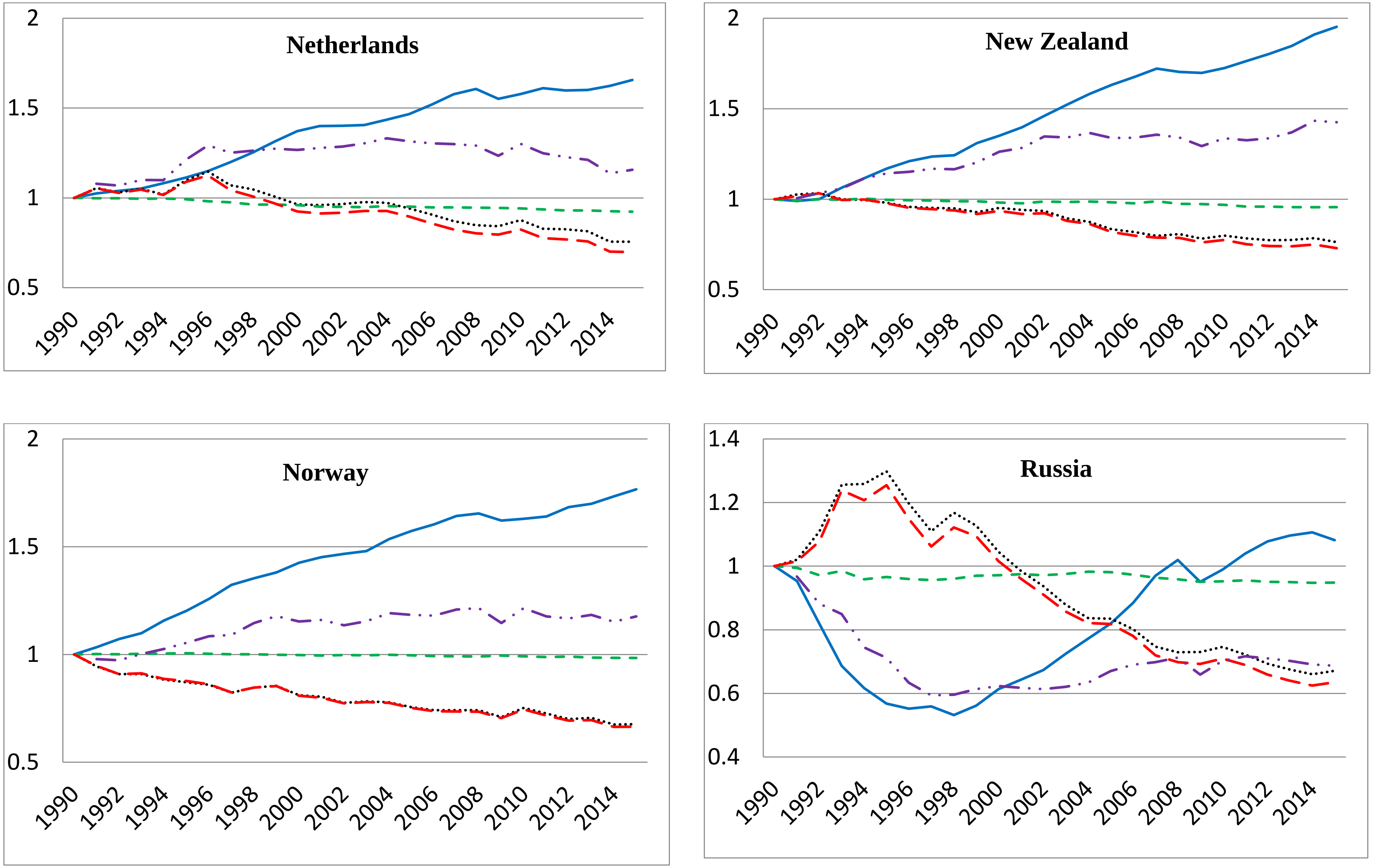

Figure 3.2 Continued

In the following graphs, —— Activity Effect, — — — Energy Intensity, - - - - Structural Effect, •••••• Efficiency Effect and •••—— Energy Consumption.

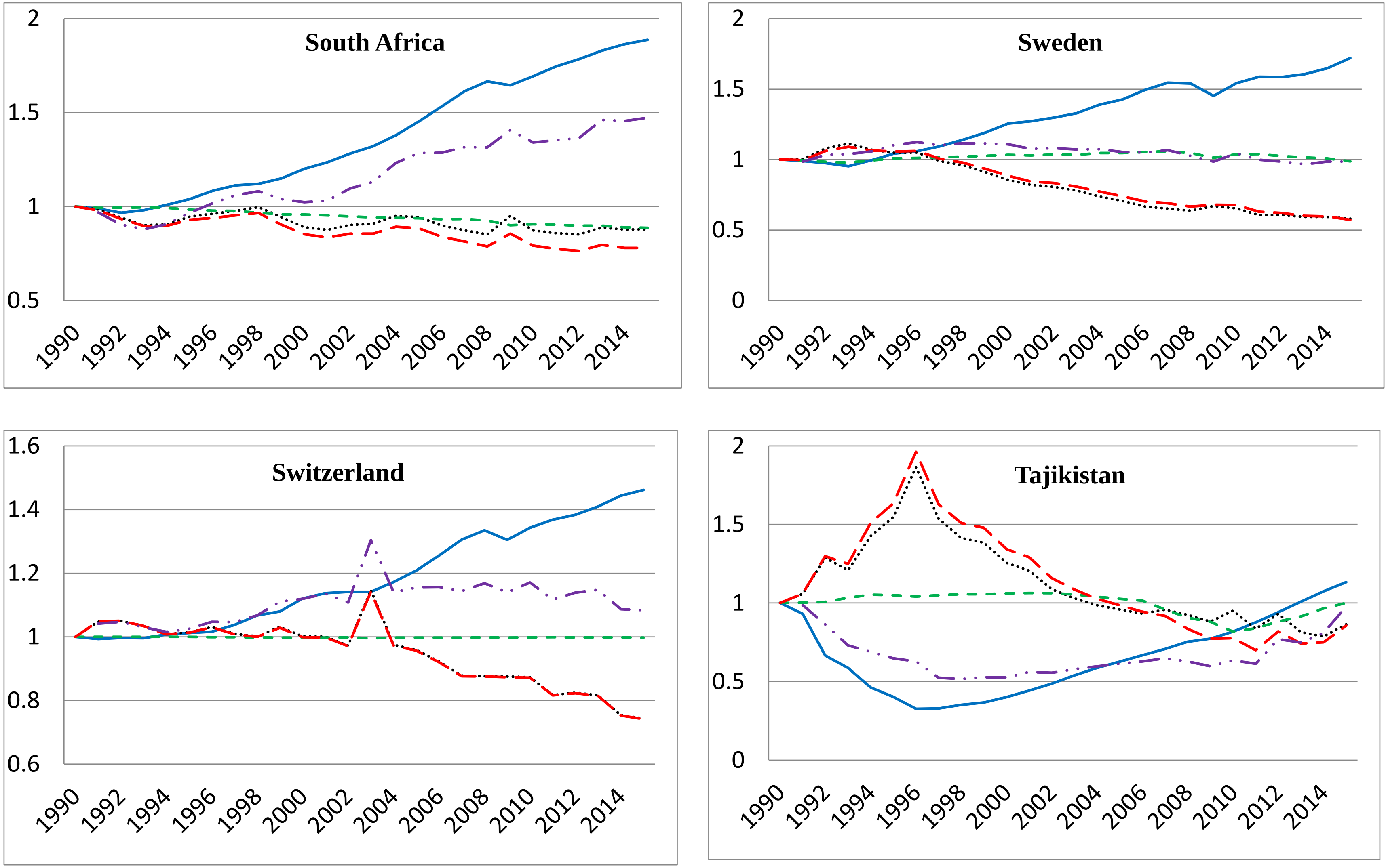

Figure 3.2 Continued

In the following graphs, —— Activity Effect, — — — Energy Intensity, - - - - Structural Effect, ······ Efficiency Effect and ··—— Energy Consumption.

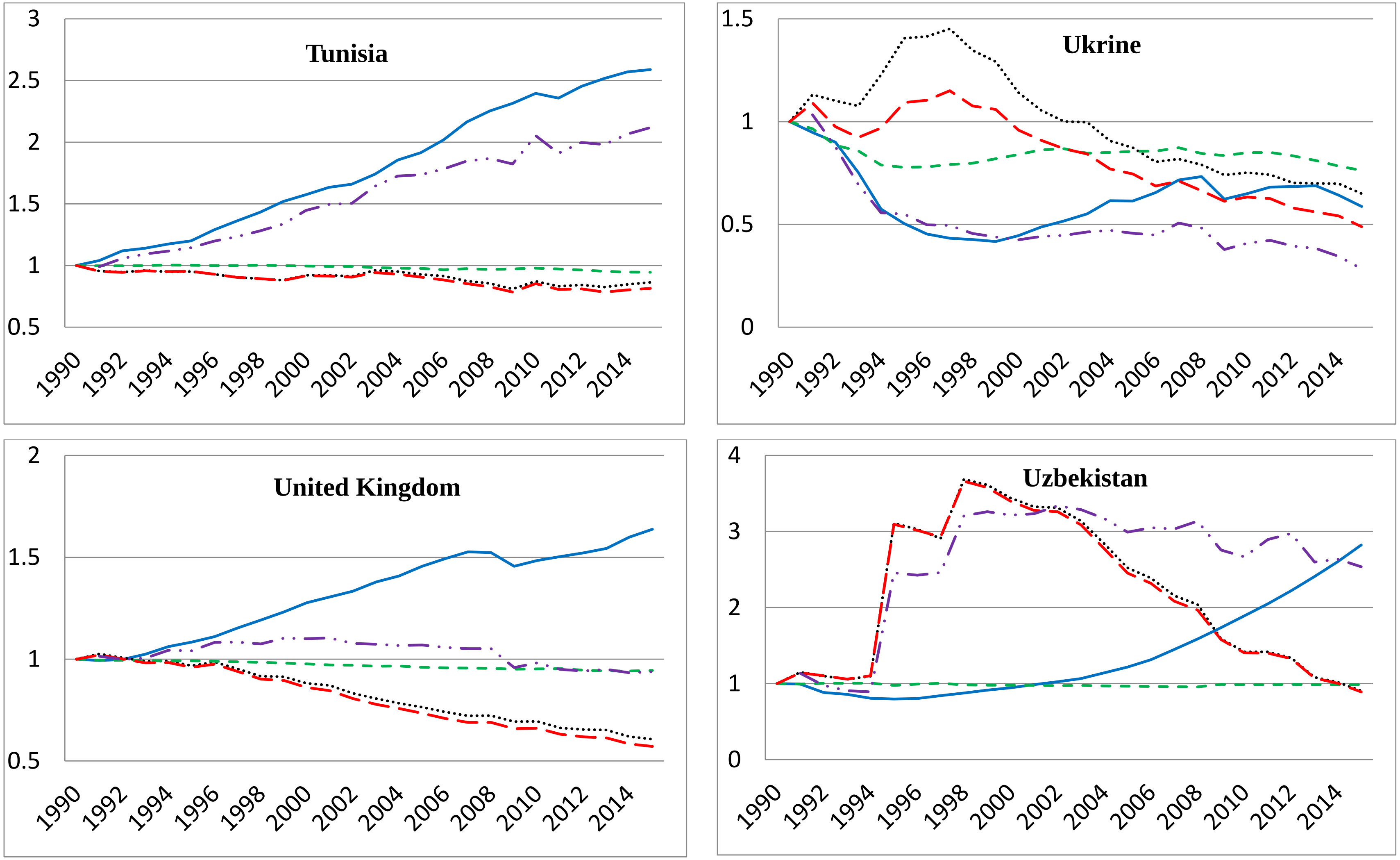

Figure 3.2 Continued

The trend of these three main drivers of energy consumption are also explained in term of annual growth rates in Table 3.2. The results of Table 3.2 show that the countries that have improved energy efficiency are Kyrgyz Republic, Cuba, Mauritius, Kazakhstan and Sweden (3.72%, 3.54%, 2.6%, 2.32% and 2.15% annually). The structural effect is relatively very weak as compared to efficiency effect i.e. 1.12% and 1.08% are the highest. The activity effect is moderate in these countries i.e. Jordan 4.83%, Chile 4.82%, Mauritius 4.73%, Costa Rica 4.12% and Colombia 3.35%. The countries where the efficiency and structural improvements jointly dominates activity effect and ultimately reduce the energy consumption are Bulgaria, Cuba, Denmark, Jamaica, Kazakhstan, Kyrgyz Republic, Russian Federation, Sweden, Tajikistan, Ukraine and United Kingdom. Not surprisingly, the contribution of each determinant factor is different among countries. This reflects differences in risk, market and owner structures, leverage levels, local credit markets and economic perspectives (Adom et al. 2018).

Table 3.2: Decomposition of Energy Consumption for the Period of 1990 To 2015; For the Case of Group 'A' Countries

				Absolute changes			Annual growth rates		
Country	**Initial Energy**	**Final Energy**	**Absolute Change**	**Activity Effect**	**Efficiency Effect**	**Structural Effect**	**Activity Effect**	**Efficiency Effect**	**Structural Effect**
Albania	904	1418	514	706	-172	-20	3.06	-1.28	-0.13
Argentina	22031	42714	20683	23202	-2283	-236	3.27	-0.52	-0.05
Australia	45212	66737	21525	29798	-7748	-525	3.09	-1.39	-0.08
Austria	12371	19181	6810	7266	-259	-197	1.92	-0.09	-0.07
Bulgaria	12213	7129	-5084	-2130	-1282	-1672	-0.86	-0.5	-0.66
Chile	7059	20976	13917	14465	-386	-162	4.82	-0.25	-0.1
Colombia	12866	20546	7680	10035	-2354	-1	3.35	-1.42	0
Costa Rica	1136	3095	1959	1976	-2	-15	4.12	-0.01	-0.05
Cuba	10551	5095	-5456	12119	-12427	-5148	1.85	-3.54	-1.12
Cyprus	709	1075	366	487	-82	-39	2.65	-0.67	-0.31
Denmark	8856	8803	-53	-172	117	2	1.55	-1.53	-0.02
Finland	13899	17862	3963	5457	-1269	-225	1.56	-0.46	-0.08
France	93546	96024	2478	7276	-4368	-431	1.55	-1.31	-0.11
Italy	78079	79975	1896	7650	-4457	-1297	0.69	-0.46	-0.13
Jamaica	1671	1640	-31	-173	48	94	1.27	-0.43	-0.9
Jordan	1513	4021	2508	2738	-226	-5	4.83	-0.82	-0.02
Kazakhstan	34702	29530	-5172	-18733	9778	3783	2.49	-2.32	-0.75
Kyrgyz Republic	4817	1992	-2825	469	-3227	-66	0.34	-3.72	-0.05
Mauritius	426	664	238	318	-70	-9	4.73	-2.6	-0.27
Mexico	57778	94437	36659	44361	-7151	-551	2.71	-0.66	-0.05
Netherlands	29316	33899	4583	8960	-3326	-1051	2.04	-1.11	-0.32
New Zealand	7821	11147	3326	4717	-1176	-215	2.71	-1.08	-0.18

Table 3.2: Continued

Norway	11991	14103	2112	3793	-1601	-80	2.3	-1.55	-0.07
Russian Federation	382928	263096	-119832	32700	-131901	-20631	0.31	-1.59	-0.21
South Africa	35672	52526	16854	22893	-3113	-2927	2.57	-0.51	-0.48
Sweden	23644	23295	-349	-874	509	16	2.19	-2.15	-0.05
Switzerland	11750	12735	985	2246	-1248	-14	1.53	-1.18	-0.01
Tajikistan	1666	1627	-39	1326	-1360	-4	0.5	-0.58	0
Tunisia	2615	5540	2925	3327	-287	-115	3.88	-0.59	-0.23
Ukraine	109115	30958	-78157	-32257	-27340	-18560	-2.11	-1.71	-1.08
United Kingdom	85479	80140	-5339	-18086	11157	1590	1.99	-1.98	-0.23
Uzbekistan	5356	13582	8226	8756	-462	-68	4.24	-0.4	-0.06

Group B) Countries with Improved Aggregate Energy Intensity only due to Efficiency Effects:

In all the countries of group B like group A, Figure 3.3 shows that the activity effect reflects the main variation in energy consumption whereas the value of intensity effect below the 1.00 for all the countries. Increased energy consumption is offset by intensity effect but not at large. However, the structural effect (it's value remains close to 1.00 but greater than 1.00) in most of the countries contributes marginally in raising the energy consumption. This result motivates the policy makers to design such policies that can actively improves the energy efficiency, consequently aggregate energy intensity in an economy. But, such steps that can improves the efficiency are not sufficient to contribute in reduction the energy use because of strong effect of output to increase it. So, other measures like changing the structural composition (structural effect) in an economy (moving from more energy intensive i.e. industrial sector to less energy intensive i.e. service sector) may conserve the energy use (González et al. 2014).

In all the following graphs, —— Activity Effect, — — — Energy Intensity, - - - - Structural Effect, ······ Efficiency Effect and ···—— Energy Consumption.

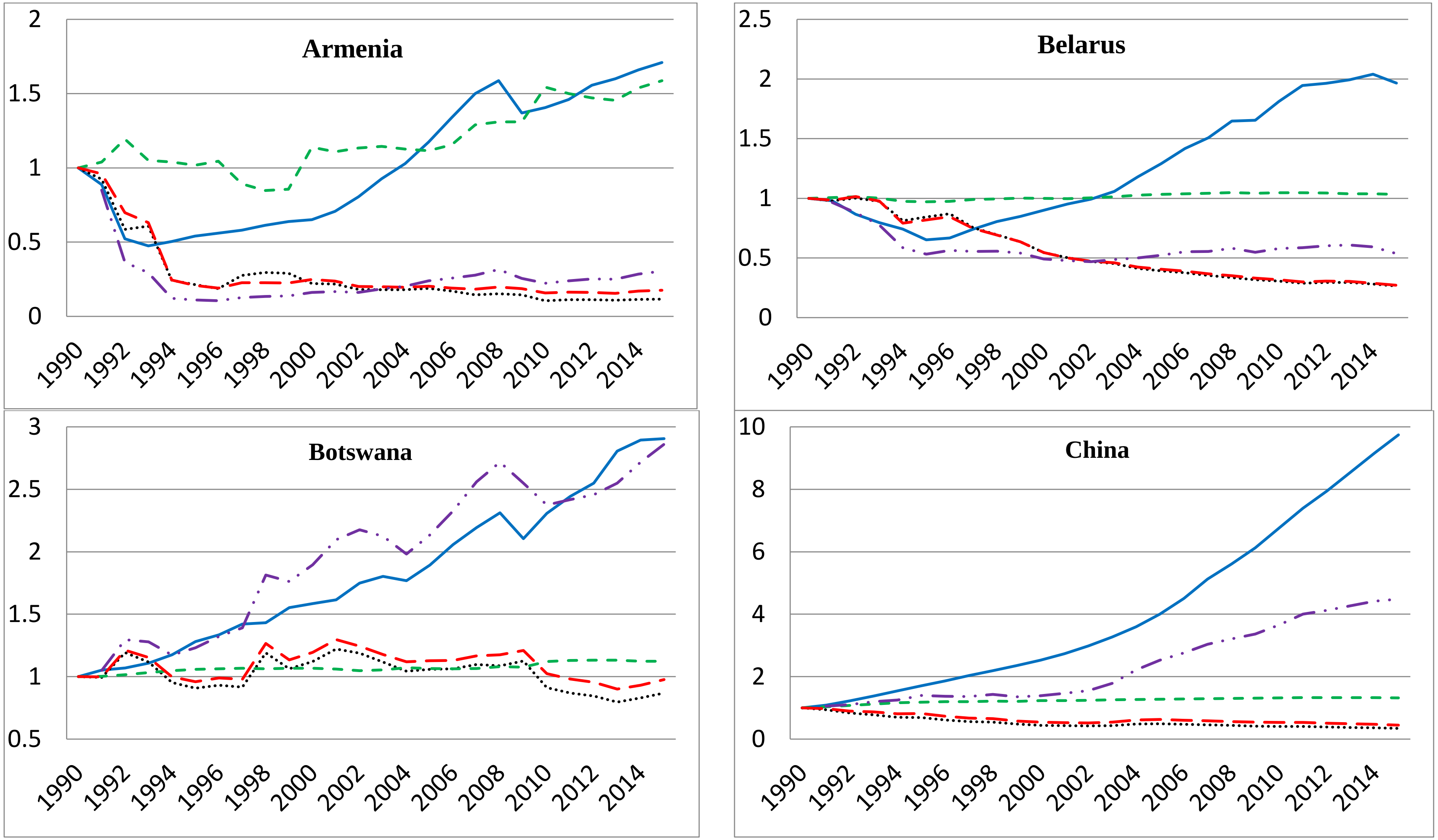

Figure 3.3: Graphical Presentation of Energy Consumption, Energy Intensity, Activity Effect, Efficiency Effect and Structural Effect; For the Case of Group 'B' Countries

In all the following graphs, —— Activity Effect, — — — Energy Intensity, - - - - Structural Effect, ······ Efficiency Effect and ··–— Energy Consumption.

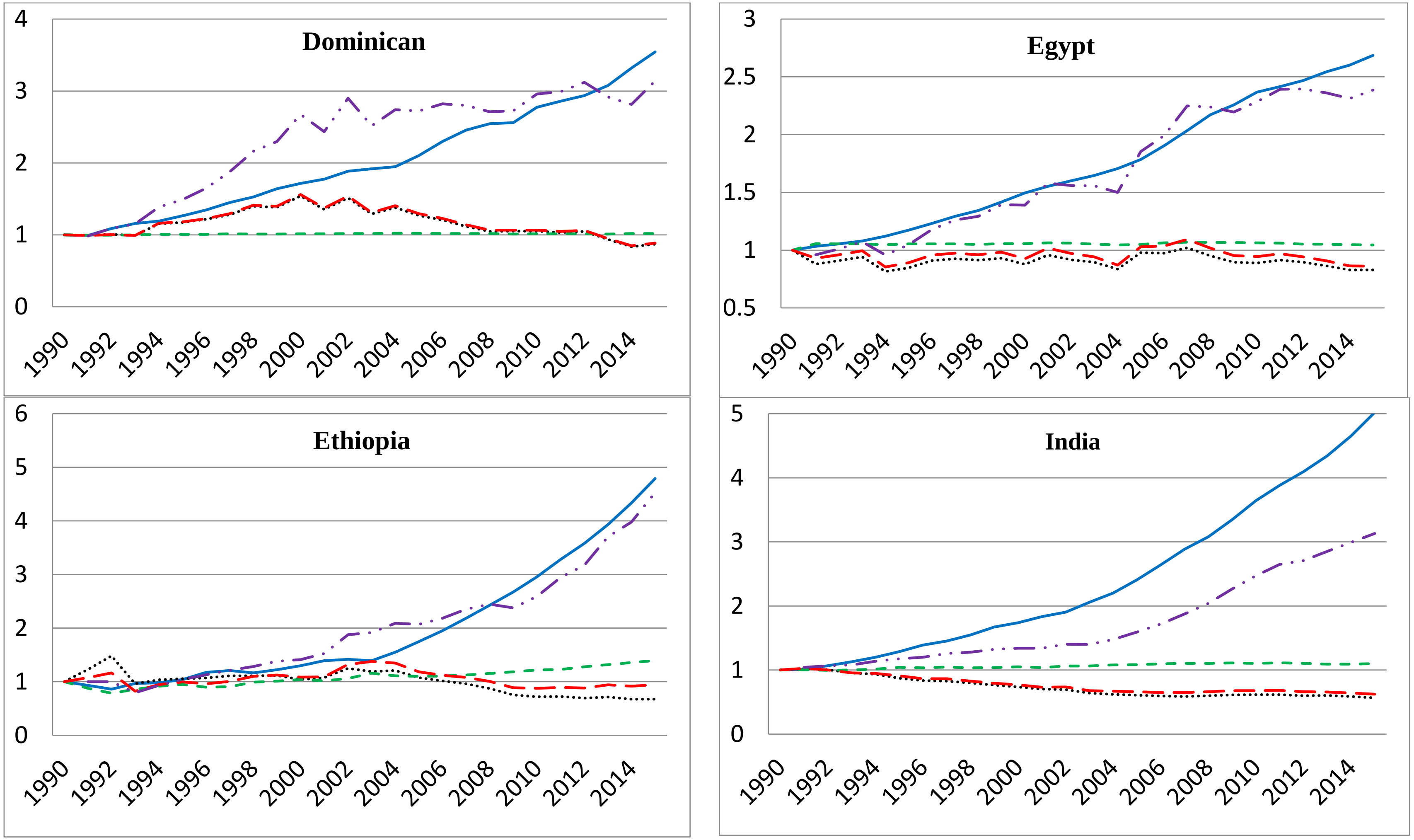

Figure 3.3 Continued

In all the following graphs, —— Activity Effect, — — — Energy Intensity, - - - - Structural Effect, ······ Efficiency Effect and ···—— Energy Consumption.

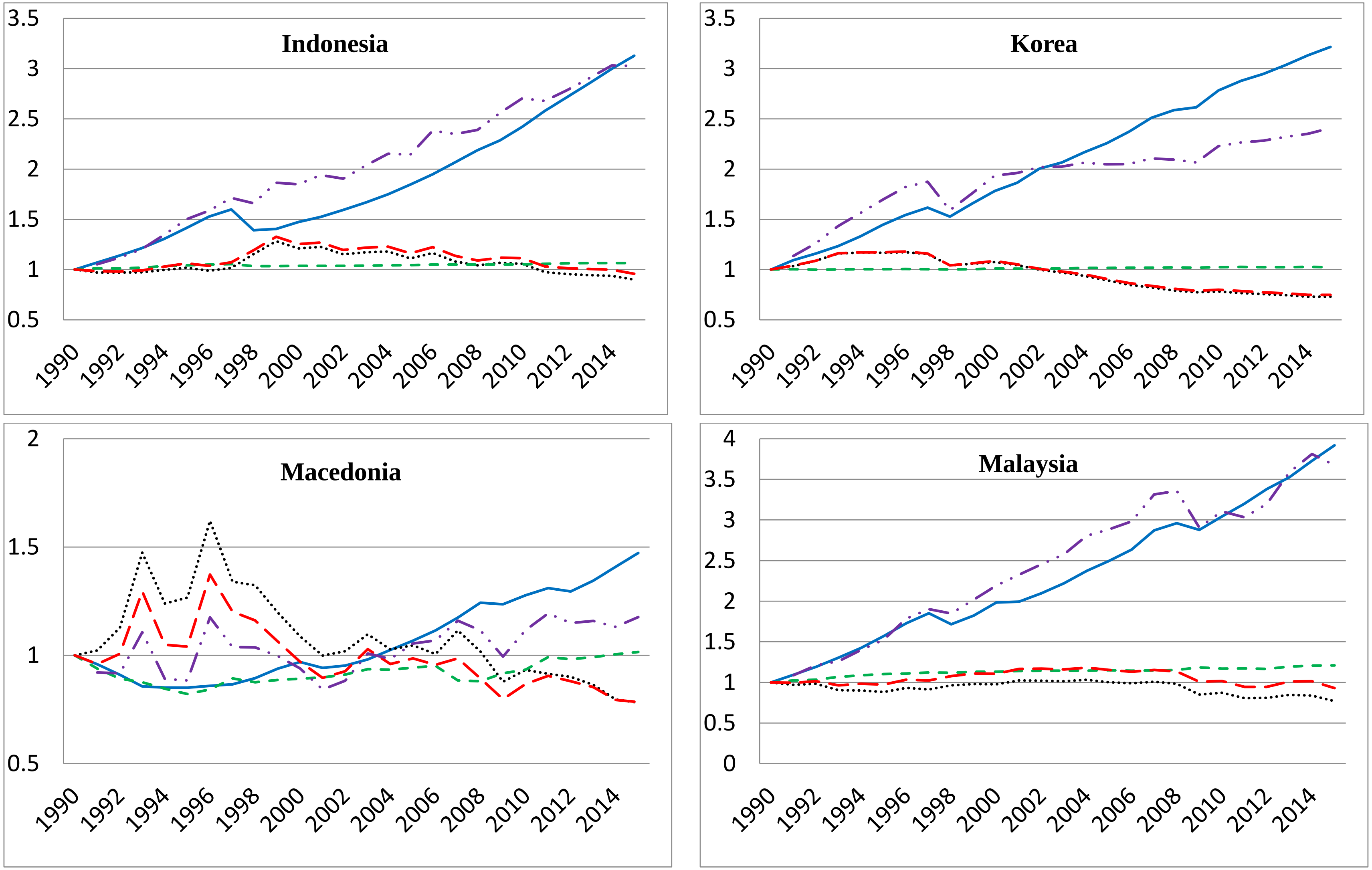

Figure 3.3 Continued

In all the following graphs, —— activity effect, — — — energy intensity, - - - - structural effect, ······ efficiency effect and ··—— Energy Consumption.

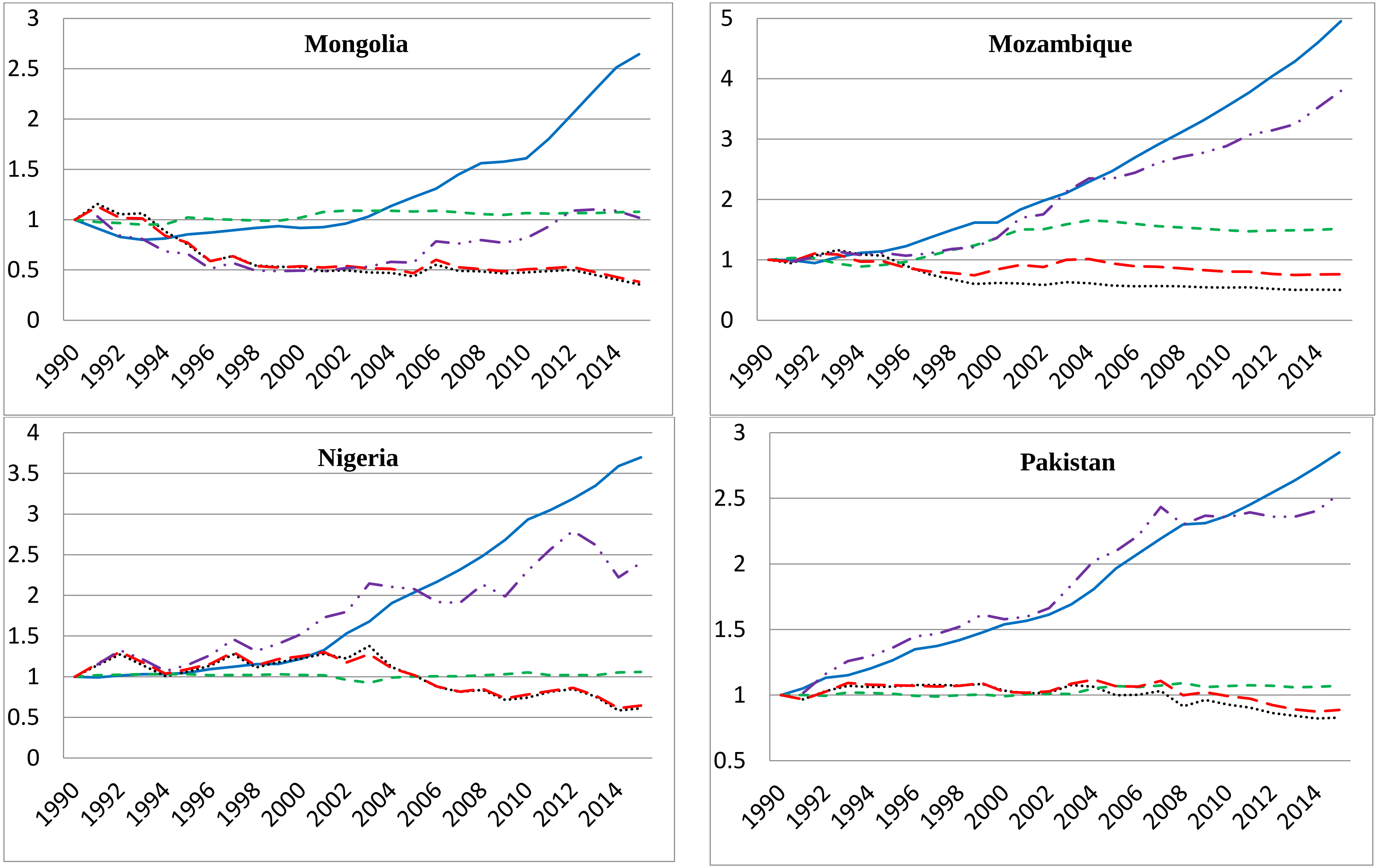

Figure 3.3 Continued

In all the following graphs, —— activity effect, — — — energy intensity, - - - - structural effect, ······ efficiency effect and ···— Energy Consumption.

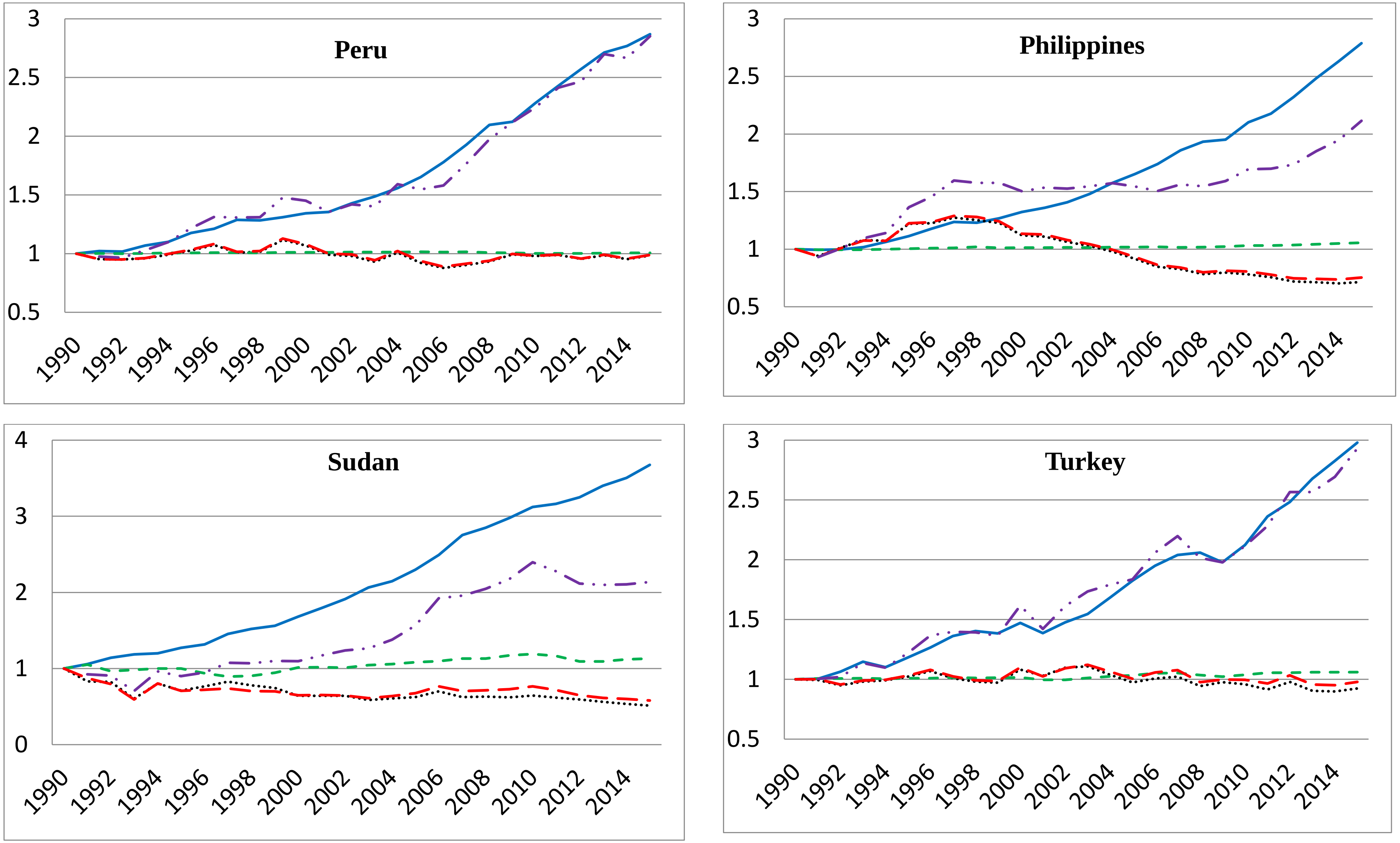

Figure 3.3 Continued

The results of activity, structural and intensity effects in term of annual growth rates are presented in Table 3.3. The main reason of reducing energy consumption in these countries is energy efficiency improvement. The leading countries in improvement of energy efficiency are Armenia, Belarus, Mongolia, Mozambique, and Sudan (annual growth is 8.27%, 5.17%, 4.04%, 2.71% and 2.64% respectively). In case of Armenia and Belarus efficiency effect is so strong and it dominates the structural and activity effect, resulting to reduce the energy consumption. Most of these countries have very strong activity effect i.e. Ethiopia 6.47%, Nigeria 5.37%, Sudan 5.34% and Dominican Republic 5.19%. The pattern of activity and structural effect influenced aggregate energy consumption positively whereas intensity effect influenced energy consumption negatively.

The improvement in aggregate energy intensity is due to efficiency effect that is the result of massive adoption of more efficient technologies. The variation of efficiency effect is attributed towards diverse characteristics of industrial structure and stage of industrialization in each country. Other than that, a number of factors– including more efficient industrial processes and transport systems, minimum efficiency requirements for energy using equipment, tougher standards and better labelling on appliances, coherent use of taxation, improving energy performance of buildings and, more generally, innovation and adaptation to more efficient technologies – tend to reduce energy consumption (González et al. 2015).

Table 3.3: Decomposition of Energy Consumption for the Period of 1990 to 2015; For the Case of Group 'B' Countries

				Absolute Changes			Annual Growth Rates		
Country	**Initial Energy**	**Final Energy**	**Absolute Change**	**Activity Effect**	**Efficiency Effect**	**Structural Effect**	**Activity Effect**	**Efficiency Effect**	**Structural Effect**
Armenia	4168	1273	-2895	-4986	-6216	4125	2.17	-8.27	1.86
Belarus	20416	10940	-9476	-34705	-26393	1164	2.74	-5.17	0.13
Botswana	438	1253	815	818	-56	53	4.36	-0.56	0.46
China	308692	1383764	1075072	1118762	-84051	40361	9.53	-4.19	1.1
Dominican Republic	1267	3978	2711	2837	-146	20	5.19	-0.56	0.07
Egypt	15069	35961	20892	22591	-2291	592	4.03	-0.75	0.17
Ethiopia	790	3578	2788	2737	-234	286	6.47	-1.56	1.34
India	105393	329972	224579	244846	-26455	6188	6.67	-2.25	0.39
Indonesia	30654	92803	62149	63192	-2952	1909	4.67	-0.42	0.25
Korea rep.	44182	106433	62251	69973	-8518	796	4.78	-1.25	0.1
Macedonia, FYR	1122	1320	198	348	-161	11	1.56	-0.98	0.06
Malaysia	11339	41663	30324	30549	-2414	2189	5.62	-1.04	0.76
Mongolia	1956	1992	36	55	-21	3	3.97	-4.04	0.3
Mozambique	795	3021	2226	2214	-278	290	6.61	-2.71	1.69
Nigeria	8040	19299	11259	12836	-1855	278	5.37	-1.96	0.23
Pakistan	13971	35427	21456	22695	-2118	878	4.28	-0.75	0.28
Peru	4844	13817	8973	9030	-83	26	4.31	-0.07	0.02
Philippines	10305	21793	11488	13171	-2094	411	4.19	-1.33	0.22
Sudan	2645	5656	3011	3471	-632	172	5.34	-2.64	0.5
Turkey	22713	66555	43842	44216	-1720	1346	4.46	-0.32	0.23

Group C) Countries with Worsened Energy Intensity due to Both Efficiency and Structural Effects:

In group c, all the countries are those where aggregate energy intensity is worsening due to both intensity and structural effects. The activity effect, structural effect and efficiency effects are shown in Figure 3.4. the values of all the effects are greater than 1.00 which reflect negative contribution towards the energy consumption of these effects. The value of aggregate energy intensity is also greater than 1.00. However, the structural effect marginally contributes in increasing the energy consumption because value that remains close to 1.00 but greater than 1.00 whereas the intensity effect significantly contributes to worsen the aggregate energy intensity because it's value is significantly greater than 1.00.

During most of the time period under review, energy consumption is observed to follow trends in activity effect for all the countries in this group similar to group A & B. This is not counterweighed by the intensity effect, as seen for most of the countries in group A & B. This may be attributable to the absence of policy measures for increasing energy efficiency at the country level (Weyman et al. 2015). On the other hand, the structural effect is seen to have a minor role in changing energy consumption over time relative to the intensity or activity effects.

In all the following graphs, —— Activity Effect, — — — Energy Intensity, - - - - Structural Effect, ······ Efficiency Effect and ···— Energy Consumption.

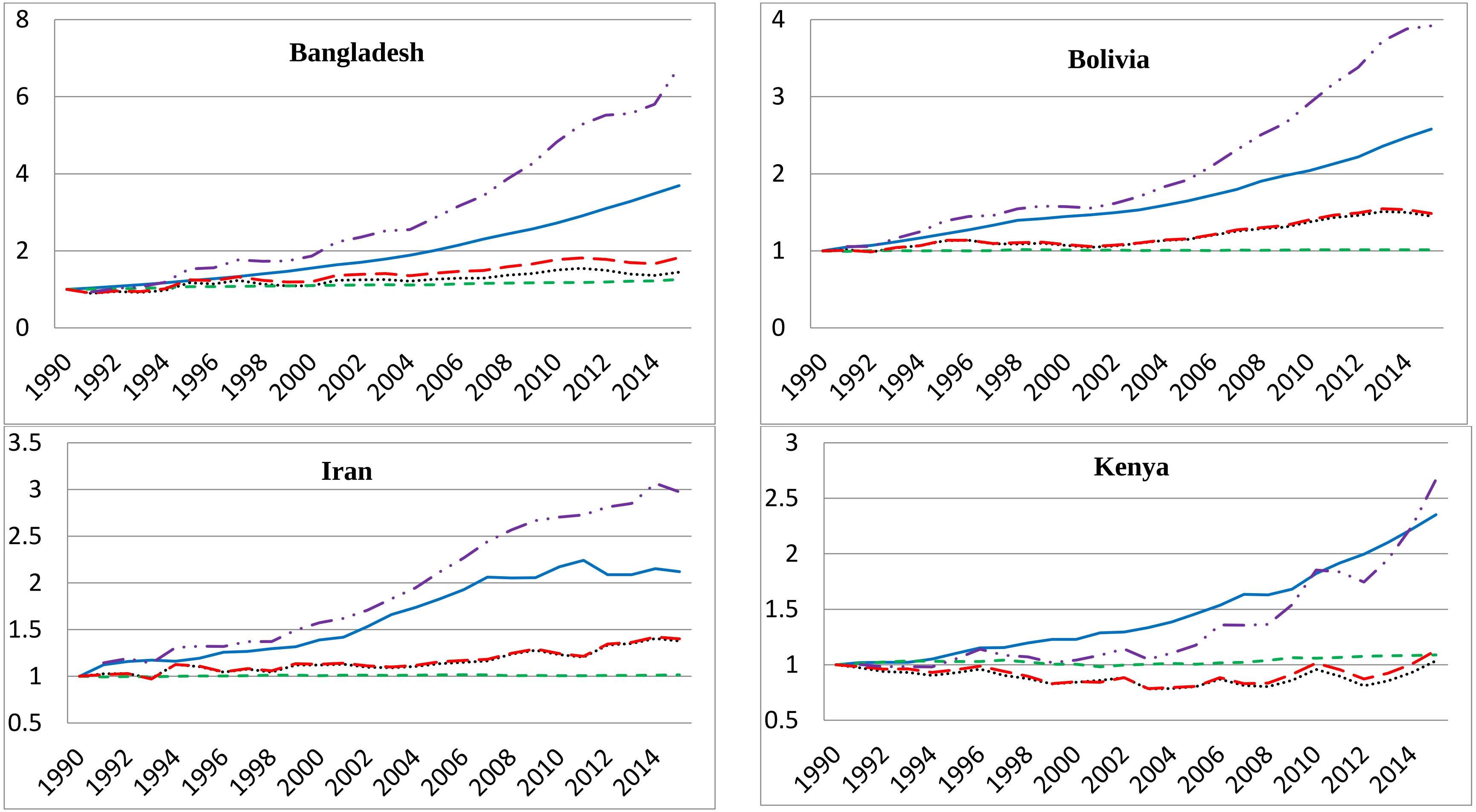

Figure 3.4: Graphical Presentation of Energy Consumption, Energy Intensity, Activity Effect, Efficiency Effect and Structural Effect; For the Case of Group 'C' Countries

In all the following graphs, —— Activity Effect, — — — Energy Intensity, - - - - Structural Effect, •••••• Efficiency Effect and ••·— Energy Consumption.

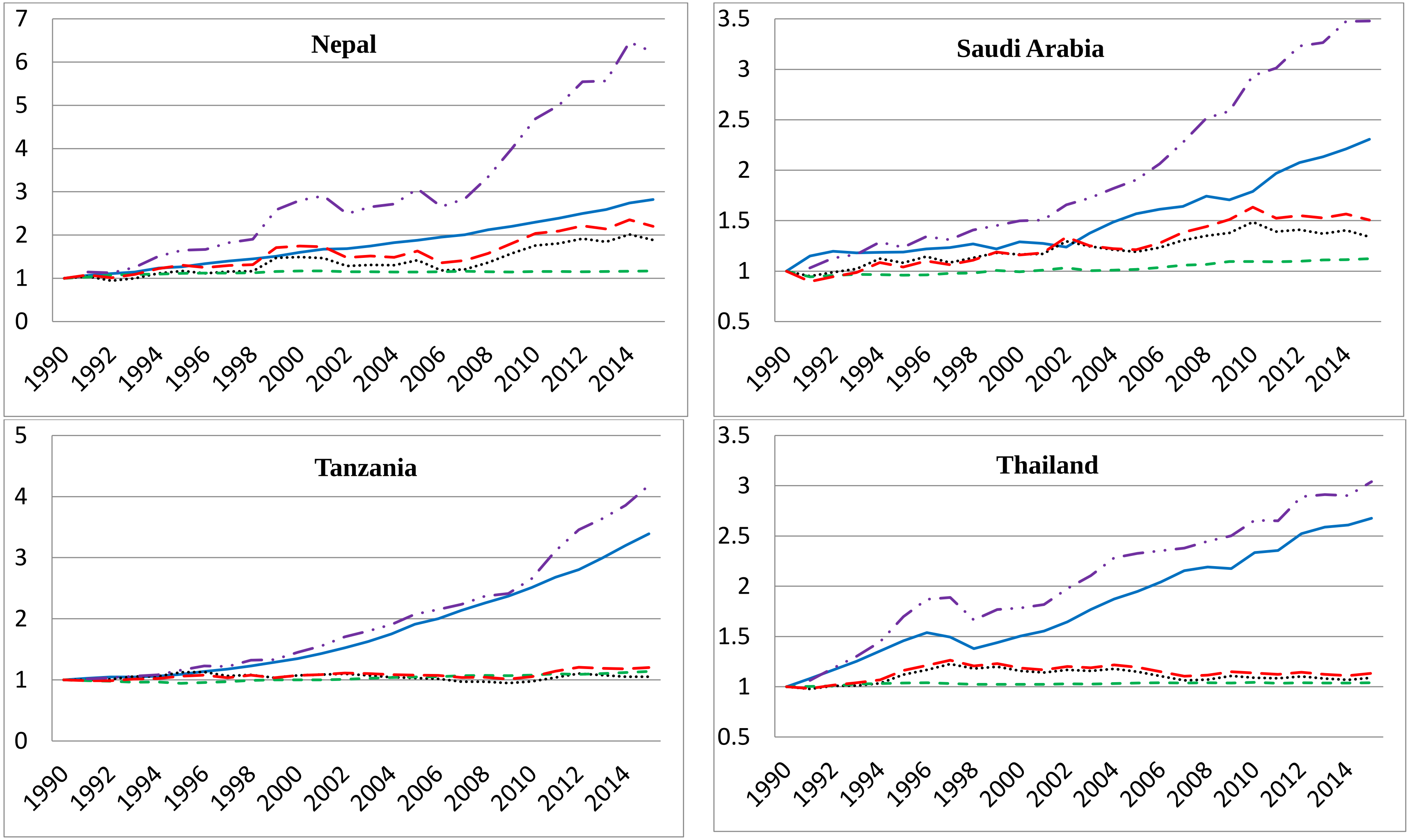

Figure 3.4 Continued

The trends of the main drivers of energy consumption in the form of annual growth rates are shown in Table 3.4. The countries where energy intensity is worsening due to both energy inefficiency and structural changes are listed in Nepal, Bolivia and Bangladesh are the countries where energy efficiency declined the most i.e. 2.56%, 1.5% and 1.49% respectively. The activity effect is moderate in this group also i.e. Bangladesh 5.36% and Tanzania 5.01%. Most of the countries that belongs to this group are using available energy inefficiently. Because, these countries have orthodox capital in their industrial structure and have energy management issues. Thus, structural effect contributed to increase energy consumption (Voigt et al, 2014). The negative contribution of structural effect in energy consumption is mainly due to a transformation process by which the importance of the industry in these countries as a whole realized to speed up the process of economic growth (Liu & Ang, 2007). The annual growth rates of activity, intensity and structural effect can be observed in the Table 3.4.

Table 3.4: Decomposition of Energy Consumption for the Period of 1990 to 2015; For the Case of Group 'C' Countries

				Absolute Changes			Annual Growth Rates		
Country	**Initial Energy**	**Final Energy**	**Absolute Change**	**Activity Effect**	**Efficiency Effect**	**Structural Effect**	**Activity Effect**	**Efficiency Effect**	**Structural Effect**
Bangladesh	1896	12850	10954	8685	1439	829	5.36	1.49	0.92
Bolivia	1290	5056	3766	2911	829	26	3.86	1.5	0.06
Iran	35540	105711	70171	51927	17515	728	3.05	1.29	0.06
Kenya	1566	4181	2615	2394	64	157	3.48	0.14	0.34
Nepal	293	1826	1533	972	471	90	4.24	2.56	0.63
Saudi Arabia	28821	100254	71433	52724	13742	4967	3.4	1.18	0.47
Tanzania	1603	6706	5103	4725	105	273	5.01	0.21	0.52
Thailand	20886	63504	42618	39550	2106	962	4.02	0.34	0.16

3.5. Determinants of Energy Efficiency: A Cross-Sectional Econometric Analysis

In previous section, energy consumption was decomposed in to three components, namely, the activity, structural and efficiency (sectoral intensities) components for the period from 1990 to 2015. The results of decomposition analysis show that the main contributing factor in variation in energy consumption over the period reviewed is energy efficiency. A follow up question then would be as to what factors drive the energy efficiency? To identify these factors driving energy efficiency, a separate econometric analysis is carried in this section using cross sectional regression model. As the structural component was found to be a minor source in explaining variation in energy consumption, the determinants of this have not been examined in detail.

The previous studies (Eatom & Kortum, 2001; Caselli & Wison, 2004; Hubler, 2011; Song and Zheng 2012; Herrerias et al., 2013; Sbia et al., 2014; Adom, 2015) mostly focus on the detrainments of the aggregate energy intensity. However, the present study analyzes the determinants of indexed base energy efficiency (sectoral intensities) components which provides the better insights to understand the changing pattern of energy efficiency. This is an addition in existing literature. To explore the underlying determining factors that better explain the variation in energy efficiency for the set of sample counties, a cross sectional regression model for energy efficiency component is devised.

In the generalized model (equation 3.14), energy efficiency component for country *i* is taken as dependent variable to be regressed on a number of explanatory variables for the respective cross sections. The available literature provides a host of variables to determine the energy efficiency in an economy. However, parsimonious approach is required to select the more relevant determinants explaining the energy efficiency.

The selection of variables[28] is based on relevant theoretical and empirical literature (Fisher-Vanden et al., 2004; Subrahmanya, M. B., 2006; Zografakis et al., 2007; Metcalf, 2008; & Song, 2012) as well as availability of consistent and reliable data. The following econometric model (3.14) is proposed to empirically analyze the relationship between energy efficiency and the set of independent variables included in the model. Theoretical justification for the inclusion of various explanatory variables in the model.

$$EE_i = \beta_0 + \beta_1\, TE_i + \beta_2\, TE_i^2 + \beta_3\, K_i + \beta_3\, K_i^2 + \beta_4\, LP_i + \varepsilon_i \tag{3.14}$$

The dependent variable (EE_i) is index of energy efficiency component of year 2015 using base 1990, as calculated in previous section. TE, K and LP denote the percentage changes in tertiary education, capital-labor ratio and labor productivity during the period of 1990 to 2015 respectively. For the construction of these variables we also need data on GDP, gross capital formation and employed labor force. Data on gross fixed capital formation, employed labor force and gross domestic product (GDP) are taken from *World Development Indicators (WDI)* whereas data on tertiary education[29] are taken from Barro-Lee data set. The data on GDP and gross capital formation are measured in constant US$ prices of the year 2010. Gross fixed capital formation is used to construct capital stock series using perpetual inventory method by setting rate of capital depreciation equal to 0.05. The series on capital labor ratio is constructed by dividing capital stock by employed labor force[30]. Similarly, labor productivity is constructed by dividing GDP by employed labor force. The study used cross sectional data for 46 countries out of 60 countries. 14 countries are dropped due to data unavailability on tertiary education.

[28] The selected variables are taken from the studies which analysis the determinants of aggregate energy intensity.
[29] The total number of students enrolled at public and private tertiary education institutions.
[30] Employed labor force is calculated by multiplying labor force with employed rate.

Tertiary Education *(TE)*

Education can play a key role in improving energy efficiency through efficient behavior and attitudes in society (Zografakis et al, 2008). The level of education attainment may likely develop the positive attitude to adopt energy saving measures. However, education at all level has not the similar effect on energy efficiency. The higher/ tertiary education influences quite significantly as compared to primary and secondary education (Ma et al, 2019). In this regard, New borough and Probert (1994) have precisely stated that "Energy squandering could be better remedied by education and legislation rather than advanced technological solutions. The probability of achieving a sustainable future increases with the energy literacy of our society".

Capital–labor ratio *(K)*

Capital to labor ratio i.e. capital deepening/intensity of capital is considered as one of the important determinant of energy efficiency. The extensive literature related to the debate on complementarity and substitutability between capital and energy exist to identify the corresponding direction of relationship (Griffin and Gregory (1976) and Griffin (1981), Metcalf (2008), Song and Zheng, 2012). The capital-labor ratio is used as a measure of technology and expected to be positively related with energy efficiency.

Labor Productivity *(LP)*

Output per worker or average productivity of labor is used to analyze the effect of increase in labor productivity on improvement in energy efficiency (Subrahmanya, 2006). Labor productivity has a negative impact on energy cost. Thus higher labor productivity lowers energy intensity and higher returns to scale and can be a substitute for using expensive technology. Labor productivity contributes to reducing the number of hours worked per unit of output produced and, therefore, the energy requirements to produce output will be reduced.

Results of Cross-Sections Regression: Dependent variable is Energy Efficiency (EE_i) Index.

Like time series data, cross sectional data have also certain problems i.e. heterogeneity, heteroscedasticity, and spatial autocorrelation. The ordinary least square (OLS) estimation technique is applied to econometrically analyze the determinants of energy efficiency. The OLS assumes classical linear regression model (CLRM) i.e. the error term is independent and identical distribution (iid). But the estimates are subject to many econometric issues if the assumptions regarding the residual are violated. The diagnostic tests, therefore, consist of checking for autocorrelation, normality and heteroscedasticity of errors.

Since reliability of the estimated model depends on outcomes of diagnostic test, firstly discussion on these issues is provided and the results are reported in Table 3.5. To confirm whether residuals follow iid assumptions, Jarque-Bera (JB) test, White's test and Breusch-Godfrey LM Test are applied for normality, Heteroscedasticity and Special correlation respectively. The test results indicate that there is no serious econometric problem in regression residuals and model specification is appropriate. The diagnostics, therefore, justify the OLS technique and appropriate to obtain estimates parameters. The adjusted R^2 is 0.214. Our model is explaining 21.4 percent variations in the energy efficiency. The value of adjusted R^2 is reasonable for cross section studies.

Table 3.5: Diagnostics of Cross-Sections Regression.

Observations	***Statistics***	46
R^2		0.3013
Adjusted R^2		0.2140
Test		**P-value**
Breusch-Godfrey LM Test (1)	1.12	0.289
Heteroscedasticity White's test	5.01	0.415
Jarque Bera normality test	2.39	0.302

The dependent variable is index of energy efficiency. As explained in previous section, if the values of index decrease, it shows the improvement in energy efficiency (decrease in sectoral energy intensities) and vice-versa. The underlying reason is that, with the improved technology, less energy is required to produce given level of output. The OLS estimates are provided in the following Table 3.6.

Table 3.6: Estimates of OLS (Dependent Variable is an Index of Energy Efficiency)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
$\mathbf{C}$	67.156*	10.958	6.1280	0.0000
$\boldsymbol{TE}$	-0.213***	0.1254	-1.7054	0.0959
$\boldsymbol{TE^2}$	0.0058	0.0046	1.2624	0.2141
$\boldsymbol{K}$	0.285*	0.0863	3.2983	0.0020
$\boldsymbol{K^2}$	-0.0038*	0.0011	-3.0830	0.0037
$\boldsymbol{LP}$	-0.357*	0.1207	-2.9585	0.0052

Note that *, ** and *** represents significance at 1%, 5% and 10% level of significance respectively.

Almost all the variables have expected sign as suggested by literature. The coefficients of all the variables are statistically significant except for the square term of tertiary education (*TE*), which is capturing the non-linear relationship between higher education and energy efficiency. The tertiary education has significant negative coefficient. It implies that with increase in number of people enrolled in tertiary education leads to reduction in index value of energy efficiency i.e. improvement in energy efficiency. The obvious reason of this favorable effect is that tertiary education is minimum level of education required to produce researchers who can innovate new product designs, production processes and other such innovative devices. Tertiary education also provides high quality skilled labor force like engineers and managers who provide lead in labor services.

The coefficient of capital labor ratio (*K*) is significantly positive and square term is negative. It implies that, initially capital-labor ratio deteriorates the energy efficiency and beyond the certain level it improves the energy efficiency. The possible reason is that initially an increase in capital-labor ratio may to some extent reflect increased use of older machines and structure, that also leads to increased energy consumption. However further increase in capital-labor ratio is most likely to be materialized by replacement of old equipment with newer and technologically more advanced machines that are designed to ensure energy conservation.

The labor productivity (*LP*) also statistically significantly improving the energy efficiency. The reason is that labor productivity has a negative impact on energy cost. The higher labor productivity lowers energy intensity and higher returns to scale and can be a substitute for using expensive technology. Labor productivity contributes to reducing the number of hours worked per unit of output produced and, therefore, the energy requirements to produce output will be reduced.

3.6. Conclusion

This paper analyzed energy consumption trends for fifty-one countries between 1990 and 2015. It decomposes energy consumption into activity, structural and technology effects in order to examine what share of temporal variation is due to actual changes in activity, energy efficiency, and what share is based merely on structural changes of the economy. The aggregate and country-level decompositions of energy consumption presented in this paper suggest very different conclusions. At the global level, a high portion of energy intensity declines is driven by the technology effect, suggesting a general move towards more efficient means of production. Out of 51 countries, in 44 countries energy intensity declined on account of efficiency in energy use. Conversely, our country-level analysis shows that the heterogeneity across countries is high and that a common pattern cannot be easily singled out. Countries' performances in terms of the structural and technology component differ independently of the economy's level of development or initial level of energy efficiency. We find that countries can be grouped in three main clusters with reference to energy intensity performance. Downfall in energy intensity thereby energy consumption is driven by both efficiency and structural effects in group A. However, the efficiency effect is stronger than the structural effect in this group. In group B, the energy intensity declines only because of efficiency effect only where as in group C, the energy intensity is worsened by either structural or efficiency effect. The activity effect influenced the energy consumption positively due to rising trend of economic growth in all the countries in our sample.

The results of our research show that policies related to increase energy efficiency clearly are not sufficient to reduce aggregate energy consumption. In most countries the growing overall economic activity and some changes from less to more energy-intensive sectors (structural effect) are strong enough to offset the expected results of energy efficient related policies. For the countries where the structural changes scaled down the energy consumption have also very meager activity effect. Thus, there is considerable scope to reduce the energy consumption through the structural transformation.

Analyzing the situation at country level as well as aggregate level, our research suggests the following energy and environmental actions related to increase in energy efficiency and structural effect that can possibly helpful in order to reduce the energy consumption. To further increase and long-lasting improvement in energy efficiency requires the diffusion of technologies from more advanced countries to less one, rational use of taxation in order to achieve more efficient use of Energy, increasing investments in order to take advantage of economies of scale in renewables, and an international agreement to promote a common effort. However, at the same time, a large proportion of these actions –such as funding renewables or some taxation – involves changes in the market that lead to readjustment in agent decisions. Thereof, this intervention is likely to affect the production structure, which relates directly to the structural effect.

With respect to the cross sectional analysis of major drivers of energy efficiency, our findings indicate that tertiary education improves energy efficiency, as higher educational attainment may likely develop a more positive attitude towards energy saving measures. With regards to capital labor ratio, the results show a U shaped relationship indicating that initially capital labor ratio deteriorates energy efficiency, but beyond a threshold level it leads to improvement in energy efficiency. The labor productivity also statistically significant which implies in improving the energy efficiency. The reason is that labor productivity has a negative impact on energy cost. The higher labor productivity lowers energy intensity and higher returns to scale and can be a substitute for using expensive technology. Labor productivity contributes to reducing the number of hours worked per unit of output produced and, therefore, the energy requirements to produce output will be reduced. In terms of policy implications, our analysis points out that investment in higher education can play an important role in improving energy efficiency. Similarly, increase in labor productivity can lead to energy efficiency as higher labor productivity reduces the energy cost.

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Appendix 3: Aggregate Energy Intensities of Three Groups of Countries

Year	Aggregate level	Group A	Group B	Group C
1990	1	1	1	1
1991	1.001	1.000	0.995	0.968
1992	0.982	0.961	0.967	0.996
1993	0.977	0.938	0.957	0.998
1994	0.946	0.883	0.925	1.095
1995	0.960	0.882	0.935	1.110
1996	0.933	0.850	0.884	1.123
1997	0.907	0.818	0.848	1.134
1998	0.896	0.806	0.839	1.114
1999	0.875	0.790	0.794	1.176
2000	0.849	0.762	0.766	1.156
2001	0.841	0.750	0.753	1.168
2002	0.837	0.738	0.738	1.217
2003	0.847	0.738	0.749	1.186
2004	0.874	0.729	0.797	1.189
2005	0.881	0.721	0.804	1.196
2006	0.875	0.704	0.791	1.213
2007	0.872	0.690	0.778	1.238
2008	0.871	0.691	0.758	1.280
2009	0.869	0.669	0.745	1.329
2010	0.881	0.678	0.740	1.345
2011	0.880	0.668	0.737	1.300
2012	0.869	0.654	0.714	1.350
2013	0.858	0.648	0.693	1.337
2014	0.843	0.623	0.673	1.365
2015	0.827	0.617	0.648	1.344

Chapter 4
Energy Intensity – Per Capita Income: Non-Linear Nexus: An Application of Spline Function

Abstract

This study explores the relationship between energy intensity and real per-capita income for the period of 1981-2015 in 60 countries. The study makes use of a spline functional form which gives flexibility of a non-liner relationship in analyzing this relationship. For the purpose of analysis, the sample of countries is divided into two categories, i.e., middle income and high income countries. On basis of diagnostic tests, pooled least square model is estimated for the sample of middle income countries, while a random effect model is run for the high income economies. The results for middle income countries show three distinct threshold levels of per capita income at which the direction of relationship between of energy intensity with per capita income changes. There threshold levels are estimated to be at annual per capita incomes of $816, $3700 and $5310. The results with respect to the high income countries does not indicate a threshold level with respect to their current level of income. This may be attributable to the fact that these countries have already passed their turning point at a period prior to 1990 and are currently on a path to reducing their energy intensity. The plausible reason of declining energy intensity in high income countries can be the changes in demand structure, fuel substitution and technological progress overtime.

***Key Words*:** *Energy Intensity, Per-Capita Income, Panel data, Spline Function, Non-Linearity*

4.1. Introduction

Globally, issues related to energy efficiency have become a center of discussion and attention for the policy makers and researchers for the past thirty years. Economic interests of various countries are being promoted via proper usage of energy for better economic performance that ultimately ensures the clean environment. Reduction in energy consumption globally and improvement in energy efficiency have gained much importance in recent times, when green economy and sustainable development have become a common slogan across the world economy.

The determinants of energy efficiency change across countries and it has become the focus of recent debates and discussions at politico-social and scientific level in the present era. Extensive discussions and research identified economic growth, energy prices, industrialization, the use of innovative technologies as the most pertinent determinants affecting energy efficiency. Energy efficiency gained through the usage of fewer energy units in order to produce a given level of economic activity remains constant. In other words, energy efficiency means the same level of output can be produced by using less units of energy. The sustainability in development calls for the energy efficiency that is assessed by the usage of energy per unit of output (Freeman et al., 1997; Streimikiene, 2007). Various factors are involved in shifting the trend of energy intensity over the time period. Of these factors, change in per capita income stands the most crucial factor in changing the trend of energy intensity (Labbé et al. 2013).

In empirical literature, how energy intensity gets shifted with the change of GDP per capita is most important area for energy research. While the economy of country is flourishing, it is being shifted from agriculture to industrial sector that ultimately boosts up the demand for energy; the per capita income gets increased. A considerable decline in energy use per unit of the given output is found when the industrial sector shifts into services sector or the services sector expedites more speedily than the other sectors. This behavior falls under the theory of dematerialization (Bernardini & Galli, 1993).

Medlock & Soligo (2001) analyzed the linkage of energy intensity with different levels of GDP per capita by employing econometric approach. The findings illustrate an inverted U shape curve between these variables. There ae two reasons of such type of curve; one is structural changes and the other one is technological changes in countries.

Structural composition of the economy changes and precedes the shifts in the structure of GDP which will rise and thereafter lower the energy intensity. Prosperous economy gives continuous rise to the income of the people that changes the living standards of them. They start using the products that extensively consume energy that mounts up the level of energy intensity. Thereafter, they come to know the unhealthy impacts of energy oriented products on the climate. Therefore, they shift from extensively energy oriented products to almost less extensively energy oriented products that lowers the energy intensity (Song & Zheng, 2012). The same argument has been provided by the Wu (2012).

The existing body of literature does not present conclusive evidence on energy intensity and per capita income nexus. This study revisits this question using a large data of 60 countries[31] using the time span 1981-2015. Unlike previous research in this area, we make use of a novel spline function which provides a functional flexibility to study the underlying relation with in two variables. The use of this functional form will enable better understanding the linkage of energy intensity with per capita income which is the main contribution of this

[31] These countries are classified with respect to income. A detailed view can be seen in appendix 4a.

research. It also finds the threshold level of GDP per-capita at which the relationship within these two variables changes direction,

Sections 1& 2 of this chapter are devoted to brief introduction and literature review respectively. Model, data and methodology used in the analysis are explained in section 3 and the results are presented in section 4. Conclusions and policy implications of the study are detailed in section 5.

4.2. Literature Review

The empirical literature on the energy intensity with its main determinants comprises two approaches. First strand of literature (Ang & Zhang, 2000; Ang, 2004; Liu & Ang, 2007; Song & Zheng, 2012; Wu, 2012) is focused on identifying the driving forces of energy intensity on the basis of index decomposition, while the second group of studies (Eatom & Kortum, 2001; Caselli & Wison, 2004; Hubler, 2011; Song and Zheng 2012; Herrerias et al., 2013; Sbia et al., 2014; Adom, 2015) analyzes the relationship of energy intensity with its determinants by using various econometrics techniques. Our research focuses on the view of second group.

Bernardini & Galli (1993) pointed out that rise in per capita income gives boost to the energy intensity because the economy passes through industrial phase. As the industrial phase of the economy reaches at extreme level, it shifts into services in nature that mitigates the use of energy which consequently scales down the energy intensity. Moreover, the campaign in favour of climate in post-industrial economy has played vital role in the reduction of energy consumption thereby energy intensity following a bell shape curve. Dasgupta et al. (2002) pointed out that energy intensity follows a pattern similar with Environmental Kuznets Curve (EKC) that shows the connection with in environmental degradation and GDP per capita.

According to Adom (2015), increase in the price of energy leads to change the existing pattern of energy usage through substituting the energy intensive techniques of productions and capital with the alternatives which consume less energy. Lin & Moubarak (2014) also found that the rise in price of energy bore a considerable impact in saving energy in Chinese industry whereas Song & Zheng (2012), upholds that policies related to the increase in the price of energy didn't play a significant role in improving the energy efficiency in China. Yang et al. (2016) maintained the same argument in his studies.

A number of studies highlighted the role of urbanization in changing the energy intensity. Andersson & Karpestam (2013) witnessed the linkage with in these two variables in some selected countries across the various continents. They observed that urbanization leads to increase in energy intensity. Rafiq et al. (2016) also highlighted it for 22 emerging economies. In addition to that, the similar impact of urbanization in Chinese economy has also been projected in the studies of Liao et al. (2007) and Song & Zheng (2012).

Various researches look in to industrialization as an important factor with regard to change in energy intensity. Poumanyvong & Kaneko (2010), Zhen-yu & Su-yun (2010), Adom (2015) analyzed that the service sector consumes less energy of the production thereby less energy intensity contrary to the products produced by the manufacturing sector. Whereas, Andersson & Karpestam (2013) indicated that there was weak linkage with in energy intensity and producing more goods in the industries in the presence of most up dated tools used in production process. Adom & Kwakwa (2014) studied the policies of Ghana related to energy efficiency wherein energy intensity was reduced in manufacturing sector with the usage of energy efficient tools and techniques that improve the energy efficiency. Herrerias et al. (2013) did not find strong evidence of effect of changes in industrial share in GDP on the energy intensity in China, although a positive effect was observed in case of some energy products

Trade openness is another factor playing a crucial role in determining the energy intensity. Foreign direct investment carries the most up dated and energy efficient tools for the production of goods which are shared with the local industries that ultimately change the ongoing energy intensity level (Adom, 2015). Rafiq et al. (2016) observed that the trade liberalization caused downturn in the level of energy intensity in developing countries. FDI and imports were found main factors in the reducing of energy intensity in China (Herrerias et al., 2013). However, Song & Zheng (2012) did not find any significant role of FDI in this context.

4.3. Model, Data and Estimation Procedure

4.3.1. Model

Like Environmental Kuznets Curve the relationship of energy intensity with per capita income may also follow inverted U-shaped pattern (Galli, 1998). This relationship is usually estimated as quadratic equation between log of energy intensity and log or per capita income. This function would yield, if at all, a single threshold level of per capita income at which the relationship turns its shape from positive direction to negative direction. However, there may be more than one such points where the nature of relationship changes due to different spurs of technological changes. In addition, the relationship may not necessarily follow the path dictated by quadratic equation.

To tackle this issue, we propose a quadratic equation with the allowance of shifts in the curve subject to continuity of the level as well as slope of the function. Suppose we allow a quadratic relationship log of energy intensity, denoted by LEI, and log of per capita income, denoted by LY, to shift at m threshold levels, of the latter. Let these threshold levels are denoted by LY_1, LY_2, …, LYm and define the following dummy variables (or indicator functions) D_j as:

$$D_j = 1 \; if \; LY \; \geq LY_j$$

$$= 0 \; otherwise$$

The functional relationship between the two variables will look like the following.

$$LEI = \alpha + \beta\ LY + \delta\ LY^2 \tag{4.1}$$

where,

$$\begin{aligned} \alpha &= \alpha_0 + \alpha_1\ D_1 + \ldots\ldots + \alpha_m\ D_m \\ \beta &= \beta_0 + \beta_1\ D_1 + \ldots\ldots + \beta_m\ D_m \\ \delta &= \delta_0 + \delta_1\ D_1 + \ldots\ldots + \delta_m\ D_m \end{aligned} \tag{4.2}$$

Substituting (4.2) into (4.1) yields:

$$\begin{aligned} LEI = {} & \alpha_0 + \beta_0\ LY + \delta_0\ LY^2 + (\alpha_1 + \beta_1\ LY + \delta_1\ LY^2)D_1 \\ & + \ldots\ldots + (\alpha_m + \beta_m\ LY + \delta_m\ LY^2)D_m + U \end{aligned} \tag{4.3}$$

This equation represents piece-wise regression in which the whole function potentially shifts at each threshold levels of per capita income. To ensure smoothness in the relationship around each threshold level, we impose the following conditions on piece-wise regression equation (4.3) for continuity of level and slope around each threshold level of per capita income.

$$\underset{LY \to LY_j^-}{\text{Limit}}\ E(LEI) = \underset{LY \to LY_j^+}{\text{Limit}}\ E(LEI) \tag{4.4}$$

$$\underset{LY \to LY_j^-}{\text{Limit}} \frac{\partial E(LEI)}{\partial LY} = \underset{LY \to LY_j^+}{\text{Limit}} \frac{\partial E(LEI)}{\partial LY} \tag{4.5}$$

The result is as follows.

$$LEI = \alpha_0 + \beta_0\ LY + \delta_0\ LY^2 + \sum_{j=1}^{m} \delta_j \left(LY - LY_j\right)^2 D_j + U \tag{4.6}$$

Equation (4.6) may be interpreted as a quadratic Spline function in which knots are the potential threshold levels LY_1, LY_2, …, LYm. In addition to the income variable, two control variables, trade openness and the share of industrial production in GDP are also included in the model to yield:

$$LEI = \alpha_0 + \beta_0\ LY + \delta_0\ LY^2 + \sum_{j=1}^{m} \delta_j \left(LY - LY_j\right)^2 D_j + \theta\ OPEN + \lambda\ IND + U \tag{4.7}$$

4.3.2. Data

The variables in this study are energy intensity, per capita income, trade openness and value added of industrial sector as a percentage of GDP (proxy for industrialization). Energy intensity means units of energy required to produce per unit of GDP. Real GDP divided by population is defined as real per capita income whereas value added of industrial sector as a percentage of GDP is used as proxy for industrialization. Trade openness is measured as total trade as ratio to GDP. Gross domestic product (GDP) is measured at constant 2010 US dollar in all variables. The source of data on these variables is *WDI (data base of World Bank).* The study uses data over the period of 1981-2015 for panel of 60 countries. Out of these 60 countries 26 belong to the category of high income countries according to World Bank classification and 34 belong to middle income category that include both upper-middle income and lower middle income countries. Those countries are selected in which the energy intensity changes remarkably over the time and for which the data for the period of under consideration is available.

4.3.3 Estimation Procedure

The first issue in the estimation of a Spline function is to select the number and placement of threshold levels. This can be done arbitrarily or through some elaborate search procedure. However, keeping in view that the objective of estimating Spline function is to allow further smoothness beyond what is available through a simple quadratic equation. In this context if the number of knots is sufficiently, defined over small intervals of the values of independent variable, the exact placement of knots is not very crucial. Our data on income variable is in natural log form and it ranges from about 6.0 to 11.5. We set ten knots with equal intervals 0.5 in logarithmic scale at 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5, 10.0, 10.5 and 11.0.

The next issue is the choice of estimation technique with panel data. For diagnostic purpose three regression equations are estimated, one for the set of 34 high-income countries, one for 24 middle-income countries and one for the combined set of 60 countries. Each of these equations is estimated by Pooled Least Squares, Least Squares with Fixed Effects and Feasible Generalized Least Squares following iterative procedure with random effects. Three tests are applied for choosing the most appropriate estimation procedure; Wald test to choose between pooled and fixed effects models, LM test to choose between pooled and random effects models and Hausman test to choose between fixed effects and random effects models. This exercise lead to the conclusion that in each of the three cases fixed effects model appears most appropriate.

At the second stage of diagnostics Chow test is applied to test as to whether fixed effects model for panel data can be justified against separate time series regression equations. This test showed that the loss of information due to pooling is highly significant and therefore fixed effects model with pooled data cannot be justified. His result placed the whole task of estimating Spline function in an awkward position because the number of time-series observations for each country are not enough to accommodate the large number of parameters (15) to be estimated. Pooling of the data is needed for two purposes, to generate sufficiently large sample for the estimation of all the parameters and to have sufficient variation in income to place enough number of knots needed for flexibility of the relationship. Although pooling is not justified on pure statistical grounds, it is needed and can be somewhat justified by arguing that all statistical models ultimately aim to capture some form of average behavior of data.

Nevertheless, the study proposes a compromise solution by resorting to Frisch-Waugh Theorem[32]. To explain the theorem, consider a regression equation with the set of k explanatory variables X. Suppose these variables are divided into two sets X_A and X_B consisting of k_A and k_B variables where $k_A + k_B = k$. Now the theorem says that OLS estimates of slope coefficients of the variables in set X_A in the multiple regression of Y on all the variables in set X will be identical to the corresponding estimates of the slope coefficients obtained when the residuals of the regression of Y on X_B are regressed on the residuals of the regression of X_A on X_B. However, the parameter estimates obtained from the two alternative procedures may differ if specification of the underlying model and/or estimation technique is changed between the two procedures.

In our context, to allow for some flexibility in the relationship and at the same time have sufficient sample size and range of variation in per capita income at the first step of estimation energy intensity and per capita income are regressed on control variables, trade openness and the share of industrial production in GDP separately for each country using time-series data. In each regression equation the best fitted ARMA structure is also included. The residuals from these estimated equations not only net out the effects of control variables but also take care of the possible fixed effects in the form of as many intercepts as the number of countries. In addition, autocorrelation in each series is also netted out. If Frisch-Waugh Theorem is followed strictly then the residuals of energy intensity should be regressed on residuals of per capita income for each country separately. However, at the second stage a single equation representing Spline function is estimated in panel setting.

32 See Frisch & Waugh (1933) for detail.

At the second stage of estimation switching points or knots are to be located with respect to per capita income but the income variable obtained as residuals after removing the effects of control variables and autocorrelation is centered at zero rather than the actual per capita income for each country. To resolve this matter, locations of the two residual series obtained at the first stage are restored around mean by adding country means to each country's residual series.

4.4. Results and Discussion

Following the estimation procedure explained in the previous section, we arrive at the final stage of estimation, that is the estimation of Spline function with panel data using mean adjusted residuals of energy intensity and per capita income as dependent and independent variables. Although the fixed effects have been netted out at the first step, there is still a possibility that fixed effects are present at second stage because the treatment of the given data set is not the same at the two stages. While residuals at first stage are obtained from country specific regression equations, the spline function at the second stage is estimated using panel data rather than country specific data. Thus, at second stage also we apply redundant fixed effects and Hausman tests for selection between pooled model, random effects model and fixed effects model. The outcomes of the diagnostics tests are given in Table 4.1.

Table 4.1: Diagnostics of Pooled and Random Effects for Middle and High Income countries

Middle income countries			**High income countries**	
Observations	**Statistic**	1190	**Statistic**	546[33]
Adj-R2		0.431		0.993
Test		**P-value**		**P-value**
Redundant test	40.22	0.112	2103.3	0.000

[33] Time period for high income countries is from 1995 to 2015, because data on industrialization is not available before 1995

Hausman test			39.41	0.000
Normality test	1.094	0.572	1.63	0.445
Pesaran CD	0.805	0.420	1.205	0.287

These tests lead to the conclusion that for middle-income countries pooled least square model is appropriate while for higher-income countries random effects model is appropriate. The regression results for middle income countries are presented in Tables 4.2, whereas, Table 4.3 shows the results for high income countries.

Table 4.2: The Results of Pooled LS Model for Middle Income Countries. Dependent Variable is LEI

Variable	**Coefficient**	**Standard error**	**t-stats**	**P-value**
C	-118.57*	9.653	-12.28	0.000
LY	35.17*	2.872	12.25	0.000
LY^2	-2.623*	0.213	-12.30	0.000
D02	3.918*	0.431	9.09	0.000
D03	-1.253*	0.480	-2.61	0.009
D04	0.453	0.453	1.00	0.317
D05	-2.313*	0.513	-4.51	0.000
D06	5.895*	1.561	3.78	0.000

* represents significance of Coefficient at 1% level of significance.

Based on the parameter estimates in Table 4.2, Spline function for middle income countries is shown in Figures 4.1.

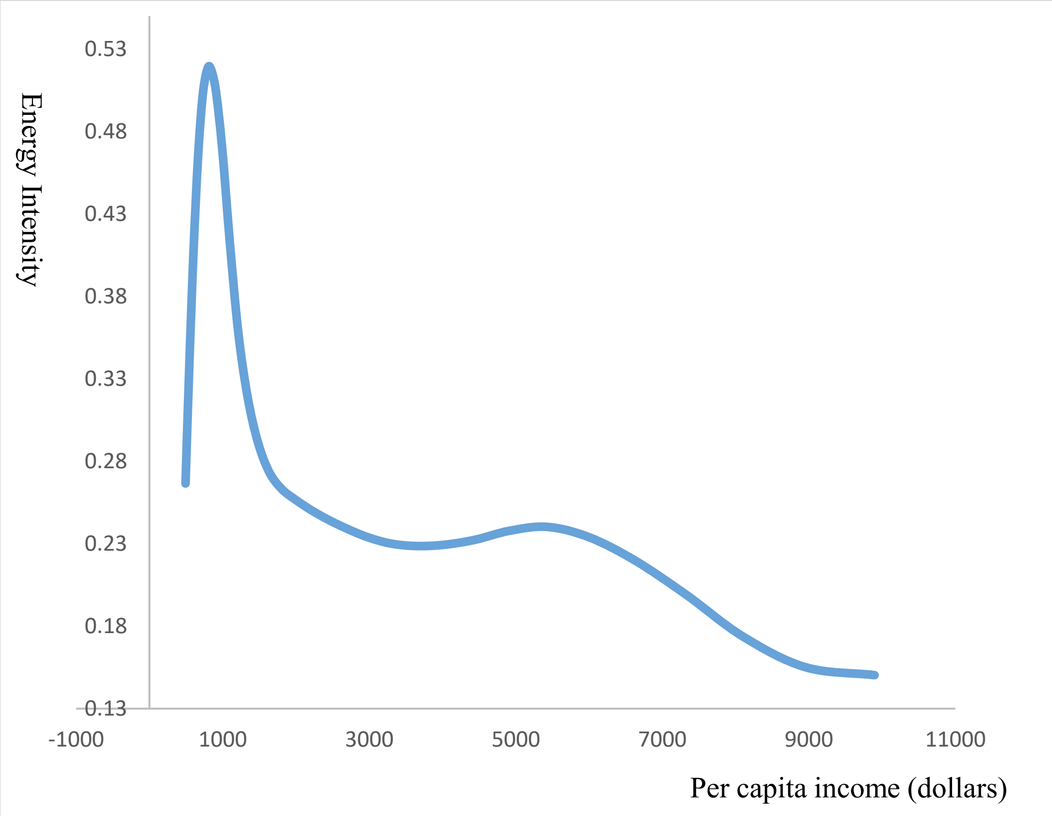

Figure 4.1: Graphical Presentation of Spline Function for Middle Income Countries.

The Spline function for middle-income countries (Figure 4.1) shows that there are three distinct threshold levels of per capita income at which the direction of relationship between of energy intensity with per capita income changes its direction. There threshold levels are estimated to be at annual per capita incomes of $816, $3700 and $5310.

At low levels of income prevalent in the countries like Bangladesh, India and Pakistan energy intensity increases with per capita income. This means that as the standards of living improve in terms of higher per capita incomes, the share of energy consumption in per capita income increases. Therefore, energy is treated as a luxury consumption good through direct household consumption and/or indirect consumption through its use in production process. This behavior is visible in terms of increasing use of electric appliances at household level and switching from labor-intensive production processes to more capital and energy intensive processes such as switching from human and animal labor to mechanization in agricultural sector. The results show that this pattern continues till the first threshold level of per capital income at $816.

Beyond this level, $816, the relationship turns negative, that is energy intensity starts declining with increase in per capita income and this pattern continues till the second threshold level of per capita income at $3700. Some of the countries that fall in this range of per capita income are Egypt, Indonesia, Philippines, and Thailand. The negative relationship in this income range means that when the income levels cross the threshold level, most of the basic necessities of life are fulfilled and the society becomes more conscious about the quality of life in terms of non-tangible things like education, health and clean environment. Environment-friendly consumption package is preferred over energy-intensive consumption basket. Clean environment replaces energy intensive consumption in the basket of luxury goods. As per capita incomes increase, countries can better afford to invest in environment both at micro and macro levels. More energy efficient consumer products, plants and machines replace energy intensive products and inputs and so on.

However, when the income level grows further beyond $3700 per capita per year, another spur of affluence hits consumption package. Larger proportions of population can now afford expensive and energy-intensive lifestyle. For example, small energy efficient motor vehicles are replaced with more fuel intensive large luxury cars and travel activities increase. Some of the middle-income families relying on one air-conditional and a few heaters are now replaced by upper middle-income families who can afford to install centrally controlled heating and cooling systems. Although these systems are more energy efficient, yet they are cost effective only for those who want to use more energy. For example, the households could afford to cool one or two rooms can now cool the entire house.

This spur of energy-intensive consumption continues up to another threshold level of per capita income at $5310 beyond which economies enter another spur of technological advancements is observed and it becomes possible to afford energy efficient but expensive devices like solar panels, electric cars and so on.

Table 4.3 shows the results for high income countries.

Table 4.3: The Results of Random Effects Model for High Income Countries. Dependent Variable is LEI

Variable	Coefficient	Standard error	t-stats	P-value
C	-9.929	38.991	-0.255	0.799
LY	1.885*	0.964	1.955	0.009
LY^2	-0.109**	0.052	-2.091	0.036
D07	0.023	0.751	0.030	0.976
D08	-0.486	0.602	-0.807	0.420
D09	1.567**	0.763	2.053	0.041
D10	-2.337**	0.999	-2.339	0.020

*,** represents significance of Coefficient at 1% & 5% level of significance.

Based on the parameter estimates in Table 4.3, Spline functions are drawn for high income countries is shown in Figures 4.2.

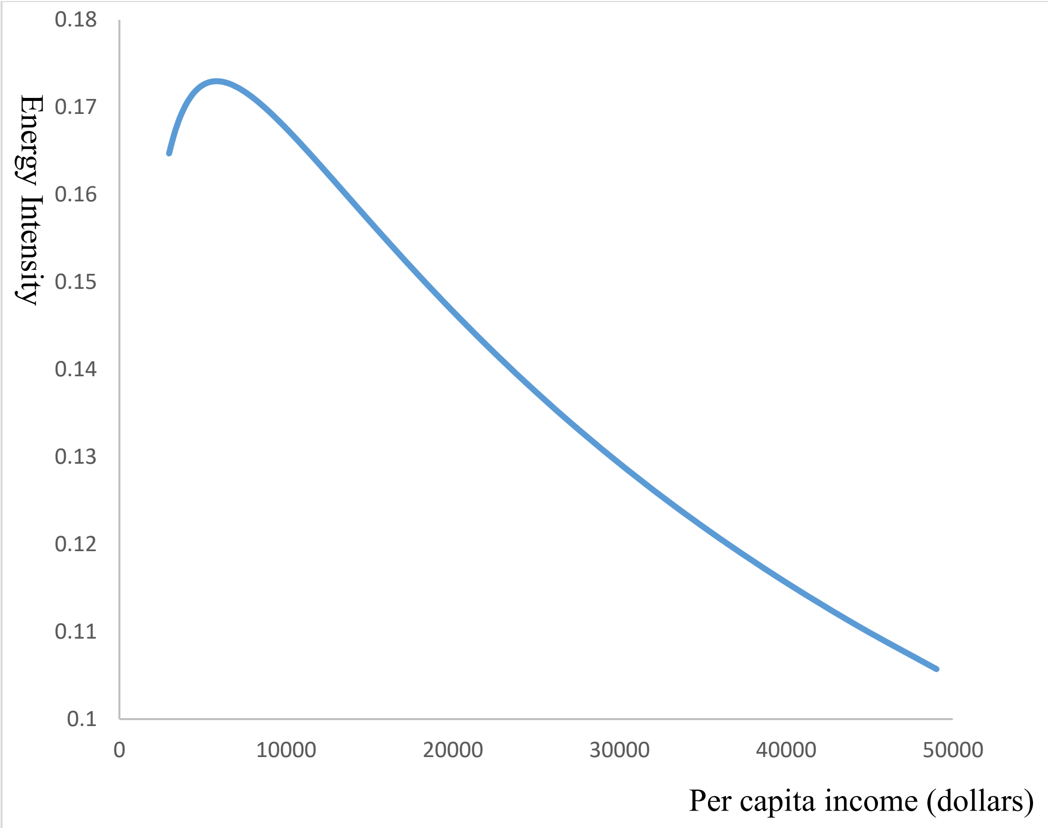

Figure 4.2: Graphical Presentation of Spline Function for High Income Countries.

The Spline curve for high-income country is shown in the figure 4.2. Spline function for high income countries show that the threshold level of per capita income $ 5431.66. The results with respect to the high income countries do not indicate a threshold level with respect to their current level of income. This maybe attributable to the fact that these countries have already passed their turning point at a period prior to 1990 and are currently on a path to reducing their energy intensity. The plausible reason of declining energy intensity in high income countries can be the changes in demand structure, fuel substitution and technological progress overtime. Furthermore, the downward sloping curve of energy use per unit of GDP flattens out at higher level of income as shown by results in table 4.3 (D9 & D10 are significant).

4.5. Conclusion

The energy security, its sustainability, oil price and the serious issues involved in climate change can be handled through the reduction of energy intensity. This study went through the empirical implications of per capita income on energy intensity while using a panel data in 60 countries for the period of 1981 to 2015. The study makes use of a spline functional form which gives flexibility of a non-liner relationship in analyzing this relationship. For the purpose of analysis, the sample of countries is divided into two categories, i.e., middle income and high income countries. On basis of diagnostic tests, pooled least square model is estimated for the sample of middle income countries, while a random effect model is run for the high income economies. The results for middle income countries show three distinct threshold levels of per capita income at which the direction of relationship between of energy intensity with per capita income changes. There threshold levels are estimated to be at annual per capita incomes of $816, $3700 and $5310. The results with respect to the high income countries does not indicate a threshold level with respect to their current level of income. This may be attributable to the fact that these countries have already passed their turning point at a period prior to 1990 and are currently on a path to reducing their energy intensity. The plausible reason of declining energy intensity in high income countries can be the changes in demand structure, fuel substitution and technological progress overtime.

The outcomes of this study discovered that the link of per-capita income with energy intensity illustrate an inverted U-shaped curve that encourages the theory of de-materialization. Policy instruments increasing per capita output to be appreciated provided that the energy intensity is lowered at higher per capita income levels. Therefore, the country should seriously target to achieve the higher real per capita income if it intends to minimize energy intensity as per thought.

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Appendices

Appendix 4a: Classification of Countries on the Basis of Income

Lower Middle Income Countries:

1. Bangladesh 2. Bolivia, 3. Cameroon,4. Egypt, Arab Rep,5. El Salvador, 6. Guatemala,7. Honduras,8. India,9. Indonesia,10. Kenya,11. Morocco,12. Pakistan,13. Philippines,14. SriLanka,15. Sudan, 16. Tunisia,

Upper Middle Income Countries:

1. Algeria, 2. Argentina,3. Botswana,4. Brazil,5. Bulgaria, 6. Costa Rica,7. Cuba, 8. Dominican Republic,9. Ecuador,10. Gabon,11. Iran, Islamic Rep, 12. Malaysia,13. Mauritius,14. Mexico,15. Panama,16. Peru,17. South Africa,18. Thailand,

High Income Countries:

1. Australia,2. Austria,3. Belgium,4. Chile,5. Cyprus, 6. Denmark, 7. Finland, 8. France,9. Germany,10. Greece,11. Ireland,12. Italy,13. Japan,14. Korea, Rep, 15. Luxembourg, 16. Netherlands,17. New Zealand, 18. Norway, 19. Portugal, 20. Singapore,21. Spain, 22. Sweden,23. Switzerland, 24. Trinidad and Tobago, 25. United Kingdom,26. Uruguay

Appendix 4b: Methodologies for Estimation in Panel Data

There are three estimation techniques for panel data.

Pooling Approach

The first approach completely pools the entire data, and assumes that data is homogenous and thus ignores unobserved heterogeneity. To explain econometric methodology, we are making model simple and including only one variable.

$$\mathrm{EI}_{\mathrm{it}} = \beta_0 + \beta_1 Y_{\mathrm{it}} + \varepsilon_{\mathrm{it}}$$

While doing so, this technique forgets the distinction of both dimension i.e. space and time; and assumes that both slope and intercept coefficients are constant over space and time. The simplicity is the main advantage of current approach. There are many drawbacks of this approach. The omitted variable bias could occur by paying no attention to unobserved heterogeneity (Skrondal & Rabe-Hesketh 2004; Hsiao 2003). Furthermore, there is no interpretation of the estimates of pooling approach, as it assumes that the between and within cross-sectional characteristics are same. Consequently, the researcher is unable to identify over the results (individual versus aggregate or panel versus cross-sectional) the relationship in fact takes place.

Fixed Effects Model

Fixed effects model permits each cross-section to have its own intercept. The FE model assumes that slope coefficients are constant over time and space but intercepts varies over space but is time irrelevant.

$$\mathrm{EI}_{\mathrm{it}} = \beta_{0\mathrm{i}} + \beta_1 Y_{\mathrm{it}} + \varepsilon_{\mathrm{it}}$$

The intercept is allowed to vary over space by introducing the dummy variables for each cross-section. The major drawback of this model is that it consumes a lot of degrees of freedom, that ultimately reduces the reliability of estimated parameters (Beck and Katz 2001; Beck 2001). The introduction of cross-section specific dummies absolves cross-sectional variation (i.e. heterogeneity) in FE model. Hence, the explanatory variables captures only the within cross-sectional effects. These within cross-sectional effects have the following interpretation: for a given country, as GDP per capita increases one dollar over the time, Energy intensity raises or declines by β_1 units. Cross-section specific explanatory variables cannot be induced due to the presence of cross-section-specific dummies, so the between-cross-sectional hypothesis cannot be tested in FE models. Joint F-test of cross-sectional dummies is performed to check the adequacy of the FE models. In this test, null hypothesis is that impact of cross-sectional dummy is jointly zero. If the test is able to reject the null hypothesis, then FE specification is preferred over pooled approach.

Random Effects Model:

In cases of panel data with a lot of cross-sections and relatively shorter time span (i.e. n is large and t is small), the application of FE model is much expensive (as it will consume too many degrees of freedom). As cross-sectional dummies capture the unobserved heterogeneity, so these are actually a symbol of deficiency of our knowledge about the true model. Hence, it would be better to address this deficiency by incorporating this heterogeneity in residual term ε_{it}?

$$EI_{it} = \beta_{0i} + \beta_1 Y_{it} + \varepsilon_{it}$$

Where $$\beta_{0i} = \beta_0 + \mu_i$$

Whereμ_i is a residual term having zero mean and a constant variance. By the incorporation of heterogeneity in residual term, we meant that the selected cross-sections are drawn from a larger universe and that they have a common mean value for the intercept (β_0) and the individual differences in the intercept values reflected in the error term μ_i. The back substitution results in

$$EI_{it} = \beta_0 + \beta_1 Y_{it} + \mu_i + \varepsilon_{it}$$

$$EI_{it} = \beta_0 + \beta_1 Y_{it} + \emptyset_{it}$$

The "composite error term $\emptyset_{it}$ consists of two components, μ_i, which is the cross-section, or individual-specific, error component, and ε_{it} which is the combined time series and cross-section error component".

For application of RE model one strong assumption should hold i.e. μ_i (cross-section, individual-specific, error term) must not be correlated with explanatory variable. Otherwise, RE model will face problem of endogeneity and the estimates will become biased.

$$COV(X_{it}, \mu_i) = 0$$

Since explanatory variables are allowed to vary both between and within cross-sections, several econometricians argue that the assumption of no correlation between the error term and explanatory variables is unrealistic one. They argue that unobserved heterogeneity is due cross-section specific characteristics, so more probably it would be associated with the explanatory variables. The FE model does not make such a controversial assumption, so it is regarded as a superior model than the RE model (Wilson & Butler 2007; Kristensen & Wawro 2003; Beck 2001). Hausman test (1978) is often applied to evaluate the competence of this contentious assumption. Furthermore, several econometricians have point of view that RE model will be appropriate if cross-sections are selected at random from a large normal population. On the contrary, in case of panel data of countries FE model is superior to RE model because selected countries are not drawn randomly and also the population is not so large (Kristensen and Wawro 2003; Beck 2001). Another drawback of the RE model is that its estimated coefficients have the similar problem as was with the coefficients of the pooling approach. However, in case of RE model the coefficients are pooled partially, contrasting to completely pooled, still the estimation procedure assumes that the between and within cross-sectional effects are same, consequently causing the interpretation of the estimated to be imprecise. The main benefit of the RE model is that the researchers are able to incorporate explanatory variables specific to cross-sections (the panel data variables that do not changes over time i.e. area of a country). Hence the researcher is able to test the hypotheses related with the between-cross-sections effects. Another advantage of the RE model is that it does not consume a lot of degrees of freedom as was the case of FE models.

Comparison of the Fixed and Random Effects Model:

Both of these techniques have contradictory advantages i.e. the advantages of one technique are the disadvantages of other. The choice between these two models is made on the basis of Hausman (1978) test. This test states that "if the FE estimator is consistent whether β_{0i} is fixed or random and the commonly used RE estimator is consistent and efficient only if β_{0i} is indeed uncorrelated with independent variables and is inconsistent if β_{0i} is correlated with these". Hence, the test proposes asymptotically chi-square distributed Wald statistic. The null hypothesis is that the RE estimates are consistent and efficient. If the test rejects the null hypothesis, then FE modeling is appropriate. It is researcher's decisive decision regarding the choice of model, and application of Hausman test ''neither necessary nor sufficient'' for the selection of models (Clark and Linzer 2012).

Chapter 5
Conclusion and Policy Recommendations

The present study contributes to the large and growing body of empirical research on understanding the global energy consumption patterns by examining three inter-related questions i) what is the energy-output nexus and is it differential across developed and developing countries; ii) what are the driving factors contributing towards changes in energy consumption over time and what are the determinants of energy efficiency (sectoral energy intenisties) iii) what is the relationship of energy intensity with per capita income.

The first part of the study employs country wise time-series as well as panel estimation for 26 developing and 18 developed countries, over the period 1980 to 2014; based on the ARDL framework. The second part of our study analyzed energy consumption trends for 60 countries, between 1990-2015 and uses the LMDI to decomposes energy consumption into activity, structural and technology. In addition to that the determinants of energy efficiency are investigated using a cross-sectional econometric analysis. The third part of the study examines the link of per-capita income with energy intensity using panel data of high income countries and middle-income countries separately for the period of 1981-2015 and applying the Quadratic spline function.

The study's findings with respect to the energy-output relationship indicate that energy consumption contributes to economic activity both in the developed and developing countries and in both short as well as the long run. It is further seen that the long-run contribution of energy use per capita to per capita output is higher in developed countries in comparison to the developing countries. The findings with respect to the aggregate and country-level decomposition of energy consumption shows that at the global level, the activity effect and efficiency effect play a pre-dominant role, whereas structural effect plays a minor role in determining aggregate energy consumption trend, over the period reviewed. On the other hand, the country-level analysis shows that the activity effect has increased energy consumption across most of the sample countries, whereas a high heterogeneity is observed for the other two effects across countries, on the basis of which countries have been grouped into three main clusters with reference to aggregate energy intensity performance. The first group includes countries where change in energy consumption (decrease) has been driven by both efficiency and structural effects; with the efficiency effect being stronger than the structural effect. The second group comprises of countries where only the efficiency effect has been responsible for changing energy consumption trend (decrease). The third group includes countries where energy consumption has been increased due to the structural and efficiency effect. In addition to that, the results of a cross-sectional analysis of main determinants of energy efficiency shows that energy efficiency improves with higher education and labor productivity while a U –shape relationship is observed in case of capital labor ratio.

The findings with regards to the third aspect show that an inverted U-shaped linkage is illustrated in relationship of income per capita with energy intensity. The results for middle income countries show three distinct threshold levels of per capita income at which the direction of relationship between of energy intensity with per capita income changes. There threshold levels are estimated to be at annual per capita incomes of $816, $3700 and $5310. The results with respect to the high income countries does not indicate a threshold level with respect to their current level of income. This may be attributable to the fact that these countries have already passed their turning point at a period prior to 1990 and are currently on a path to reducing their energy intensity

A number of important policy implications emerge from the analyses carried out. Our findings indicate that there is a need to integrate innovative approaches into national and regional development programs, to improve access to affordable, modern and clean energy, including household access to electricity from renewable energy technologies, for all populations and productive sectors. Since the impact of energy consumption on economic activity is relatively less is developing countries; these countries could also be encouraged to conserve energy through technology transfer and other incentives such as energy-use sensitive trade policies in developed countries.

In order to reduce global energy consumption, policy needs to focus on changing countries' economic structures as well as increasing efficiency. However, as the process of structural transformation is a slow process taking many decades, immediate policy measures should consider improving efficiency of the existing economic structures across the emerging and developing countries. To promote long-lasting improvement in energy efficiency, the transfer of technologies from more advanced countries to less developed countries should be facilitated. Other measures to improve energy efficiency can include rational use of taxation and increasing investments in renewable energy resources. Furthermore, to increase the energy efficiency there is need to chalk out such policies that can promote higher education and improve labor productivity

The findings with respect to change in energy intensity due to rise in per–capita income has an important lesson especially for the developing economies. These countries should devise policies for achieving higher real per capita income, through among others reducing their population growth rates.