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Implications of Energy Efficiency and Economic Growth in Developing Countries

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It is essential that society shift toward more efficient energy consumption patterns. A sector basis analysis of energy consumption provides some suggestions regarding this view. In the residential sector, energy resources change with the advancement of development stages. The industrial sector is characterized by a diverse range of energy intensity in each subsector. Relevant policies and measures are considered based on the relevant sector information.

1. Introduction

Developing countries, particularly Asian countries, have experienced a rapid growth in energy consumption and carbon dioxide emissions. Such growth is a risk to sustainable development in terms of stabilizing energy supply/demand balance and maintaining environment quality.

It is estimated that primary energy demands will increase by 1.6 times between 2009 and 2035, with non-OECD countries responsible for 90% of the increase[1]. Accordingly, developing countries need to modify their development processes from conventional activities to low-carbon sustainable processes by reducing energy consumption and carbon dioxide emissions.

In this paper, we review and examine the relationship between economic development and energy consumption, and analyze energy consumption trends by sector to determine the implications for an energy efficient society.

2. Economic development and energy consumption

The relationships between economic development and energy consumption and economic development and carbon dioxide emissions have become important issues. For developing countries, these are crucial issues that continue to tie vital economic growth with the need to reduce energy consumption.

The environmental Kuznets curve has gained increasing attention, representing a hypothetical process where low carbon development accompanies economic development. This hypothesis provides some suggestions for an appropriate process for economic development and environment quality. The process consists of two stages: the relationship between income and environment is positive in early development stages and then turns negative as development advances. This hypothesis is supported in cases of hazardous materials such as sulfur oxides and nitrogen oxides[2]. In contrast, some research has demonstrated that the relationship between energy consumption and economic development does not follow this hypothesis and experiences monotonic increases instead[e.g., 3].

Researchers have even gone further and raised issues concerning the relationship between energy consumption and economic development, describing it as a black box and therefore we cannot see which factors influence the process[4]. To elucidate these issues, several indicators were proposed in addition to economic development, including a scale factor, structure factor, and technical factor.

However, contradictory results exist regarding the Kuznets curve[e.g., 5] and particularly, the relation between development and energy consumption among OECD and non-OECD countries[6]. We need to determine which factors influence economic development and energy consumption patterns. Because of the complexity of energy consumption, and the fact that energy is widely used in various sectors, it is difficult to identify a simple pattern of energy consumption for all sectors. The heterogeneous characteristics of energy consumption in each individual sector are considered important and a sector-level analysis can provide such valuable information[7]. Thus, to determine applicable policies and measures for effective energy efficiency, it is useful to examine the sector-based structure of energy consumption. Here we analyze two sectors to examine the factors that underlie energy efficiency in developing countries.

3. Energy consumption trends

In general, energy consumption per capita is said to increase with economic development, and energy consumption per GDP, i.e., energy intensity, is said to decrease, partly because of the application of energy efficient technologies[8]. This means that the growth rate of energy consumption is slower than the growth rate of GDP, and faster than the growth rate of population. In reality, trends differ according to each country and period. Figure 1 shows energy consumption trends per GDP for several countries. The lines of the OECD countries are reasonably stable; however, for non-OECD countries, the

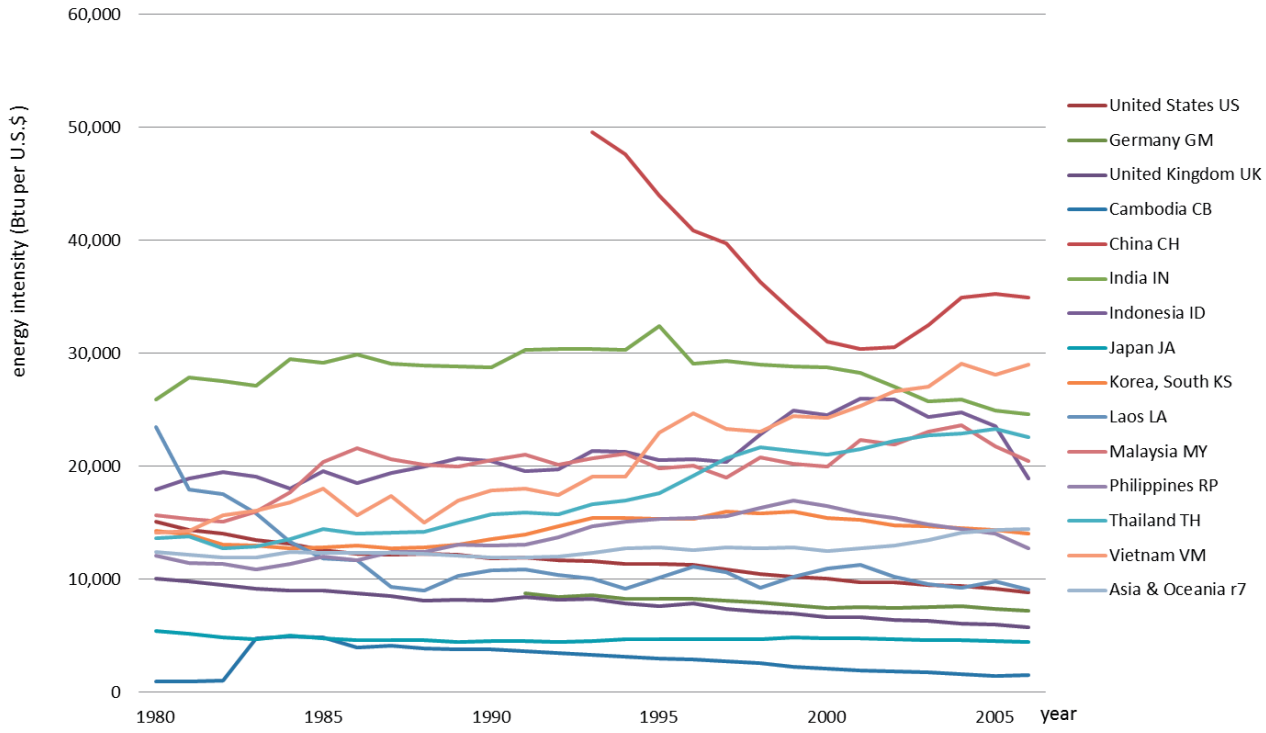


Fig. 1 Primary energy consumption intensity.
Source: EIA[9)]

trend lines often show uptrend lines or downtrend. The intensity curve for China is unique as it decreases steeply until 2000, and then increases somewhat. Some studies have investigated the factors responsible for such a trend in China; technology development was identified as having the largest influence[e.g., 10, 11)].

In focusing on sector characteristics, we considered final demand side energy consumption trends. Compared with supply side, demand side analysis is more complex because there are many sectors that consume energy. Effective policy measures regarding supply side are simpler, for example energy resource substitution, which brings more energy efficient generation. However, regarding demand, we have to consider various approaches according to sectors.

Several authors have conducted analyses on multi-country demand situations by sector[12, 13)]. Hamilton and Turton[12)] demonstrated trends in OECD countries and found that energy intensity reduction was observed in service and industry sectors but not in agriculture sectors. The International Energy Agency (IEA)[13)] analyzed energy trends in major sectors in OECD countries. However, there have been an insufficient number of studies focusing on multi-sector analysis in developing countries as a whole.

Here we examined patterns of increase in energy consumption, focusing on residential and industrial sectors, the two major energy consuming sectors in developing countries. Data are cross-sectional data from non-IEA members in 2007[14)] because of limitations in time series data[(1)]. Population and GDP data are sourced from the United Nations[15)] and World Bank[16, 17)], with the exception of Fig. 1.

4. Energy consumption in the residential sector

Residential energy consumption represents an average of 35% of total energy consumption in non-OECD countries. While this figure is the highest of all sectors, the share of residential energy is declining in line with economic development. The residential energy indicator is analyzed as energy per capita because energy is consumed by individuals (Fig. 2). Figure 2 suggests a possible trend of a positive relationship.

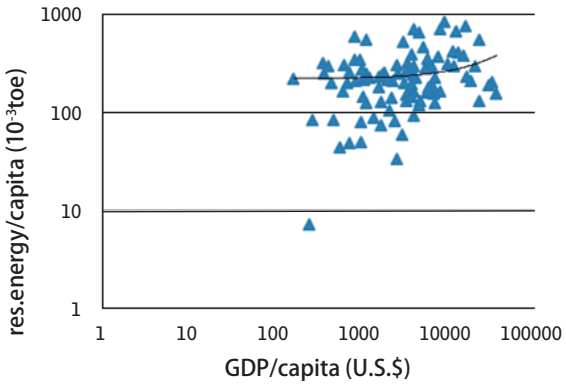


Fig. 2 Residential energy consumption.
Source: IEA[14)], World Bank[16)]

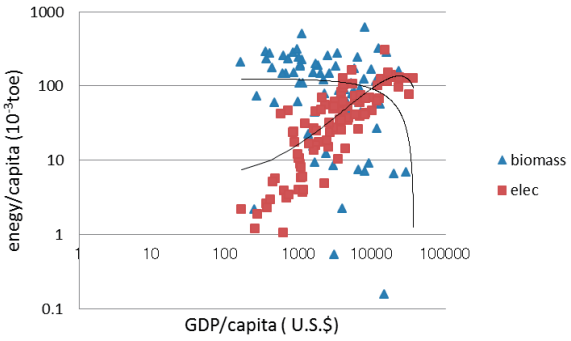


Fig. 3 Use of biomass and electrical energy.
Source: IEA[14], World Bank[16]

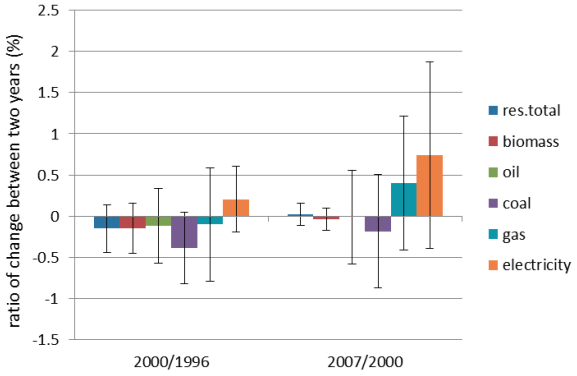


Fig. 4 Time series changes in selected Asian countries.
Note: Data represent averages and standard deviations for 13 countries
Source: IEA[14], World Bank[16]

Energy resources in residential sectors are classified as either biomass or commercial energy. In this study we determined the relationship between each energy resource and economic development. Biomass appears to have a negative relationship with economic development and commercial energy a positive one.

In addition, commercial energy can be broken down into several energy sources. Electricity energy has a strong correlation with economic development (Fig. 3), as has been reported in previous literature[e.g., 13]. In a primary development stage, residential energy resources are dominated by biomass energy, and in an advanced stage of development commercial energy is dominant. The demand for residential energy appears downward initially, and then the demand for electrical energy increases energy demands in accordance with the rapid diffusion of electric appliances.

Surveys of individual developing countries show the significant contribution of electricity to increasing residential energy consumption. In China, data for some cities showed that an increase in income was correlated to an increase in electricity consumption[e.g., 18]; the same trend has been observed in Thailand and Vietnam[19, 20].

Time series data regarding changes in energy sources in selected Asian countries are shown in Fig. 4. This figure shows residential energy per capita declined slightly between 1996 and 2000 and increased slightly from 2000 to 2007. Biomass and coal consumption has decreased and electricity use has significantly grown; the standard deviation varies in part because of the difference in speed of growth of electricity in each country.

Similar trends have been observed in OECD countries. The IEA[13] showed that between 1990 and 2004 residential energy consumption increased by 14% and energy per capita by 4%. The use of electrical appliances has increased by 1.5 times, a major contributor to the energy growth in this period.

The results of the analysis show that the energy growth deprived from electricity growth is expected to be a major determinant in the general trend in both developing and developed countries. The promotion of the efficient use of electric appliances will be key to reducing household energy.

According to Zhao et al.[18], ownership of electrical appliances in China, particularly air conditioners, has increased rapidly over the past several years. They suggested that one of the effective measures that can be used to control electricity consumption is to deregulate the price of energy, because regulated low energy prices have resulted in an increase in energy consumption. Electricity has been subsidized for a long time in China, and inexpensive electricity might hamper energy saving efforts. According to Dianshu[21], most people are not overly concerned about their electric bill. He suggests that the paying system should be changed so that information regarding the price of electricity is disseminated to all members of the household.

Another measure to promote energy saving is to increase people's level of awareness with regard to energy saving issues. An energy saving mindset can play an important role, and it is necessary to provide more guidance and information regarding residential energy conservation[e.g., 18]. However, people's knowledge of this issue varies depending on their cultural and social backgrounds, thus efforts to educate the public should be designed according to people's specific ideas and concerns in a designated region. One idea to promote awareness of energy efficiency in residential sectors is appliance labeling; this has already been introduced in some Asian countries.

Furthermore, household energy consumption is affected by other factors such as temperature, social structure, resource endowment, and infrastructure[e.g., 22], and further investigations into those factors would be useful.

5. Energy consumption in industrial sectors

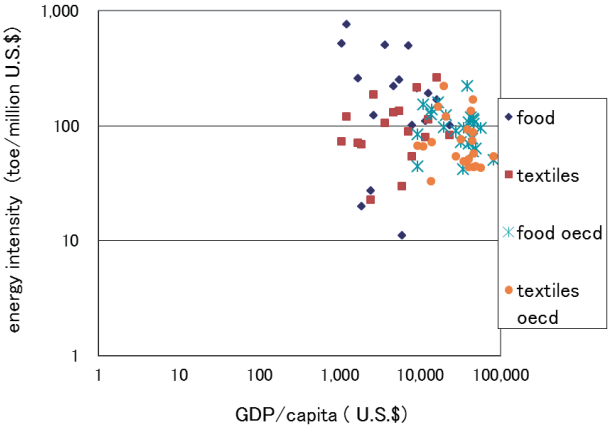
Industrial energy consumption accounts for an average of 22% of all energy consumption in non-OECD countries. The energy indicator for industry is generally estimated as energy consumption per GDP. The relationship between industry energy consumption and GDP per

Fig. 5 Energy intensity per industry.
Source: IEA[14], World Bank[16]

capita is shown in Fig. 5. As seen in Fig. 1, the measure of the steepness of energy intensity varies among the countries, and similarly to the trends in Fig. 1, no clear trend can be identified in Fig. 5.

The energy intensity of an industry can be categorized into four major subsectors (see Fig. 6). The decomposition in Fig. 6 shows the differences among the subsectors. The intensity of light industry such as food and textiles is shown in the upper figure, and the lower figure shows the intensity of heavy industry such as chemical and machinery. Heavy industry has higher energy intensity than light industry. The intensity of non-OECD countries varies; there exists a substantial difference in energy intensiveness among countries. The food subsector ranges from 11 to 517 (unit: toe/M US$), with data plotted over a wide area, textiles range from 23 to 262, which is a relatively narrow range, machinery from 3 to 423, and chemical from 6 to 12,958, which is one of the most energy intensive subsectors and diverse by country. In contrast, intensity data for OECD countries are plotted in a narrow area. Thus, it is reasonable to predict that in the future the efficiency of non-OECD countries will converge to the narrow area of OECD countries. The improvements in the intensity figures in the major subsectors is crucial because the potential global energy savings of major subsectors is huge; in OECD countries, the estimated savings of the five most intensive manufacturing sectors (chemical, iron and steel, cement, pulp and paper, and aluminum) is equivalent to 13% of all industrial energy used in 2006[24].

Between 1990 and 2004 in 19 OECD countries, industry output increased by 31%, but energy consumption only by 3%[13]. In contrast, in non-OECD countries, GDP output increased by 38% and energy consumption by 35% in same period. Data from 1990 to 2000 and 2000 to 2007 for several Asian countries show that their intensity generally improved in each period (with the exception of Nepal and Mongolia)[14]. As the growth rate of industry outputs in each period exceeded the rates of intensity reduction, developing Asian countries experienced high rates of growth in energy consumption (Fig. 7) This phenomenon is known as the rebound effect where



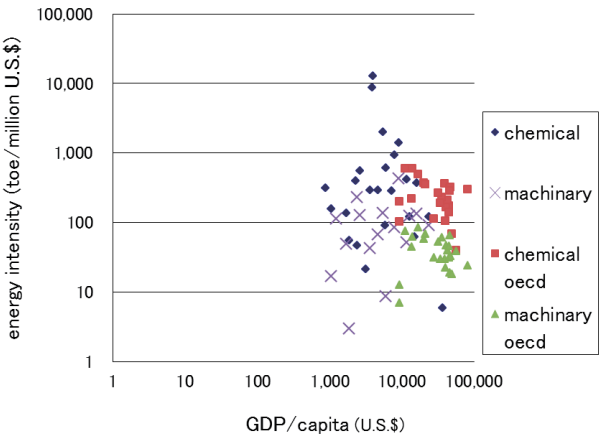


Fig. 6 Energy intensity of four subsectors.
Note: Energy intensity is calculated using energy consumption, divided by sector value added in each subsector.
Source: IEA[14), 23)], United Nations[15)], World Bank[16)]

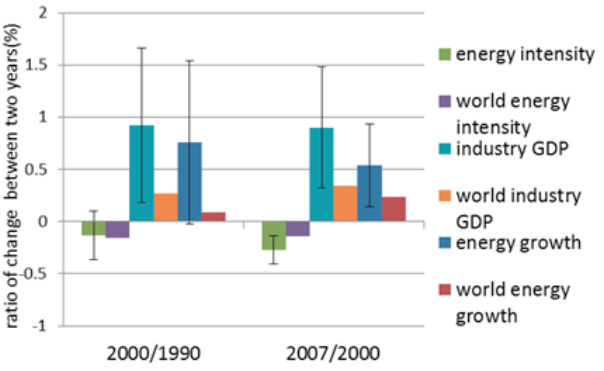


Fig. 7 Time series changes in selected Asian countries compared with world averages.
Note: Energy includes feedstock
Source: IEA[14], World Bank[16]

energy efficiency can encourage an increase in energy consumption. However, this does not mean that energy efficiency policies are ineffective[8, 25].In summary, industry sector energy consumption continues to increase because of its high growth in outputs, and because the energy intensity of each subsector in the various industries is characterized by diverse industrial structures and industrial traits in each countries. The OECD data range shows that the intensity figures in each subsector are plotted in a narrow area, and therefore these figures for non-OECD countries may converge in the future with OECD countries.

For example, the chemical sub-sector exhibited the biggest change in energy intensity between OECD and non-OECD. This means there is a huge potential for energy saving in the chemical industry. IEA[26] pointed out that the chemical industry is responsible for 10% of global energy consumption, which is equivalent to 36 EJ. The potential for energy saving in the chemical sector is expected to be higher than 13 EJ owing to the introduction of the best available technology (BAT). This means the potential energy saving is one-third of the total consumption. However, realizing this potential will require a great deal of investment to introduce BAT. Therefore, the government needs to provide incentives, including financial assistance, technical assistance, and an increase in societal awareness. According to Lin et al.[27], the energy intensity gap between the chemical sub-sectors in Japan and China can be narrowed by implementing several policy incentives. Technical development is the most important factor, followed by productivity improvement[(2)], scale of enterprise, and energy cost. According to Hu[28], incentives for energy saving in the Chinese industry sector include subsidiaries, tax exemptions, and assistance with investment.

In some developing countries, the food industry is a major consumer of energy. For example, in Thailand, the food sub-sector was responsible for 30% of the total energy consumption in manufacturing in 2000. As development has progressed in energy-intensive sub-sectors such as the chemical industry, the share of energy consumption of the food sector has declined during the years 1981–2000[29]. Energy requirements in food sub-sectors are lower than those of high intensity industrial sectors; however, the figures diverge in developing countries. A variety of incentives should be considered, especially economic incentives. Hasanbeigi et al.[30] cited many companies in Thailand acknowledged that energy cost reduction is connected with production cost reduction, and thus, they concluded that guidance regarding the benefits of energy conservation can be effective.

Accordingly, a more detailed investigation of energy intensity is required in each subsector—the identification of their industry characteristics will be useful to promote efficiency. A further investigation is necessary to examine how determinants affect the relationship with energy intensity in each subsector, including product efficiency, scale of industry, and management structure, which could provide valuable information for energy saving.

6. Conclusion

The focus of this survey was a multi-sector analysis in developing countries. This has not been performed in the past owing to data limitations. Our analysis on energy consumption in developing countries showed the typical features of household and industry consumption. Household energy consumption is dominated by biomass energy in early development stages. Biomass is then replaced by commercial energy, particularly electricity, which rapidly increases as development advances. Therefore, energy savings must correspond with increases in electricity use and so the efficient use of electric appliances is essential.

In industry sectors the level of energy consumption is relatively stable in developed countries. In contrast, in developing countries, because of rapid growth in development, energy consumption showed an upward trend. In this situation, the current improvement rate in energy intensity is not enough and rapid growth in output has exceeded any reduction in energy intensity. Thus, all industry policy measures must promote energy savings according to each subsector's characteristics.

In summary, promoting energy efficiency is the key in both the household and industry sectors. There is the potential for these two sectors to significantly reduce energy consumption. In 2006, the greatest energy savings achieved by 11 IEA member countries were in the manufacturing sector (41%), followed by the household sector (23%)[31].

Along with the involvement of all stakeholders, we need to promote the unique factors and motivation of each sector, necessary policies and measures (e.g., changing people's minds, technology revolution, and environmental regulation[2] to achieve the desired energy savings.

Note:

(1) Recently panel data were often used in other researches; however, sometimes sector base data are missing or unreliable for developing countries.

(2) Productivity improvement affects GDP change through cost reduction, and as such it requires careful consideration[7].

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