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Asia-Pacific's changing energy intensity trend: a decomposition analysis based on seven countries from the Asia-Pacific region

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Abstract: This paper presents stylized facts on energy intensity developments in the productive sectors of seven countries from the Asia-Pacific region over the period from 1980-2004. The paper first analyzed the trend in energy intensity based on the energy consumption data and gross value added data acquired from IEA and Groningen Development center. Secondly, the paper applies the Log Mean Divisia Index (LMDI) to decompose energy intensity into the relative contributions of structural changes and efficiency improvements. The main results are: (1) there was absolute convergence in energy intensity of the productive sectors between the seven countries being analyzed; (2) the industry sector contributed the most to changes in energy intensity from 1980-2004; (3) structural changes involving shifts of production between subsectors increased overall energy intensity, whereas efficiency improvements within each of the subsector pushed down energy intensity.

Key words: *Asia-Pacific, energy intensity, productive sectors, structural changes, efficiency improvements.*

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1. Introduction

The oil crisis in the 1970s has led the policymakers to bring the energy question back to table and during the last two decades, there has been an increase in the interest on the energy economics due to the increasing interdependence and uncertainty of the energy market, as well as the increase in the attention paying to sustainable development in respect that current and projected trends for population, income as well as energy demand growth suggest that the pressure on energy and natural resources will increase in the coming decades (European Commission 2010; Robertson 1999; Wolfram et.al 2012). According to Tol and Weyant, during the last two decades, research topics on energy economics range from corporate planning to environmental issues and from energy commodities price volatility to energy market regulation (Tol and Weyant 2006). Moreover, according to Ang and Liu, one of the most popular field of study in energy economics is the analysis of energy intensity and its decomposition at different levels of disaggregation (Ang and Liu 2007). The vast amounts of literatures on this field had contributed to methodologies, for instance, the Log Mean Divisia Index (LMDI) decomposition method to calculate energy intensity was presented by Ang and Zhang (2000) and this method had been described as the most influential method in energy policy 2006 (Nielsen 2013).

According to Nanduri, the term energy intensity is always used interchangeably with the term energy efficiency (Nanduri 1996). Energy intensity refers to the energy used per unit of output or activity, the total energy consumed in a sector is the product of energy intensity per unit of output and the total amount of output provided (Nanduri 1996). When output is measured in physical units, an estimate of physical energy intensity is obtained, such like "terajoule/tonne", on the other hand, economic energy intensity is calculated using dollar value output measures, such as "terajoule/gross domestic product in dollars" (Nanduri 1996). Energy intensity is the most widely used basis for identifying trends in energy efficiency in respect that a truly technical definition of energy efficiency can only be obtained through measurements at the level of a particular process or plant (Nanduri 1996). Energy intensity is considered to be inversely related with energy efficiency, the less energy required to produce a unit of output can indicate better efficiency, thus, declining energy intensities can indicate improvements in energy efficiency (Nanduri 1996).

Since the 1980s, there has been a large number of theoretical and empirical literatures analyzing the changes in energy intensity by decomposing energy intensity into its constituent factors (Marrero and Ramos-Real 2013). Although initially most studies were country-specific and focused on the industry, most recent papers have extended the analysis to the aggregate economy by using sectoral data, at the same time, decomposition studies which include cross-country perspectives are always limited in sector detail and focus on a single sector with emphasize on heavy industries (Marrero and Ramos-Real 2013). This paper will contribute to the literature of energy intensity decomposition in cross-country comparisons by comparing seven countries of the Asia-Pacific region with respect to their productive sectors. Consequently, the main question to be answered can be formed as:

How do structural changes and efficiency improvements affect the changes in energy intensity in the seven countries of the Asia-Pacific region?

The paper is structured as follows,

The second section will discuss the previous research regarding the topic. Section three provides both the historical and theoretical background regarding the topic. Section four will present the testable hypothesis, as well as the data and method. In section five, the results will be both presented and discussed. Finally, in the last section, the outcomes of the research will be summarized and some implications will be drawn.

2. Previous research

As mentioned before, the recent decomposition studies which include cross-country perspectives are always limited in sector detail and focus on a single sector with emphasize on heavy industries. For instance, Unander (2007) examined manufacturing energy use in ten International Energy Association (IEA) countries between 1973 and 1998, the changes in energy use are calculated using Laspeyres indexes to enable energy decomposition into changes in the overall output of manufacturing and to consistently compare the results across countries. The results show that structural changes have led to a reduction in manufacturing energy use in most countries, especially in the US and Japan (Unander 2007). For ten IEA nations, the net effect of structural changes accounted for more than one third of the decline in total manufacturing energy use per unit of output between 1973 and 1998, the rest of the reductions during this period are contributed by the falling energy intensities in individual manufacturing branches (Unander 2007).

However, there are some exceptions, for example, Mulder and Groot (2011) presented the stylized facts on energy intensity developments of 19 countries and 51 sectors over the period from 1980 to 2005, Mulder and Groot found that in most countries energy intensity decreased not only at the aggregate economy level, but also at the level of the aggregate manufacturing sector, in comparison, a range of countries shows increasing levels of energy intensity at the level of the aggregate services sector (Mulder & Groot 2011). Mulder and Groot also found that energy intensity levels tend to converge across countries at all levels of aggregation, and such convergence is particularly stong in the manufacturing and services sector, and not very strong in the agriculture and construction sector (Mulder & Groot 2011). Moreover, Mulder and Groot found that structural changes play an increasingly important role in driving aggregate changes in energy intensity, no matter positive or negative (Mulder & Groot 2011). In addition, Mulder and Groot (2012) evaluated energy intensity across 18 OECD countries and 50 sectors over the period from 1970 to 2005.

For another exception, Kander and Henriques (2010) had done a decomposition analysis on 10 developed economies and 3 emerging economies, according to the decomposition analysis done by Kander and Henriques, a service transition is rather modest in real terms, the major driver of the decline in energy intensity rests within the manufacturing sector (Kander and Henriques 2010). For emerging economies such as Brazil and Mexico, it is the residential sector which drives down the energy intensity due to the declining share of this sector as the formal economy grows (Kander and Henriques 2010). Furthermore, for emerging economies, it was found that the technology effects were the main drivers for the decreases in energy intensity, and emerging economies converge with developed countries in energy intensities, a fact which does not give support to the notion that emerging economies play the role of being the factory of the world (Kander and Henriques 2010). In addition, India develops its industry and service sectors at the same time, the combined structural effects from these two movements did not act to drive India’s energy intensity down, instead, it is the technology effect that was responsible for the decline in India’s energy intensity during the last decades (Kander and Henriques 2010).

Theodoridis (2012) was not only a paper which had made cross-country comparisons by focusing on multiple sectors, but also the only paper which compares the changes in energy intensity between Asian and Latin American developing countries. By using the LMDI decomposition, it was found that from 1971-2005, energy intensity has decreased in most of the countries being analyzed, however, the decreasing trend does not follow a steep decline but rather a fluctuating decrease for the majority of countries, as opposed to what the Environmental Kuznets Curve would suggest (Theodoridis 2012). Moreover, it was found that technical changes within sectors were the major drivers in the decline of total energy intensity for India, Philippines, Colombia as well as Peru, in contrast, the decline in total energy intensity in Indonesia, Thailand, South Korea, Brazil and Mexico was contributed the most by their residential sector rather than their productive economy (Theodoridis 2012). Furthermore, from 1971-2005, a convergence in energy intensity between the 10 developing countries was found. In addition, the major finding of this paper was that the improvement in efficiency driving by technologies did not occur evenly across developing countries both in Asia and in Latin America, some of them are on the right way while others are falling behind and need further policies (Theodoridis 2012).

Metcalf (2008) was the only analysis of changes in energy intensity at the state level. Metcalf carried out an analysis to compare the changes in energy intensity within US states, what he found was that aggregate energy intensity in the US has been declining steadily since the mid-1970s and the first oil shock (Metcalf 2008). At the national level, roughly three quaters of the improvements in US energy intensity after 1970 results from efficiency improvements, which should reduce concerns that the US is off-shoring its carbon emissions (Metcalf 2008). Furthermore, the decomposition done by Metcalf shows that most of the reduction in energy intensity at the state level have occurred due to improvements in energy efficiency rather than shifts from energy intensive to less intensive economic activity (Metcalf 2008). In addition, Metcalf had found that rising per capita income had contributed to improvements in energy intensity within US states (Metcalf 2008).

Ma and Stern (2006) was the only decomposition study of energy intensity which investigated the role of inter-fuel substitution in the changes in energy intensity by separating the inter-fuel substitution effect from the general technological effect. Ma and Stern investigated the changes in energy intensity in China from 1980-2003, by using the LMDI decomposition method, Ma and Stern found that from 1980-2003, technological change was not only the dominant contributor to the decline in energy intensity in China, the slowdown and reversal of the technological effect also becomes the major reason for China's stagnancy from 1988-1990 and the new trend since 2000 (Ma and Stern 2006). Whereas structural change in the industry sector increased energy intensity in China and inter-fuel substitution contribute very little to the changes in energy intensity in China from 1980-2003 (Ma and Stern 2006).

Stern (2003) discussed the relationship between income per capita and environmental degradation. According to David Stern, the concept of Environmental Kuznets Curve (EKC) proposes that there is an inverted U-shape relationship between income per capita and environmental degradation, in other words, during the early stages of economic growth environmental degradation will increase, but beyond some level of income per capita, the trend reverses (Stern 2003). By collecting both the theoretical and econometric critiques of EKC, Stern argued that the statistical analysis on which the EKC is based is not robust, there is little evidence for a common inverted U-shape pathway which countries follow as their income rises, however, there might be an inverted U-shaped relationship between urban ambient concentrations of some pollutants and income per capita, thus the EKC is not a complete model of emissions (Stern 2003). Stern further argued that the true relationship between income per capita and environmental degradation is likely to be monotonic but the curve shifts down over time, in slower growing economies, emissions-reducing technologies can overcome the scale effect of rising income per capita on emissions, in fast growing economies the effects of rising income could overwhelm the contribution of technologies in reducing emissions (Stern 2003).

3. Background

3.1 Historical background

Before moving to the results and discussion, it is worth to provide a historical background of the Asia-Pacific region, in order to better understand their roles in the global energy consumption.

The Asia-Pacific region plays an important role in the global energy markets nowadays, The countries of Asia-Pacific are large and growing consumers of oil and increasingly important consumers of natural gas (Wu et.al 2007). As major importers from other regions especially the Middle East, their participation in the global oil and gas markets influences the availability and cost of energy throughout the world, and their growing dependence on imports also draws concern regarding energy security in the region (Wu et.al 2007). Besides oil and gas, coal is also a particularly important energy source for countries of Asia-Pacific region, especially in China and India. Given the low levels of technology currently in use in some of the Asia-Pacific countries, heavy dependence on coal had led to harmful air pollution and global warming (Wu et.al 2007).

Energy consumption of the Asia-Pacific region grew more rapidly than other regions of the world, between 1965 and 2005, primary commercial energy consumption in the region increased by sixfold and the growth rate is accelerating (Wu et.al 2007). In 1995, the Asia-Pacific region accounted for 27% of the global primary commercial energy consumption, up to 2005, such figure had increased to 32% and it had been projected that by 2015, the Asia-Pacific region will account for 38% of the world's energy consumption (Wu et.al 2007). The huge population of the Asia-Pacific region could also suggest that the region is an important player in the world energy markets, by mid-2005, the Asia-Pacific region accounted for 56% of the world population, which was over twice the size of any other region (Wu et.al 2007). Although it had been projected that fertility will decrease in the Asia-Pacific region, the region will still account for more than 50% of the world population in 2050 (Pupulation Reference Bureau 2005). Even though total energy consumption in the Asia-Pacific region is large due to its large population, the energy per capita in the region is relatively low, on average, ten people in the Asia-Pacific region consume energy as much as two people in Europe and one person in the US (Wu et.al 2007). The current low energy consumption per capita in the Asia-Pacific region means that there will still be a large potential for energy consumption growth in the future for the region.

Rapid growth in energy consumption in the Asia-Pacific region was also resulted from unprecedented economic growth in the region, trends in the Asia-Pacific region offers a very good illustration of how economic growth and primary energy consumption always go hand in hand (Wu et.al 2007). From 1980-2005, the average annual economic growth of the Asia-Pacific region was 4.2%, while at the same time the average annual growth in primary energy consumption was 4.4% (Wu et.al 2007). From 1990-1996, there was an increase in the growth rate of energy consumption due to economic booms, the economic growth rate and the growth rate of energy consumption slowed significantly from 1997-1998 due to Asian financial crisis, however, after the Asian financial crisis, both the economic growth rate and the growth rate of energy consumption of the Asia-Pacific region increased very fast again (Wu et.al 2007).

Among specific energy resources, the Asia-Pacific region uses more coals and less natural gas than other regions. However, without China and India, the energy consumption of the Asia-Pacific region is dominated by oil, and in fact the Asia-Pacific region is more dependent on oil than other regions if both China and India are excluded (Wu et.al 2007). From 1995-2005, according to Facts Global Energy (2006), oil consumption in the Asia-Pacific region has increased by 32%. In comparison, at the same time, global oil consumption also increased but only by 18% (BP 2006). As a result, from 1995-2005, the share of the Asia-Pacific region in global oil consumption had increased from 26% to 29% and it had been projected that such share will increase to 33% by 2015 (Wu et.al 2007). Among major countries of Asia-Pacific, oil is the most important source of commercial energy consumption in Indonesia, Thailand, Philippines, Japan, South Korea as well as Singapore (Wu et.al 2007). It is worth to mention that most Asia-Pacific countries depend on oil imports, countries which depend heavily on oil imports include Thailand, Philippines, Japan and Singapore. These countries will be affected the most by rising oil prices. In contrast, the impact of rising oil prices are much smaller on countries like Indonesia, which is an oil exporter.

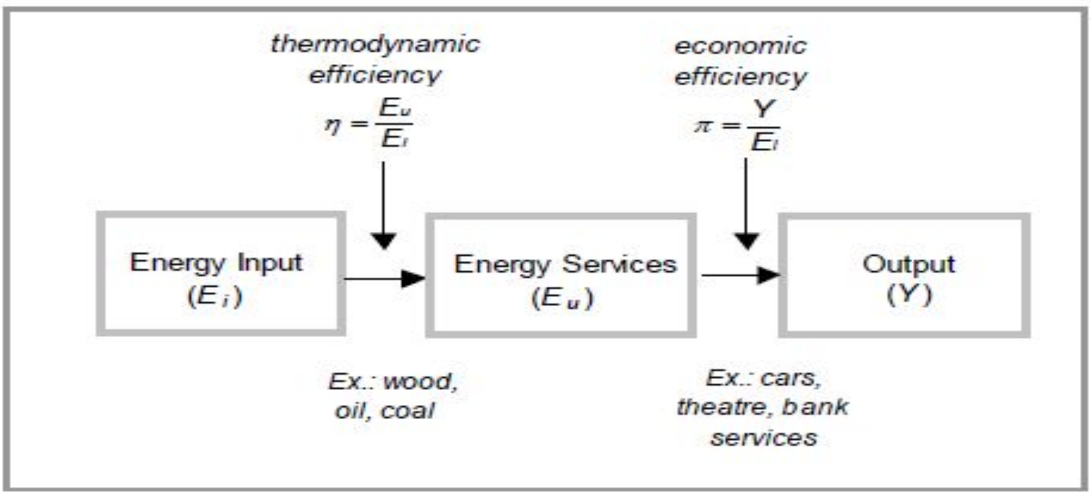
The consumption of natural gas in the Asia-Pacific region starts at a much smaller base, but grew much faster than the consumption of oil. According to Facts Global Energy (2006), natural gas consumption in the Asia-Pacific region had increased by 82% from 1995-2005. In contrast, at the same time, global natural gas consumption increased by 28% (BP 2006). From 2005 to 2015, it had been projected that natural gas consumption will continue to grow faster in Asia-Pacific than in other regions of the world. Within the Asia-Pacific region, Japan consumes the most natural gas (Wu et.al 2007).

3.2 Theoretical background

3.2.1 Thermodynamic efficiency vs economic efficiency

According to Kander et.al (2012), the size of the energy flow is not necessarily correlated with the value we give to a particular economic output, thus and similarly, there is a difference between the thermodynamic efficiency of the physical conversion of energy from one form to another, and the economic efficiency in turning energy into units of value. The difference is shown in figure 3.1 below,

Figure 3.1: Energy input, Energy services and Output



Source: Kander et.al (2012).

For thermodynamic efficiency, the conversion of energy from one form into another will entail losses, the part of energy which is successfully retained in the next stage is expressed in thermodynamic efficiency rates (Kander et.al 2012). For instance, if 90% of the energy of the wood is lost during burning while only 10% is required to heat the room, then the thermal efficiency will be 10%. Thermal efficiency can be expressed as:

$$\eta = \frac{E_u}{E_i}$$

Where E_u refers to the useful energy, or energy services as indicated in Figure 3.1, and E_i refers to the input of energy.

For economic efficiency, it can also be expressed as a ratio, a ratio between value and energy inputs. Usually, this ratio is measured between the output and the energy input, rather than the energy services (Kander et.al 2012). This is due to firstly, it is the energy input which represents an actual cost, and secondly, there are difficulties of measuring the service accurately (Kander et.al 2012). Economic efficiency can be expressed as:

$$\pi = \frac{Y}{E_i}$$

Where Y refers to the output in monetary terms and E_i refers to the input of energy.

Both the thermodynamic efficiency and the economic efficiency are linked, for instance, the transition from biological engines to mechanical engines during the Industrial Revolution represents both a rise in thermodynamic efficiency and economic efficiency (Kander et.al 2012). The formula for thermodynamic efficiency deals with merely the technical structure, whereas the formula for economic efficiency is more comprehensive and deals with both technical and institutional changes which determine the final relationship of value generated by energy inputs

(Kander et.al 2012).

4. Research design

The intention of this paper is to contribute to the literature of energy intensity decomposition in cross-country comparisons by comparing countries of the Asia-Pacific region with respect to their productive sectors. Due to the availability of Data, seven countries of the Asia-Pacific region will be analyzed in this paper, the countries include India, Indonesia, Philippines, Thailand, Japan, South Korea and Singapore. The time period being chosen is from 1980 to 2004, in respect that most of the value added data are only available until 2005 and for Japan, the value added data is only available up to 2004. This time period will be further divided into two time periods in order to see the pattern of changes in energy intensity, according to Marrero and Ramos-Real, the period from 1991 to 2005 corresponds to the implementation of the majority of environmental and energy directives around the world, and the early 1990s serves as the reference point for the emission reduction goals of plans such as the Kyoto Protocol in 1997 (Marrero and Ramos-Real 2013). Thus, the period 1980-2004 is divided into two periods, the period 1980-1990 and the period 1990-2004 respectively. The sectors that will be focused are the productive sectors, distinguishing between agriculture, industry, services as well as transportation. However, since transport and communication are part of services, the transportation sector will be incorporated into services and this paper will focus on agriculture, industry and services sectors.

4.1 Testable hypothesis

Base on the previous literatures, the hypothesis that will be tested in this paper are as follow:

1. Due to the low energy prices from 1980-1990 and the implementation of the majority of environmental and energy directives from 1991-2005, the period 1990-2004 will show slower growth or faster reduction in energy intensity compared with the period 1980-1990.

2. There is a convergence in energy intensity between the seven countries of the Asia-Pacific region for the whole period.

3. Efficiency improvements within sectors are the major driving force in changes in energy intensity for the whole period, rather than structural changes across sectors.

4.2 Data

According to definition, decomposition of energy intensity requires the data of energy consumption with indicators which measure output or activity (Mulder and Groot 2011). The latter can be expressed either in physical indicators, such as metric tonnes, or in terms of economic indicators, such like value added. Examples of decomposition using physical indicators include Neelis (2007), which studies the trends in energy efficiency in the Dutch manufacturing industry between 1995 and 2003 using publicly available physical production indicators. The main advantage of physical indicators is that they usually establishes a straightforward relationship between output and energy inputs, regardless of changes in market-based product prices as well as changes in the characteristics of products, however, the application of physical indicators is hindered by difficulties regarding the aggregation across sectors as well as limited data availability, which is particularly true in a cross-country setting as well as in sectors which not only have a great variety of products, but also have a large degree of processing (Mulder and Groot 2011). In comparison, economic indicators such as value added not only stimulates comparison of energy intensity across countries or sectors, but also facilitates interpretation within an economic framework which includes other inputs such as capital and labor (Mulder and Groot 2011). Due to these reasons, in this paper, the activity levels will be expressed in economic terms using value added data.

Thus, the data in this paper include both the energy consumptions as well as the gross valued added of each country. The data regarding energy consumptions of the productive sectors for each country is obtained from the the International Energy Agency (IEA) database. The IEA was created after the first major oil crisis during the 1970s, the core mission of the IEA is to make sure the secure supply of energy for its member countries, the advanced industrial democracies (Colgan 2009). The IEA's mandate was to coordinate emergency supply measures and to improve the governance of long-term energy issues (Colgan 2009). The data regarding the gross value added of the productive sectors for each country is obtained from the Groningen Growth and Development Centre 10-Sector database. The Groningen Growth and Development Centre was founded in 1992 within the Economics Department of the University of Groningen by a group of researchers working on comparative analysis of levels of economic performance and differences in growth rates (Groningen Growth and Development Centre). The major role of the Centre is to conduct research based on a range of comprehensive databases on indicators of growth and developments which the Centre compiles on a regular basis (Groningen Growth and Development Centre). The Groningen Growth and Development Centre 10-Sector database provides long-run internationally comparable dataset on sectoral productivity performance in Asia, Europe, Latin America as well as the US, variables covered in the dataset include annual series of value added, output deflators and persons employed for 10 sectors, it contains series for 10 countries in Asia, 9 countries in Latin America, 9 countries in Europe and the US (Groningen Growth and

Development Centre, 10-Sector Database).

4.3 Method

For the decomposition techniques, there are two broad categories, namely the structural decomposition analysis (SDA) and the index decomposition analysis (IDA). The SDA and IDA are also referred as input-output techniques and disaggregation techniques respectively. According to Hoekstra and van der Bergh (2003), The SDA approach is based on final demands from input-output tables as well as input-output coefficients whereas the IDA approach uses aggregate input and output data which are generally at higher level of aggregation than input-output tables. Such difference also determines the advantages and disadvantages of both approaches. The SDA approach basically have two advantages over IDA approach. Firstly, the input-output model includes indirect effects, which are the supplying sectors's demand for inputs that can be attributed to the demand of downstream sectors, thus, the SDA approach can distinguish between direct and indirect demands for energy (Hoekstra and van der Bergh 2003). In comparison, the IDA approach is unable to capture indirect demand effects. Secondly, due to the greater structural detail in the input-output table, the SDA approach can distinguish between a number of technological effects and structural effects which are not possible for the IDA approach (Hoekstra and van der Bergh 2003). In comparison, the advantage of the IDA approach is that it can be applied to any data at any level of aggregation. Since input-output tables may be available only occasionally, the IDA approach can be applied to data in time series form (Hoekstra and van der Bergh 2003). In this paper, the IDA approach will be used in respect that it is the most frequent used approach and the SDA approach requires a lot of data which is not possible to collect.

Within the IDA approach, there are a variety of different methods. For the methods of decomposition which are built upon the theoretical rigor of Divisia aggregation, there are the Arithmetic Mean Divisia Index (ADMI) and the Logarithmic Mean Divisia Index (LMDI). Boyd et. al (1987) had suggested the Divisia index approach in energy decomposition analysis, in which the index was defined as the weighted average of logarithmic growth rates. Another widely used IDA approach in energy intensity decomposition is the Laspeyres index proposed by Étienne Laspeyres (Park 1992; Zhang 2003). Since the weights for Laspeyres index are based on base year values, the results are thus sensitive to the choice of the base year. There are problems with the base year weight in isolating two or more effects, one of the biggest problem is that the isolation of each main effect related with a change in the corresponding variable to energy intensity could lead to an unexplained residual value, while holding all other variables constant regarding the base year (Ang and Choi 1997; Ang and Zhang 2000). In comparison, the weights for the Divisia index are allowed to change over time. Moreover, another difference between the Laspeyres index and the Divisia index is that the Laspeyres index is based on percentage change while the Divisia index is based on logarithmic change. Tornqvist et.al (1985) had argued that the logarithmic change is the only additive, symmetric and normed indicator of relative change. Besides the difference between the Layspeyres index and the Divisia index, there are also differences between the ADMI and the LMDI methods, although both methods are linked to Divisia. According to Ang, both ADMI and LMDI methods satisfy the time reversal test (Ang 2004). However, LMDI is the only method which satisfies the Irving Fisher's factor reversal test (Fisher 1922; Sato 1976). Both ADMI and LDMI methods have computational problems with zero values in respect that both methods are based on logarithmic changes, such problem becomes extremely significant when different fuel vectors are included in order to test the fuel mix effects. Such problem can be solved by substituting the zero values with a small positive number, such as 1/10000000000, and thus finding converging results as the small positive number approaches zero (Ang and Choi 2001; Ang and Choi 2002). Nevertheless, according to Ang and Choi (1997), only the LMDI method can guarantee the converging results, the AMDI method will not necessarily lead to converging results, thus, the LMDI method is preferred over other methods of decomposition. Ang had argued that the most important advantage of the LMDI method is that it is the best decomposition method delivering complete decomposition results with no residual among various alternatives widely used in literatures (Ang 2004). Thus based on the previous literatures regarding the decomposition methods within the IDA approach, the LMDI decomposition method will be used in this paper due to its superiority over other methods.

The following part illustrates the LMDI model,
The LMDI model (Nielsen 2013):

$$I_t = \sum_i S_{i(k),t} I_{i(k),t}$$

Where t stands for time period, i stands for productive sector, k represents personal consumption sector,

I	Final energy intensity (= E/Y)
Ii	Energy intensity of sector i (= Ei/Yi)
E	Final energy consumption (= ∑Ei+∑Ek)
Ei	Energy consumption in economic sector i (Agriculture, Industry, Transportation and Services)
Y	Total value added (constant prices)
Yi	Gross value added of sector i (constant prices)
Si	Share of sector i in total value added (=Yi/Y)
Dtot	Total energy intensity change
Dstr	Change due to structural effect (between-sector changes)
Dint	Change due to technological effect (within-sector changes)
Dpcons	Change due to personal consumption effect (non-economic sector changes

To calculate the total change in energy intensity in the productive sector, the formula is given as,

$$D_{tot} = D_{str} D_{\text{int}} \qquad (1)$$

Where D_{tot} refers to total change in energy intensity, D_{str} refers to the changes in energy intensity driven by structural shifts, which represents between-sectors changes and measures the impact of changes in the share of output from different sectors (Nielsen 2013). D_{int} refers to changes in energy intensity driven by technological changes, which represents within-sectors changes, or changes which increase output of a sector by using the same amount of energy or that delivering the same amount using less energy (Nielsen 2013). In order to calculate D_{str}, the formula is given as,

$$D_{str} = \exp[\sum_i w'_i \ln(\frac{s_i^T}{s_i^0})] \qquad (2)$$

In order to calculate D_{int}, the formula is given as,

$$D_{\text{int}} = \exp[\sum_i w'_i \ln(\frac{I_i^T}{I_i^0})] \qquad (3)$$

The calculation of the weight (w') of each sector as well as the calculation of the logarithmic mean function are represented by formula (4) and formula (5) respectively,

$$W'_{i(k)} = \frac{L(\frac{E_{i(k)}^T}{Y^t}, \frac{E_{i(k)}^0}{Y^0})}{L(I^T, I^0)} \qquad (4)$$

$$L(x, y) = \frac{(x - y)}{\ln(\frac{x}{y})} \qquad (5)$$

The calculation of energy intensity of the productive sector (agriculture, industry, services) of the seven countries basically involve nine steps[1]. At step one, the time period is chosen, which is from 1980 to 2004, this time period is further divided into two periods (1980-1990 and 1990-2004); At step two, the energy data is compiled into energy units and value added in constant prices for each sector and for each time period; At step 3, the energy intensity of each sector and value added shares is calculated by dividing the energy of the sector by the value added of that particular sector; At step 4, the change in total energy intensity is calculated by dividing the energy intensity of year T by the energy intensity of year 0 ($D_{tot} = I_T / I_0$); At step 5, the normalized weights $w'_{i(k)}$ for each sector is calculated using formula (4); At step six, the structural change is calculated using formula (2); At step seven, the change in intensity is calculated using formula (3); At step eight, the total impacts by sector is calculated by multiplying the structural impact of the sector by the technological impact of that sector; At step nine, the results are checked by making sure that there is no residual, in other words, the result is checked by making sure that $D_{tot} /(D_{str} * D_{\text{int}}) = 1$.

4.3.1 Limitation of LMDI

According to Muller, most literatures on energy intensity decomposition identified the LMDI method as the most appropriate approach, this is based on four features of the method, namely its ability to handle zero and negative values, the absence of residual term, the ease of calculation as well as its ability to remain invariant under time and factor reversal (Muller 2006). However, as argued by Muller, several of these motivations have no basis as guidelines for the quality of a decomposition method, on the one hand, the zero and negative value problems stem from ill-defined operations during the calculations and can be avoided, the treatment of zero and negative values by the LMDI can lead to wrong results (Muller 2006). On the other hand, the residual

[1] The amount of calculation i had done was vast, the excel regarding calculations can be traced from the author by request.

reflects the fact that any such decomposition is based on integral approximation, this is due to the fact that the functions involved in decomposition are only known for discrete point in time such as annually, thus the residual is not necessarily zero for an optimal decomposition method, forcing the residual to be zero could also involve mutually canceling terms of opposite sign in different parts of the decomposition (Muller 2006). This could make the zero-residual decomposition even less exact than a decomposition with non-zero residual based on good approximation (Muller 2006). Therefore, the LMDI method may not be perfect and by using the LMDI method in this paper, some problems can not be avoided. However, despite these shortcomings, the LMDI method still remain the best available method.

5. Results and discussion

5.1 Trends of energy intensity

We start our discussion by shown Table 5.1, Table 5.1 below shows the average annual growth rates of energy intensity, energy consumption and gross value added at the aggregate productive sectors. Table 5.1 shows that firstly, changes in energy intensity at the aggregate productive sectors differ significantly across countries, it varies from a 1.75% average annual decrease in India to a 2.87% average annual increase in Indonesia for the whole period 1980-2004, for the two sub-periods, changes in energy intensity also differ significantly across countries. Secondly, energy intensity of less developed Asian countries tend to increase while energy intensity of relatively developed Asian countries tend to decrease, for instance, from 1980-2004, Indonesia and Thailand had experienced the highest average annual growth in energy intensity, at 2.87% and 1.17% respectively. While both Japan, South Korea and Singapore had experienced an average annual decline in energy intensity from 1980-2004, at 0.89%, 0.19% and 0.86% respectively. However, there are exceptions, India, as a less developed country, had experienced an average annual decline in energy intensity from 1980-2004, at 1.75%, the period that had contributed to the decline in energy intensity in India was from 1990-2004. Another exception is Philippines, whose energy intensity also declined at an averaging annual rate of 0.51% from 1980-2004. Third, from 1980-2004, the growth in gross value added in India, Philippines, Japan, South Korea and Singapore outpaced the growth in energy consumption in these countries, resulting in the decline in energy intensity in these countries, meanwhile, the growth in energy consumption in Indonesia and Thailand outpaced the growth in gross value added in these countries, resulting in an increase in energy intensity in these countries. Furthermore, According to IEA (2004), for the period from 1980-1990, the growth in energy intensity worldwide was higher compared with later periods, this was due very much to the relatively low and decreasing energy prices during the 1980s, which happens after a period of high energy prices caused by the energy crises during the 1970s as well as improvements in energy efficiency. In contrast, growth in energy intensity from 1990-2004 was relatively slow compared with the period from 1980-1990 in respect that the period from 1991-2005 corresponds to the implementation of the majority of environmental and energy directives around the world, and the early 1990s serves as the reference point for the emission reduction goals of plans such as the Kyoto Protocol in 1997 (Marrero and Ramos-Real 2013). However, from Table 5.1, it can be seen that such worldwide trend does not apply to every country. Countries such as India, Indonesia and South Korea seem to follow this trend, their energy intensity either grew at a slower rate or declined at a faster rate for the period from 1990-2004, compared with the period from 1980-1990. For Philippines, the trend even reverses, with an averaging annual growth in energy intensity for the period from 1980-1990, and an averaging annual decline in energy intensity for the period from 1990-2004. In comparison, countries such like Thailand, Japan and Singapore did not seem to follow the worldwide trend. For Japan, its energy intensity declined at a slower rate for the period from 1990-2004, compared with the period from 1980-1990. While for Thailand and Singapore, their energy intensity declined for the period from 1980-1990, but increased for the later period from 1990-2004. Thus, the first proposition of our hypothesis can be rejected.

Table 5.1: average annual growth rates of energy intensity, energy consumption as well as gross value added at the aggregate productive sectors.

	Energy intensity			Energy consumption			Gross value added		
	1980-2004	1980-1990	1990-2004	1980-2004	1980-1990	1990-2004	1980-2004	1980-1990	1990-2004
India	-1.75%	-0.80%	-2.55%	4.99%	5.26%	2.82%	11.96%	6.63%	8.71%
Indonesia	2.87%	5.72%	0.36%	18.43%	17.08%	6.32%	9.05%	6.97%	5.65%
Philippines	-0.51%	0.77%	-1.31%	2.56%	2.49%	1.91%	3.52%	1.58%	4.02%
Thailand	1.17%	-0.37%	2.32%	17.01%	10.00%	10.00%	12.24%	10.82%	5.70%
Japan	-0.89%	-1.35%	-0.57%	1.78%	2.85%	0.67%	3.42%	4.93%	1.35%
South Korea	-0.19%	-0.13%	-0.22%	13.95%	11.18%	6.74%	14.82%	11.48%	5.19%
Singapore	-0.86%	-2.16%	0.19%	11.37%	5.12%	9.71%	15.58%	9.54%	9.26%

Source: IEA and Groningen Growth and Development Centre, 10-Sector Database. Based on own calculations.

Table 5.2 below shows the average annual growth rates of energy intensity in each of the subsector, namely agriculture, industry and services. From Table 5.2, it can be seen that at the sectoral level, changes in energy intensity also differ significantly across countries. Table 5.1 above shows that the countries which had experienced an increase in energy intensity from 1980-2004 are Indonesia and Thailand. And from Table 5.2, it can be seen that the sector which had contributed the most to the increase in energy intensity in Indonesia was the industry sector, whose energy intensity increased by an average of 2.236% annually from 1980-2004. The sector which had contributed the most to the increase in energy intensity in Thailand was also the industry sector, whose energy intensity increased by an average of 1.055% annually from 1980-2004. From table 5.1 above, the countries which had experienced a decline in energy intensity from 1980-2004 are India, Philippines, Japan, South Korea and Singapore. And from Table 5.2, it can be seen that for these five countries, the decline in energy intensity in the industry sector had contributed the most to the decline in total energy intensity. For India, Philippines, Japan, South Korea and Singapore, industry energy intensity had declined at an averaging annual rate of 1.517%, 0.614%, 1.287%, 0.533% and 1.037% respectively from 1980-2004. Thus it can be seen that for all countries, industry sector is the major driving force in changes in energy intensity.

Table 5.2: average annual growth rates of energy intensity by sector.

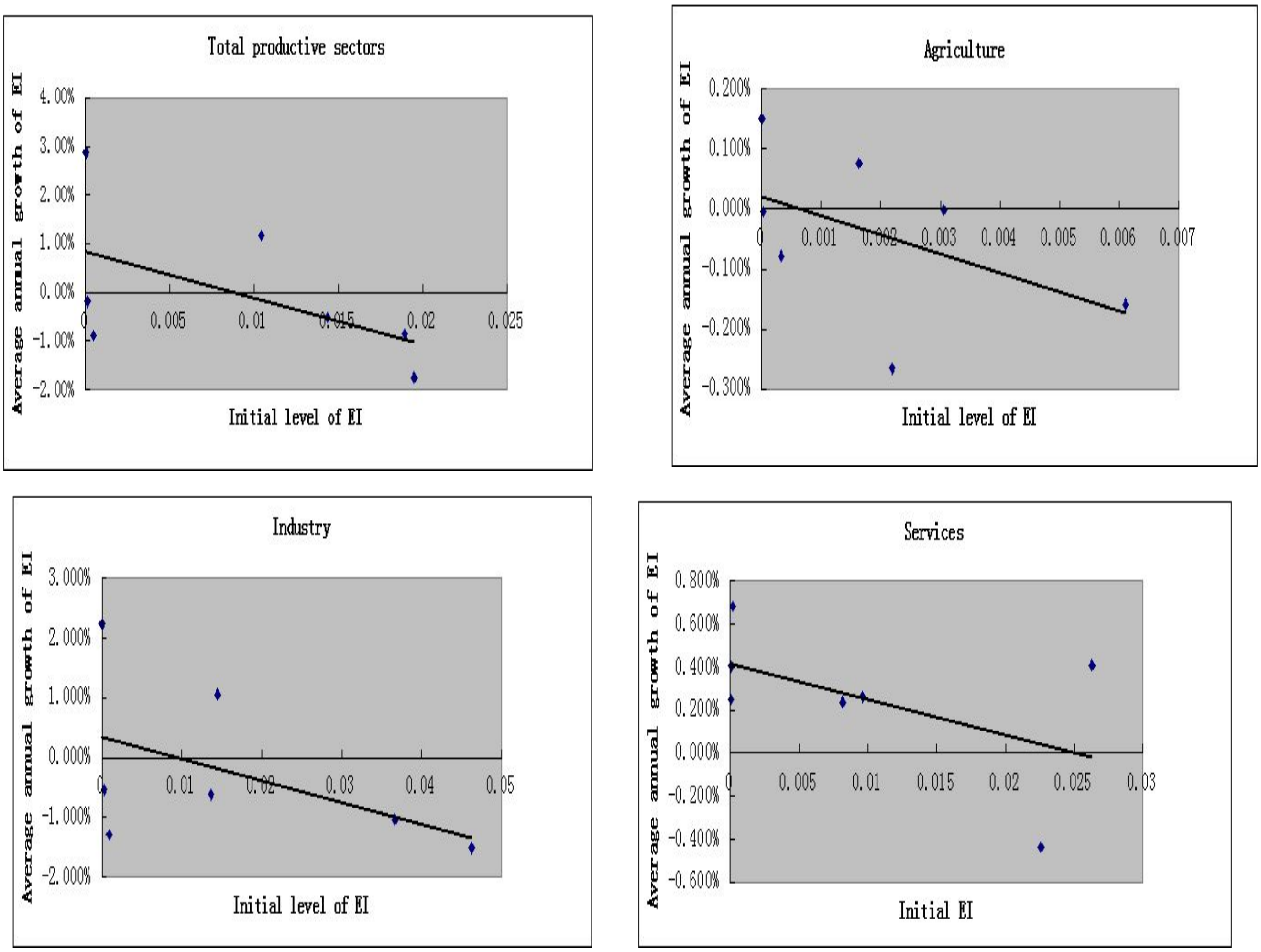
	Agriculture		Industry		Services	
	1980-2004	1990-2004	1980-2004	1990-2004	1980-2004	1990-2004
India	0.076%	0.031%	-1.517%	-2.293%	-0.439%	-0.423%
Indonesia	0.149%	0.197%	2.236%	-0.114%	0.250%	0.281%
Philippines	-0.265%	-0.069%	-0.614%	-1.680%	0.409%	0.564%
Thailand	-0.158%	0.047%	1.055%	1.837%	0.263%	0.332%
Japan	-0.078%	0.001%	-1.287%	-0.985%	0.684%	0.483%
South Korea	-0.004%	-0.165%	-0.533%	-0.032%	0.405%	-0.020%
Singapore	-0.001%	0.004%	-1.037%	0.133%	0.238%	0.052%

Source: IEA and Groningen Growth and Development Centre, 10-Sector Database.
Based on own calculations.

Next, Figure 5.2 is presented to show whether there is a convergence in energy intensity between India, Indonesia, Thailand, Philippines, Japan, South Korea and Singapore. Figure 5.2 below shows, for each sector, the scatter plot between initial level of energy intensity and the average annual growth of energy intensity for the whole period from 1980-2004. A negative slope in this relationship will indicate absolute convergence. This negative relationship, as shown by Figure 5.2, is found not only for the total productive sectors, but also for each of its subsector although there are outliers within each sector. This means that in general, there was a convergence in energy intensity in total productive sectors as well as in each of its subsector between the seven countries of the Asia-Pacific region from 1980-2004. Therefore, the second proposition of our hypothesis holds for the sample of countries analyzed in this paper.

Here, it is worth to mention that the gross valued added data, which is used to derive the changes in energy intensity, is in purchasing power parity. Thus this could yield greater convergence compared with using nominal exchange rate. The reason for why purchasing power parity yield greater convergence still remain a puzzle. As stated by Engel and Morley (2001), the real puzzle is why nominal exchange rate convergence so slowly, therefore, it is not clear how transaction costs, which are supposed to be relatively insignificant for foreign exchange markets, account for the slow convergence of nominal exchange rates.

Figure 5.2: the relationship between initial levels of energy intensity and energy intensity changes in the total productive sectors as well as in each of its subsector from 1980-2004.



Source: IEA and Groningen Growth and Development Centre, 10-Sector Database. Based on own calculations.

5.2 Decomposition

Changes in energy intensity at the total productive sectors not only result from efficiency improvements, but also from the changing composition of the sectors. Thus the LMDI approach is used to decompose changes in energy intensity into a structure effect and an efficiency effect, to see which one was the main driving force in changes in energy intensity. The structure effect measures the changes in energy intensity which are caused by the changing composition of sectors, while the efficiency effect measures the changes in energy intensity that result from technology-driven efficiency improvements within each sector, in other words, efficiency effect refers to within-sector changes, and such within-sector changes include both economic and thermodynamic efficiency. In this paper, the structure effect of the total productive sectors measures the changes in energy intensity that are caused by the changing composition of its subsectors, namely agriculture, industry, and services. In comparison, the efficiency effect of the total productive sectors measures the changes in energy intensity which are driven by the efficiency improvements within each of its subsectors, namely agriculture, industry and services.

Table 5.3 below shows the structure and efficiency effects at the aggregate total productive sectors. From Table 5.3, it can be seen that for the total productive sectors, from 1980-2004, changes in energy intensity in India, Indonesia, Japan, South Korea and Singapore were impacted the most by efficiency improvements within sectors rather than structural changes across sectors, for countries such as India and Indonesia, efficiency improvements had played a much bigger role in driving changes in energy intensity compared with structural changes. In comparison, for Philippines and Thailand, it was the structural changes which were the major driving force in changes in energy intensity. Overall for the seven countries of the Asia-Pacific region, efficiency improvements were the major driving force in changes in energy intensity of the total productive sectors and such finding not only corresponds with most of the energy decomposition studies, such as Ang and Liu (2007), but also confirms the third proposition of our hypothesis. Moreover, efficiency improvements had driven down energy intensity in five countries while structural changes had only driven down energy intensity in three countries. Overall for the seven countries of the Asia-Pacific region, efficiency improvements within sectors had driven down energy intensity for the period from 1980-2004, the net effect was -29%. Whereas structural changes across sectors had pushed up energy intensity for the period from 1980-2004, the net effect was +27%. Thus it can be seen that from 1980-2004, for the seven countries in general, the reduction in energy intensity of the total productive sectors driving by efficiency improvements within sectors was almost offset by the increase in energy intensity driving by structural changes between sectors.

Table 5.3: percentage change in energy intensity of total productive sectors driven by structure and efficiency effects.

	Total productive sectors					
	structure effect			efficiency effect		
	1980-2004	1980-1990	1990-2004	1980-2004	1980-1990	1990-2004
India	9.1%	12.6%	-3.7%	-48.4%	-19.0%	-35.9%
Indonesia	2.6%	-2.9%	6.1%	67.5%	67.9%	-0.6%
Philippines	-7.6%	-6.9%	-2.5%	-5.7%	16.6%	-17.6%
Thailand	19.1%	5.3%	10.4%	8.6%	-10.6%	22.1%
Japan	-5.2%	-1.0%	-4.6%	-16.1%	-13.9%	-4.2%
South Korea	18.5%	11.8%	3.6%	-19.5%	-11.9%	-6.6%
Singapore	-5.2%	-4.1%	-2.4%	-15.4%	-20.4%	5.4%

Source: IEA and Groningen Growth and Development Centre, 10-Sector Database.
Based on own calculations.

6. Conclusion

Based on the calculation of changes in energy intensity in seven countries of the Asia-Pacific region from 1980-2004, it was found that energy intensities had declined in five countries, namely India, Philippines, Japan, South Korea and Singapore.

Whereas energy intensity had increased in both Indonesia and Thailand from 1980-2004. The hypotheses that had been proposed are as follow:

1. Due to the low energy prices from 1980-1990 and the implementation of the majority of environmental and energy directives from 1991-2005, the period 1990-2004 will show slower growth or faster reduction in energy intensity compared with the period 1980-1990.

2. There is a convergence in energy intensity between the seven countries of the Asia-Pacific region for the whole period.

3. Efficiency improvements within sectors are the major driving force in changes in energy intensity for the whole period, rather than structural changes across sectors.

Based on the average annual growth rate of energy intensity from 1980-2004 both at the total productive sectors and each of its subsector namely agriculture, industry and services, it was found that firstly, changes in energy intensity at the total productive sectors differ significantly across countries, it varies from a 1.75% average annual decrease in India to a 2.87% average annual increase in Indonesia. At the sectoral level, changes in energy intensity also differ significantly across countries. Secondly, it was found that the increase in energy intensity in both Indonesia and Thailand from 1980-2004 was contributed the most by the increase in energy intensity in the industry sector, whereas the decline in energy intensity in the rest of the countries from 1980-2004 was mainly due to the decline in energy intensity in the industry sector. Thus, industry sector had contributed the most to changes in energy intensity in the seven countries of Asia-Pacific region from 1980-2004. In addition, it was found that for the seven countries of the Asia-Pacific region, the first hypothesis does not hold in respect that for Japan, its energy intensity declined at a slower rate for the period from

1990-2004, compared with the period from 1980-1990. For Thailand and Singapore, their energy intensity declined for the period from 1980-1990, but increased for the later period from 1990-2004. Therefore, it can be seen that the slower growth or faster reduction in energy intensity from 1990-2004 is not a generalized phenomenon which occur in every country of the Asia-Pacific region. The reasons behind why Japan, Thailand and Singapore show the opposite trend are beyond the scope of this paper.

By comparing the initial level of energy intensity with the average annual growth of energy intensity from 1980-2004, it was found that in general, from 1980-2004, there was an absolute convergence in energy intensity in total productive sectors as well as in each of its subsector between the seven countries of the Asia-Pacific region from 1980-2004. Therefore, the second hypothesis holds for the sample of countries being analyzed in this paper.

Finally, by decomposing changes in energy intensity using the LMDI method, it was found that for most countries which include India, Indonesia, Japan, South Korea and Singapore, efficiency improvements within sectors were the major driving force in changes in energy intensity. For India, efficiency improvements had pushed down energy intensity by 48% from 1980-2004, indicating a significant improvement in the efficiency of production processes in India. While for Philippines and Thailand, structural changes across sectors were the major driving force in changes in energy intensity. Overall, for the seven countries of the Asia-Pacific region, efficiency improvements contributed more to changes in energy intensity from 1980-2004, compared with structural changes. Thus this finding confirms the third hypothesis. Furthermore, for the aggregate of the seven countries of Asia-Pacific region, efficiency improvements had pushed down energy intensity by 29% from 1980-2004, whereas structural changes had pushed up energy intensity by 27% from 1980-2004, which almost offset efficiency improvements.

The findings of this paper suggest that in order to reduce energy intensity in the seven countries of the Asia-Pacific region, firstly, policies should be primarily targeting at the industry sector due to its major contribution to changes in energy intensity. Secondly, the finding that structural changes in general pushed up energy intensity and almost offset the decline effect from efficiency improvements in the seven countries of the Asia-Pacific region suggest that further studies on why structural changes had such a big impact on pushing up energy intensity in these countries need to be done.

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8. Appendix:

Table A.1: energy consumption of selected countries (ktoe):

India				
	Agriculture	Industry	Services	Total
1980	2627	43735	7627	53989
1990	5571	70261	9367	85199
2004	13560	96331	11393	121284
Indonesia				
	Agriculture	Industry	Services	Total
1980	561	6746	357	7664
1990	991	20287	785	22063
2004	3047	36757	3180	42984
Philippines				
	Agriculture	Industry	Services	Total
1980	313	3369	661	4343
1990	92	4604	837	5533
2004	65	5066	1987	7118
Thailand				
	Agriculture	Industry	Services	Total
1980	1127	3982	371	5480
1990	1822	8658	1031	11511
2004	3554	22110	3122	28786
Japan				
	Agriculture	Industry	Services	Total
1980	3468	91233	20341	115042
1990	2229	102841	46013	151083
2004	2708	95927	67528	166163
South Korea				
	Agriculture	Industry	Services	Total
1980	424	10310	2550	13284
1990	1656	19279	8692	29627
2004	1928	39787	17886	59601
Singapore				
	Agriculture	Industry	Services	Total
1980	1	487	174	662
1990	1	616	418	1035
2004	4	1521	1018	2543

Source: Energy Balances of OECD countries, Energy Balances of Non-OECD countries, IEA statistics.

Table A.2: gross value added by sector of the economy (constant prices):

India (Million Rupees)				
	Agriculture	Industry	Services	Total
1980	1605722	945352	1104086	3655160
1990	2257295	1879257	2185820	6322371
2004	3129118	4166140	7285763	14581022
Indonesia (Millon Rupiahs)				
	Agriculture	Industry	Services	Total
1980	119616949	213801153	169600315	503018417
1990	174075280	367496913	347057510	888629704
2004	248222800	737276200	656207920	1641706920
Philippines (Million Pesos)				
	Agriculture	Industry	Services	Total
1980	142771	246501	159422	548695
1990	160734	255548	227857	644139
2004	224669	380795	426610	1032074
Thailand (Millon Bath)				
	Agriculture	Industry	Services	Total
1980	184576	275388	372714	832678
1990	263607	735432	824282	1823321
2004	390006	1646424	1344797	3381227
Japan (Million Yen)				
	Agriculture	Industry	Services	Total
1980	10444914	102343433	124041981	236830328
1990	12045884	155231956	197912591	365190431
2004	8480800	165289900	265618700	439389400
South Korea (Million Won)				
	Agriculture	Industry	Services	Total
1980	14546900	39505400	49438153	103490453
1990	20287100	110614900	103313467	234215467
2004	23725221	256534075	206651684	486910980
Singapore (Million Singapore Dollar)				
	Agriculture	Industry	Services	Total
1980	327	13287	21334	34948
1990	178	24836	46612	71627
2004	172	55748	115177	171098

Source: Groningen Growth and Development Centre, 10-Sector Database.

Table A.3 : decomposition of changes in energy intensity for the period 1980-1990

Energy intensity 1980-1990							
	India	Indonesia	Philippines	Thailand	Japan	South Korea	Singapore
Agriculture							
Structure	0.988	0.989	0.998	0.926	0.994	0.980	0.998
Intensity	1.023	1.011	0.951	1.023	0.987	1.045	1.001
Total	1.012	1.000	0.949	0.947	0.981	1.024	0.999
Industry							
Structure	1.120	0.976	0.905	1.158	0.988	1.164	0.940
Intensity	0.840	1.656	1.249	0.859	0.804	0.750	0.771
Total	0.941	1.615	1.130	0.995	0.794	0.873	0.725
Services							
Structure	1.017	1.006	1.030	1.001	1.008	0.981	1.021
Intensity	0.942	1.003	0.982	1.018	1.085	1.124	1.031
Total	0.958	1.009	1.012	1.019	1.093	1.103	1.053
Total productive sector							
Structure	1.126	0.971	0.931	1.073	0.990	1.118	0.959
Intensity	0.810	1.679	1.166	0.894	0.861	0.881	0.796
Total	0.912	1.630	1.085	0.959	0.852	0.985	0.763

Source: IEA and Groningen Growth and Development Centre, 10-Sector Database.

Based on own calculations.

Table A.4: decomposition of changes in energy intensity for the period 1990-2004

Energy intensity 1990-2004							
	India	Indonesia	Philippines	Thailand	Japan	South Korea	Singapore
Agriculture							
Structure	0.958	0.985	0.998	0.969	0.992	0.975	0.999
Intensity	1.049	1.045	0.991	1.039	1.008	1.000	1.002
Total	1.005	1.029	0.990	1.007	1.000	0.975	1.001
Industry							
Structure	0.968	1.076	0.945	1.154	0.926	1.075	0.964
Intensity	0.677	0.914	0.791	1.105	0.920	0.926	1.059
Total	0.656	0.983	0.748	1.275	0.852	0.995	1.020
Services							
Structure	1.038	1.001	1.033	0.987	1.039	0.989	1.014
Intensity	0.902	1.041	1.050	1.063	1.032	1.008	0.994
Total	0.937	1.042	1.085	1.050	1.072	0.997	1.008
Total productive sector							
Structure	0.963	1.061	0.975	1.104	0.954	1.036	0.976
Intensity	0.641	0.994	0.824	1.221	0.958	0.934	1.054
Total	0.617	1.055	0.803	1.349	0.914	0.968	1.029

Source: IEA and Groningen Growth and Development Centre, 10-Sector Database.

Based on own calculations.

Table A.5: decomposition of changes in energy intensity for the period 1980-2004

Energy intensity 1980-2004							
	India	Indonesia	Philippines	Thailand	Japan	South Korea	Singapore
Agriculture							
Structure	0.949	0.968	0.994	0.901	0.981	0.967	0.997
Intensity	1.074	1.072	0.939	1.066	0.999	1.033	1.003
Total	1.019	1.037	0.934	0.961	0.980	0.999	1.000
Industry							
Structure	1.083	1.049	0.864	1.336	0.910	1.261	0.902
Intensity	0.573	1.486	0.980	0.946	0.746	0.687	0.821
Total	0.621	1.559	0.847	1.264	0.678	0.867	0.741
Services							
Structure	1.061	1.010	1.076	0.990	1.040	0.972	1.032
Intensity	0.839	1.052	1.024	1.077	1.126	1.133	1.026
Total	0.890	1.063	1.102	1.066	1.171	1.101	1.059
Total productive sector							
Structure	1.091	1.026	0.924	1.191	0.928	1.185	0.928
Intensity	0.516	1.675	0.943	1.086	0.839	0.805	0.846
Total	0.563	1.718	0.871	1.294	0.779	0.954	0.785

Source: IEA and Groningen Growth and Development Centre, 10-Sector Database.

Based on own calculations.