Pakistan Languages and Humanities Review P-ISSN 2708-6453
April-June, 2022, Vol. 6, No. 2[1090-1102] O-ISSN 2708-6461

Pakistan Languages and Humanities Review
www.plhr.org.pk

RESEARCH PAPER

Energy Efficiency and Structural Change Developments across Newly Industrialized Economies: A Sectoral Decomposition Analysis

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DOI	http://doi.org/10.47205/plhr.2022(6-II)92

PAPER INFO

Received: March 25, 2022
Accepted: June 28, 2022
Online: June 30 , 2022

Keywords: Energy Efficiency Energy Consumption, Log Mean Divisia Index (LMDI), Structural Change

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ABSTRACT

Variation in energy consumption patterns is prominently coupled with efficiency change in newly industrialized countries. The current study estimates the shift in energy consumption in Newly Industrialized countries considering three main economic sectors through the Logarithmic Mean Divisia Index (LMDI) during the period 1990–2015 to analyse the changing patterns of energy consumption. The study considers the change in activity, efficiency and structural components as vital factors that cause changes in energy consumption across the countries. Of these components, the activity component is the major cause of escalating the energy consumption in all the countries whereas the Energy efficiency component contributes to reducing energy consumption except in Brazil, but its contribution is far less than the opposite effect of the activity component. However, the structural component increases energy consumption in China while a more or less persistent behaviour in other countries. The next finding of the study is that, in most countries, energy intensity follows the energy efficiency pattern. The main contributing factor in reducing energy consumption is the improvement in energy efficiency. There is considerable scope to reduce energy consumption through the structural transformation in these economies.

Introduction

In wake of expansion in industry, the extensive use of energy has given set – back to the climate at large as the level of greenhouse gases particularly, CO_2, is higher than ever before and has become a hot topic for environmentalists at the international level for the last some years. On the flip side of this issue, this is not only upgrading the living styles of the people but also playing a basic role in economic growth Ayres et al. (2013). Ever since the newly industrialized counties emerged on the map of the global economy, the emission of Carbon Dioxide (CO_2) got accelerated further that are posing threats not only to the global environment but also to the human existence on the planet. The surge in gasses is the result of fossil energy consumption as the newly industrialized countries either lack outdated technology or the absence of renewable resources that may cause the reduction in the al warming and other factors badly affecting human existence on this planet as well on others.

If the world has decided to avert the effects of global warming on this planet, it is imperative to cut down the level of greenhouse gases in the environment. It is the only possible way to achieve the 2 –degree Celsius target of the Copenhagen Accord 2009 Chappe (2015). The break-down in the emission of greenhouse gases is conditioned by the reduction of energy consumption yet it has become a very complicated dilemma that the environmental targets and economic growth side by side and both are inevitable for the stability of the world. However, a lot of literature on this topic has been established wherein the policymakers strived a lot to develop harmonization between the environment and the economic growth via green growth in the world for their sustainability.

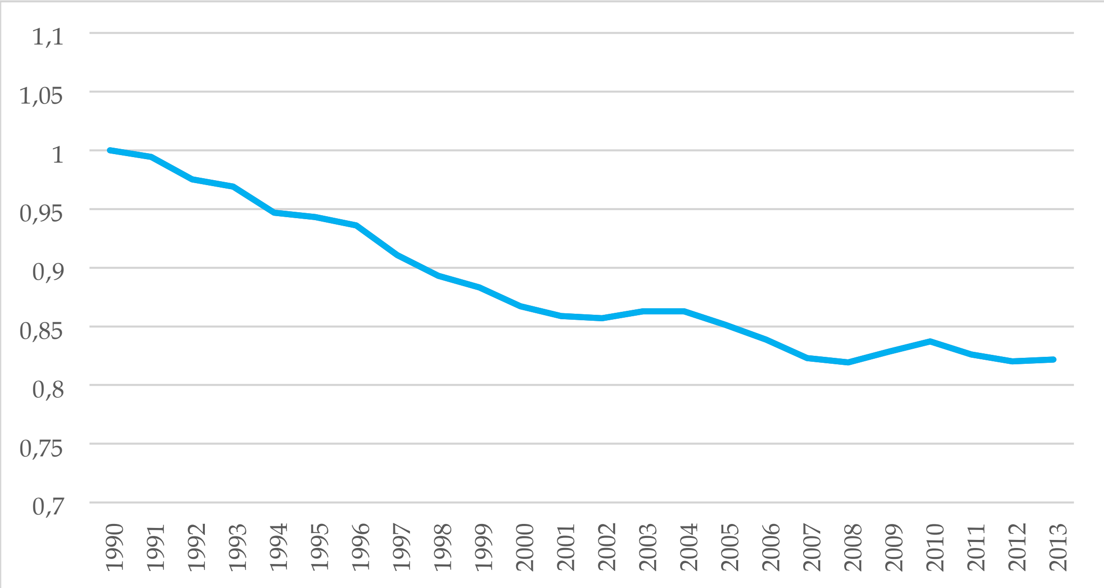


Figure 1: Trends of energy intensity across the globe (world (energy consumption / GDP)) from 1990.

After going through the literature on green growth, the acceleration in economic growth with the limited global warming can only be targeted through the replacement of non–renewable energy sources with renewable resources of energy. The green growth is coupled with modern technology which is still lacking at the global level though some countries are fully equipped with technology the majority need improvements in their energy sector Wirl and Yegorov (2015). The energy intensity can also be declined with the disassociation of economic growth from energy consumption. With the introduction of the green growth economy, the energy intensity has been consecutively reduced.

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 et al., 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 the efficiency effect that was mainly attributed to the usage of efficient technologies and energy mix; while this steady decrease was not observed for developing countries. Ang (2004) decomposed the energy intensity change during 1973-2013, using LMDI.

Few studies examined the trend of energy consumption by using decomposition analysis. (Wang et al., 2014; González et al.,2014; Lin & Long, 2014; Mendiluce et al., 2010) decomposed energy consumption into various components like activity, intensity etc. considering mostly developed countries. Their findings indicated that the energy intensity effect had a central role in reducing energy consumption.

The study will explore the driving factors behind the energy consumption changes in the economy and their effects on the energy intensity in totality in each member state of (NIC) from 1990 to 2015. The reason for exploring such factors is that it provides better insights to policymakers in order to formulate energy conservative policies by targeting the specific factor. For that, the multiplication version of log means Divisia index LMDI-I has been used as it bears the perfect decomposition feature. This paper will also disaggregate the energy consumption trends in the key sectors of each economy in our study. Each country is different from the other with regard to the energy areas so will definitely be having varied causes of changes in energy consumption (2011). After highlighting the causes of change in energy consumption, it will be helpful in formulating the policies in the right direction. The study will examine the effect of three main factors influencing energy consumption as well as highlight the factor(s) affecting aggregate energy intensity. On basis of this analysis, the policymakers can devise better plans for the future direction of energy consumption and energy-saving policies.

The paper is comprised of four sections. Section 2 discusses the LMDI decomposition analysis method along with its data requirements. The obtained results of the LMDI factor decomposition analysis are presented in Section 3. The last section concludes the paper and provides relevant policy implications.

Materials and Methods

An extensive literature documented the usage of various Index Decomposition techniques for the decomposition of energy intensity into structural effect and efficiency but the Logarithmic Mean Divisia Index is considered the robust technique by Ang (1995b), Ang et al. (2010), and Liu and Ang (2007). Various new studies have employed the Logarithmic Mean Divisia Index (LMDI) to decompose the total energy consumption in its driving factors – activity effect, structural effect, and efficiency effect in order to find factor (s) which can affect the energy consumption trend over the time, which includes Baležentis et al. (2011), Zhang et al. (2011), Lin and Long (2014), González et al. (2014) and Wang et al. (2014). The factors influencing the energy consumption shifts have been studied through decomposition analysis for which the multiplicative version of the Log-Mean Divisia Index Method-I (LMDI-I) decomposition has been preferred Ang (1995), Ang and Liu (2001).

This method is preferred in the literature on account of four key cited reasons. Firstly, the Laspeyres index considers the ordinary percentage change that is the source of asymmetric of relative change. F urther, it is also non-additive in nature 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, the Arithmetic Mean Divisia Index (AMD) method has not been used because it doesn't satisfy the properties of the factor reversal test that leads to residual. Thirdly, Ang and Choi (1997) suggested log-mean Divisia Index Method-II (LMDI-II) for the solution to the issue of residual yet it remains inconsistent in aggregation. Lastly, LMDI-I accepts even the decomposition of incomplete datasets (Xu et al., 2016). LMDI-I has sound adaptability, a reliable theoretical base as well as the capacity to establish perfect decompositions (Jung et al., 2012). Owing to the above-mentioned stances, the LMDI-I has been more focused than other methods in our study.

Decomposition of energy consumption based on the Log Mean Divisia Index

We describe the decomposition of total final energy consumption into activity effect, structural effect, and efficiency effect. In the following descriptions, subscripts i and t refer to the activity

sectors and time respectively. E and Y denote the total final energy consumption and gross value added (GVA) of the economy while E_i and Y_i denote the energy consumption and the GVA of sector i. Finally, $EI_i = E_i/Y_i$ and $s_i = Y_i/Y$, respectively, measure the energy intensity of sector i and its proportion to gross value added. By definition, our aggregate energy consumption variable is the sum of the final energy consumed in all sectors considered, that is;

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

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 the time in an economy, taking the derivative of the equation 1 with respect to time

$$\frac{d(E_t)}{dt} = \sum_{i=1}^{n} \left[\frac{d(EI_{it})}{dt} s_{it} Y_t + \frac{d(s_{it})}{dt} EI_{it} Y_t + \frac{d(Y_t)}{dt} EI_{it} s_{it} \right] \tag{2}$$

Dividing both sides by E_t yields:

$$\frac{d(E_t)}{E_t\, dt} = \frac{1}{E_t} \sum_{i=1}^{n} \left[\frac{d(EI_{it})}{EI_{it} dt} EI_{it} s_{it} Y_t + \frac{d(s_{it})}{s_{it} dt} s_{it} EI_{it} Y_t + \frac{d(Y_t)}{Y_t dt} EI_{it} s_{it} Y_t \right] \tag{3}$$

As $\frac{d(x_t)}{x_t\, dt} = \frac{d(lnx_t)}{dt}$

$$\frac{d(lnE_t)}{dt} = \frac{1}{E_t} \sum_{i=1}^{n} \left[\frac{d(lnE_{it})}{dt} EI_{it} s_{it} Y_t + \frac{d(lns_{it})}{dt} s_{it} EI_{it} Y_t + \frac{d(lnY_t)}{dt} EI_{it} s_{it} Y_t \right] \tag{4}$$

$$\frac{d(lnE_t)}{dt} = \sum_{i=1}^{n} \left[\frac{d(lnEI_{it})}{dt} + \frac{d(lns_{it})}{dt} + \frac{d(lnY_t)}{dt} \right] * \left(\frac{EI_{it} s_{it} Y_t}{E_t} \right) \tag{5}$$

Now $w_{it} = \frac{EI_{it}s_{it}Y_t}{E_t} = \frac{E_{it}}{E_t}$

$$\frac{d(lnE_t)}{dt} = \sum_{i=1}^{n}\left[\frac{d(lnEI_{it})}{dt} + \frac{d(lns_{it})}{dt} + \frac{d(lnY_t)}{dt}\right] * w_{it} \quad (6)$$

The Divisia terms in equation 6 can be used for the data that is continuous in nature. But, in its application of discrete date, it is essential to weight[1] each of the three factors and an approximation of the solution which must be integrated over a discrete time interval 0 and T.

$$\ln\left(\frac{E_T}{E_0}\right) = \sum_{i=1}^{n} ln\left(\frac{EI_{iT}}{EI_{i0}}\right) * w_{it} + \sum_{i=1}^{n} ln\left(\frac{s_{iT}}{s_{i0}}\right) * w_{it} + \sum_{i=1}^{n} ln\left(\frac{Y_T}{Y_0}\right) * w_{it} \quad (7)$$

The above equation can also be written as:

$$\frac{E_T}{E_0} = e^{\sum_{i=1}^{n} ln\left(\frac{EI_{iT}}{EI_{i0}}\right)*w_{it}+\sum_{i=1}^{n} ln\left(\frac{s_{iT}}{s_{i0}}\right)*w_{it}+\sum_{i=1}^{n} ln\left(\frac{Y_T}{Y_0}\right)*w_{it}} \quad (8)$$

$$D_{tot} = \frac{E_T}{E_0} = e^{\sum_{i=1}^{n} ln\left(\frac{EI_{iT}}{EI_{i0}}\right)*w_{it}} \; e^{\sum_{i=1}^{n} ln\left(\frac{s_{iT}}{s_{i0}}\right)*w_{it}} \, e^{\sum_{i=1}^{n} ln\left(\frac{Y_T}{Y_0}\right)*w_{it}} \quad (9)$$

$$D_{tot} = D_{int}D_{st}D_{act} \quad (10)$$

The formula given in equation 10 is the multiplicative version of Log Mean Divisia Method-I. In this method, change in total energy consumption can be decomposed in to three effects- efficiency effect D_{int}, activity effect D_{act} , and structural effect D_{st} from time period 0 to time period T.

Thus, the total increase or decrease (D_{tot}) in energy consumption is calculated by multiplying the rates of each individual effect. Following the index number convention, the energy consumption of the initial year is set at 100, and, then the energy consumption for final year is determined in comparison to the base year. In our study, the index is calculated for 1991 to 2015 using 1990 as base period.

To avoid the residual problem, Ang (1997) proposed the use of the logarithmic mean scheme of weights $w_{i,0}$ and $w_{i,t}$ to yield.

$$L(w_{i0}, w_{it}) = (w_{i0} - w_{it})/\ln\left(\frac{w_{i0}}{w_{it}}\right) \quad (3.11)$$

These final weights are normalized so that they add to unity, thus satisfying all the properties that result in the exact decomposition.

12.The weight function is approximated for each factor is taking the arithmetic average of the weights of the time period 0 and time period t. this leaves a small residual, to avoid the residual problem, Ang (1997) proposed the use of the logarithmic mean scheme of weights $w_{i,0}$ and $w_{i,t}$ to yield. $L(w_{i0}, t) = (w_{i0} - w_{i,t})/\ln\left(\frac{w_{i0}}{w_{i,t}}\right)$ *.The* final weights are normalized so that they add to unity, thus satisfying all the properties that result in the exact decomposition

For the purpose of decomposition total energy consumption is disaggregated into three sectors- agriculture sector, industrial sector, and services sector. Data on final energy consumption are taken from *International Energy Agency* (*IEA*). Energy consumption is measured in thousand tonnes of oil equivalent (ktoe). GVA and GDP are both measures of final output, and they are related by the following formula: GDP = GVA + taxes on products − subsidies on products. As taxes and subsidies on products are only available at the whole economy level, GVA is used for measuring gross domestic product (final output) for each country as well as for 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*).

Results and Discussion

This section mainly presents the results of energy consumption decomposition into its effects i.e. activity effect, efficiency effect and structural effect. The decomposition is primarily done at two levels i.e. aggregate level and disaggregate (country) level.

Analysis at aggregate level (for all NIC countries)

The decomposition results of energy consumption into activity, efficiency and structural effects at aggregate level by using the LMDI using data for the period of 1990 to 2015 are in the following figure 2.

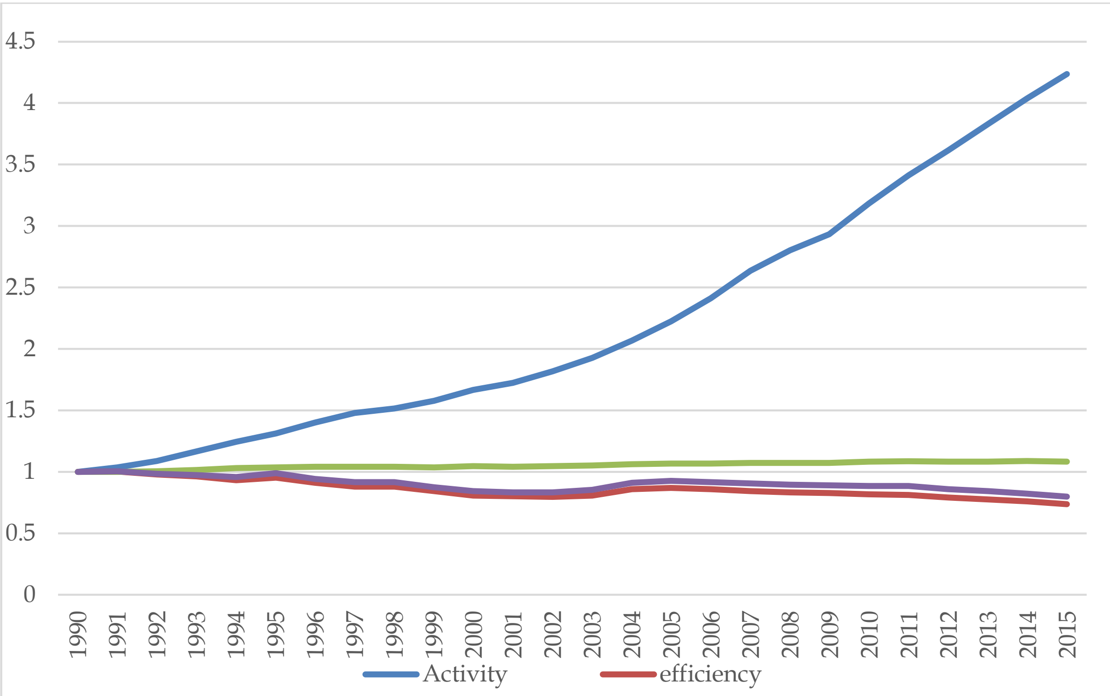


Figure 2: Time path of activity, efficiency, structural effects and aggregate energy intensity

Figure 2 shows the findings of decomposition in energy consumption changes into the constituent activity, structural, and efficiency effects in newly industrialized countries. The key findings of the study, over the period of 1990-2015, are as follows:

- The biggest contribution to energy consumption is through the activity effect at aggregate level. Moreover, with newly industrialized countries continuing to witness strong growth, the potential of increasing production to contribute towards future growth in energy consumption is significant.

- The structural effect has a lower but positive contribution in increasing energy consumption, but it indicates that overall these economies are moving towards higher energy-intensive industrial structures.

- The aggregate energy intensity declines due to efficiency effect which partially offsets the increased effect of energy consumption to some extent. Energy intensity is employed as a common indicator to gauge the performance of energy efficiency.

In these countries, aggregate energy intensity shows an improvement in energy efficiency, by showing the decreasing trend of intensity effect. Both energy efficiency and aggregate energy intensity follow a similar trend.

Table 1
Growth dynamics of activity, efficiency and structural effects for the case of aggregate level

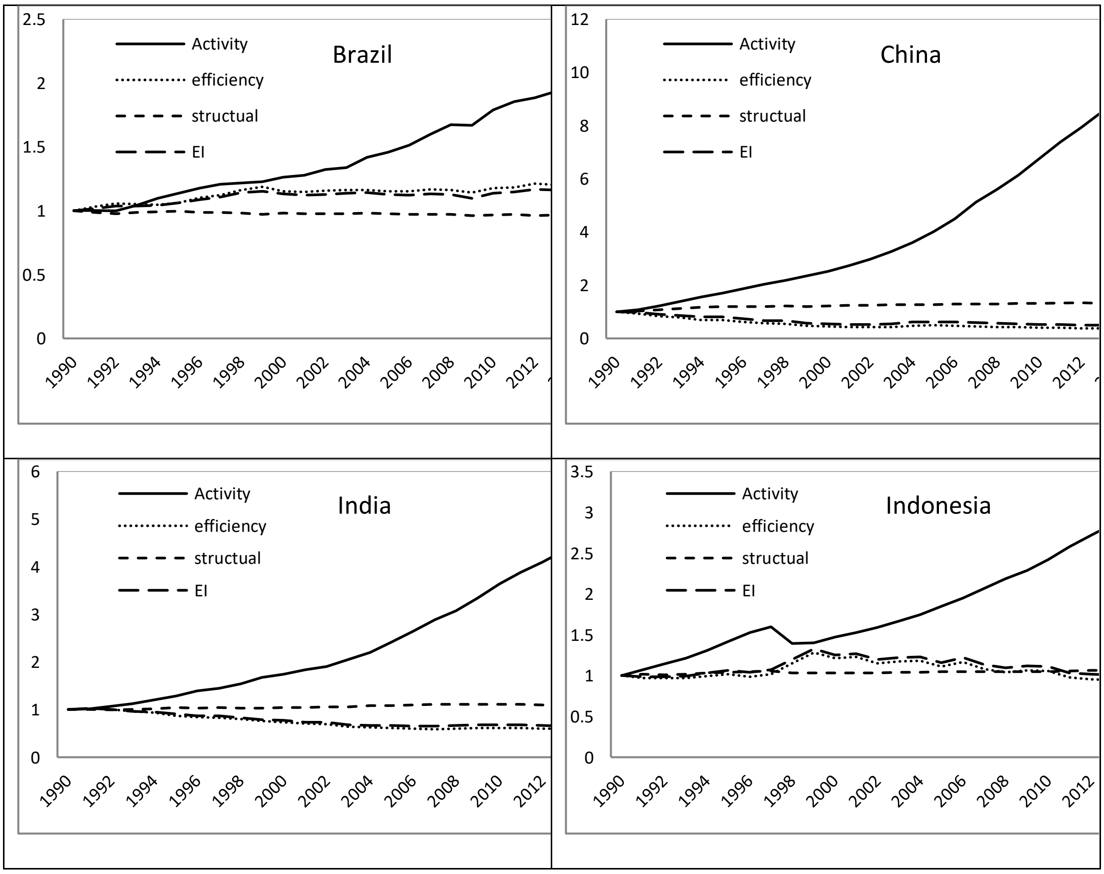
	Percentage Changes LMDI Index				Shares (in percentage)			
	Activity	efficiency	structural	energy	Activity	efficiency	Structural	Energy
1990-95	31.15	-4.67	3.68	30.16	103.28	-15.49	12.21	100
1996-00	35.45	-14.62	0.86	21.69	163.43	-67.39	3.96	100
2001-05	56.04	6.22	1.97	64.23	87.25	9.68	3.06	100
2006-10	95.57	-5.15	1.68	92.10	103.77	-5.59	1.82	100
2011-15	105.51	-8.09	0.22	97.64	108.06	-8.29	0.23	100
1990-15	323.72	-26.31	8.41	305.82	105.85	-8.60	2.75	100

The table 1 shows the growth dynamics of activity, efficiency and structural effects at aggregate level for 10 newly industrialized countries considering five, five-year windows from 1990 till 2015. During the period of 1990 to 2015, the energy consumption is increased 323.72% due to expansion of the economies in term of activity effect. On the other hand, efficiency improvement has offset this increased effect of output on energy consumption by 17.61%, whereas the role of structural effect in contributing towards energy consumption is positive. Although the role of structural effect to change the energy consumption pattern is very small relative to activity effect, yet it is a source of increasing energy consumption. The role of activity effect and structural effect in increasing the energy consumption is increasing over the time. However, this increased effect of energy consumption is offset to some extent by efficiency effect thereby a source of decreasing the aggregate energy intensity. Similar dynamics are also revealed in following figure as well as in table 1. One additional information can be analyzed i.e. the behavior of aggregate energy intensity is similar to energy efficiency effect over the time for which the study analyzed. These all trends can also be observed in figure 1. The main conclusion of the aggregate analysis is that energy efficiency is the major driver of the change in energy consumption pattern that results in reducing the aggregate energy intensity. In other words, aggregate energy intensity is decreasing due to energy efficiency effect in all the countries. Improved energy efficiency may be attributable to the use of more efficient production techniques and use of more recent of capital equipment in the most of the countries included in our study.

Analysis at country level

The decomposition of total energy consumption in to its effects discussed in the previous section at aggregate level indicates the stable pattern of structural effect contributing in energy consumption positively for all the countries included in our sample. In contrast, the efficiency effect kept decreasing with an exception of period from 2001 to 2005. whereas the activity effect of energy consumption is increasing during the entire period. The overall trends shown previously can be traced to the heterogeneous country performances in terms of structural and technological component.

A common finding of analysis carried out so far is that activity effect always leads to an increase in energy consumption, whereas the structural effect results in a smaller increase in energy consumption relative to the former effect. Therefore, in this section, decomposition exercise is carried out at the country level to distinguish between the structural and efficiency effect on change in energy consumption across the countries. Based on the results of LMDI, behavior of these three effects of energy consumption in these countries are presented in table 2 and figure 3.



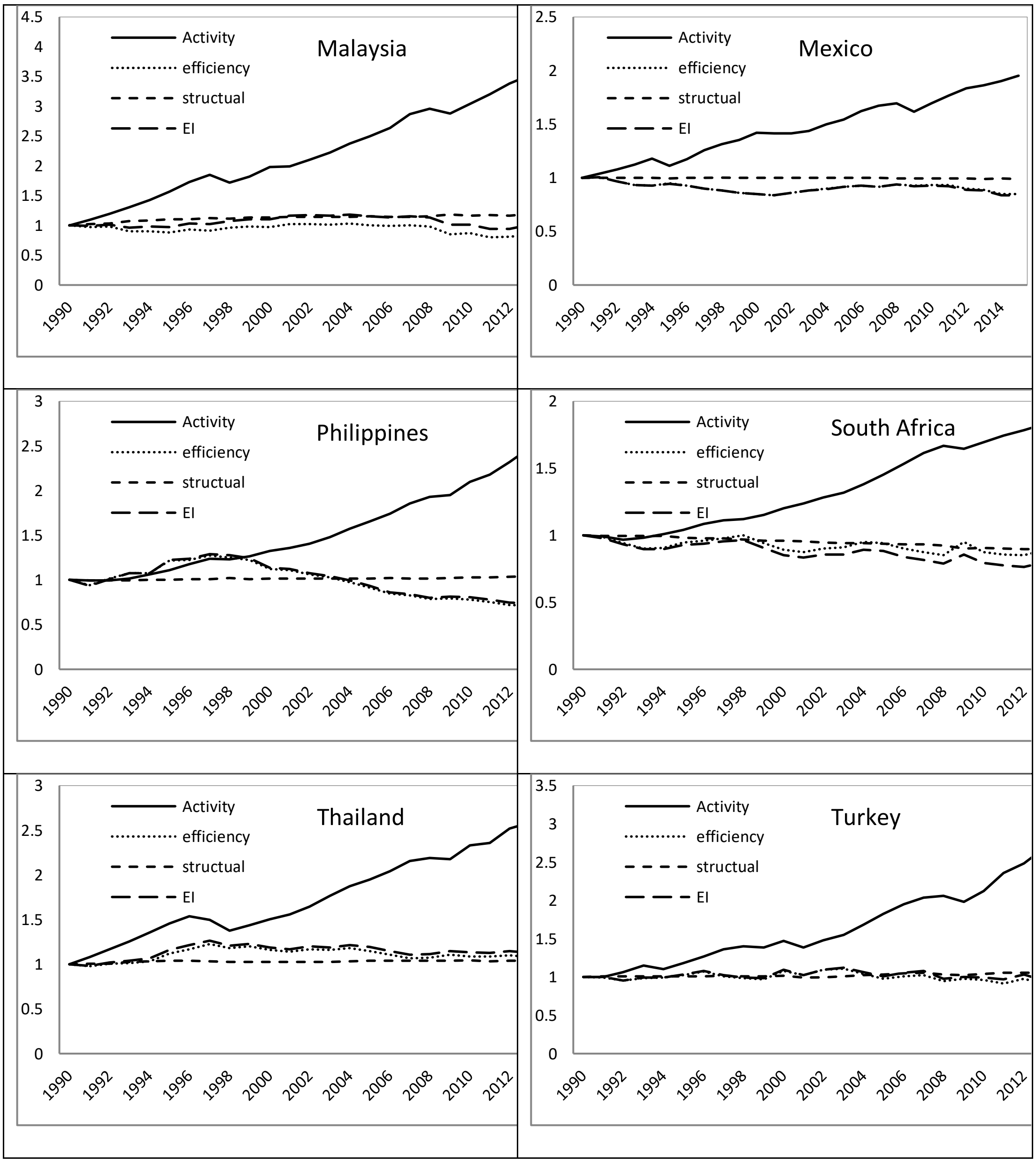


Figure 3: Time path of activity, efficiency, structural effects and aggregate energy intensity

Figure 3 shows the behavior of activity effect, structural effect, and efficiency effect. In all the countries, energy efficiency is improved except Brazil and Thailand. In most of the countries, the pattern of aggregate energy intensity follows a pattern of energy efficiency (sectoral energy intensities changes over the time).

Table 2
Growth dynamics of activity, efficiency and structural effects for the period of 1990 to 2015 for each country

				Absolute changes			Annual growth rates		
Country	**Initial Energy**	**Final Energy**	**Absolute Change**	**Activity Effect**	**Efficiency effect**	**Structural effect**	**Activity effect**	**Efficiency Effect**	**Structural Effect**
Brazil	83516	186386	102870	84079	22936	-4145	2.56	0.86	-0.18
China	308692	1383764	1075072	1118762	-84051	40361	9.53	-4.19	1.1
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

Malaysia	11339	41663	30324	30549	-2414	2189	5.62	-1.04	0.76
Mexico	57778	94437	36659	44361	-7151	-551	2.71	-0.66	-0.05
Philippine	10305	21793	11488	13171	-2094	411	4.19	-1.33	0.22
South Africa	35672	52526	16854	22893	-3113	-2927	2.57	-0.51	-0.48
Thailand	20886	63504	42618	39550	2106	962	4.02	0.34	0.16
Turkey	22713	66555	43842	44216	-1720	1346	4.46	-0.32	0.23

In these countries, structural effect is causing the energy consumption to raise. The underlying reason is that; these countries are in stage of rapid industrialization and migration phenomena of population from rural to urban areas. The main reason of reducing energy consumption in these countries is energy efficiency improvement. From table 2, it can be observed that the leading countries in improvement of energy efficiency are China, India, Philippine, and Malaysia (annual growth is 4.19%, 2.25%, 1.33 %, and 1.04% respectively). In case of Thailand and Brazil efficiency effect affect the energy consumption positively and there by a cause to increase aggregate energy intensity. However, structural effect contributes positively towards energy consumption in all the countries excluding Brazil, Mexico, and South Africa. The large scale use of efficient technologies leads to a decline in energy consumption which subsequently results in lower energy intensity. The magnitude of efficiency effect is different due to diverse characteristics of industrial structure and stage of industrialization in each country. Besides this, there are a number of other factors leading to higher energy efficiency, which includes more efficient industrial processes and transportation systems, setting minimum efficiency requirements for industrial equipment, higher standards and better labelling of appliances, rationalizing taxation policy, and, more generally, innovation and adaptation of more efficient technologies.

Conclusions

This paper analyzed energy consumption trends for ten newly industrialized countries between 1990 and 2015. It decomposes energy consumption into activity, structural and intensity effects in order to examine their respective contribution in the change in energy consumption. This analysis has been undertaken for the at the aggregate level as well as at the country separately. The main findings of this paper indicate that the activity effect has contributed towards increasing energy consumption, both at the aggregate level as well as separately across all countries examined and in all time periods. In addition, the structural effect has also lead to increase in energy consumption at the aggregate level across all time periods, while at the country level, it has resulted in increase in energy consumption across all countries, except Brazil, Mexico and South Africa. On the other hand, the efficiency effect has partially offset the increase in energy consumption due to the activity and structural effect, at the aggregate level except for the period 2001-05, while at the country level it has offset increase in energy consumption across all countries except Brazil and Thailand.

The results of our research show that policies related to increase energy efficiency clearly are working to reduce aggregate energy consumption but not to the desired level. In all 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 structural transformation in the newly industrialized countries.

Analyzing the situation at country level as well as aggregate level, our research suggests a number of energy and environmental actions related to increase in energy efficiency and structural effect that can help to reduce the energy consumption. To further improve energy efficiency, diffusion of technologies from the more advanced countries to less developed ones is required. In addition, taxation measures can also be put in place to promote energy efficiency. With the ongoing structural transformation in the newly industrialized economies, it is expected that the share of less energy energy-intensive sectors will over time increase relative to the industrial sectors, leading to a subsequent reduction in aggregate energy intensity.

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