Intensity Of Energy Use In The U.S.A.: 1949 - 2003

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ABSTRACT

The particular role that energy plays in the economy of a country, and the relationship between energy consumption and economic growth are of interest to researchers, analysts, and policymakers. Energy consumption can be seen as either a cause of, or a symptom of economic growth. Therefore, understanding the nature of the interactions between energy consumption and gross domestic product (GDP) can help guide energy policies. This paper examines the energy-GDP relationship in the U.S.A. One common method used in analyzing the energy-GDP relationship is energy intensity (also called the intensity of energy use (IEU)), which is the amount of energy required to produce a unit of income (GDP). The paper begins with a substantial literature review of energy intensity studies from around the world. A summary of the findings is discussed, including the factors that were found to directly influence the intensity of energy use. The Kuznets environmental curve is then presented and used in developing a model for the IEU. The model is then tested with data for the U.S.A. from 1949 – to 2003. The results show that energy consumption is very sensitive to energy prices, which in turn impacts the GDP, and that the IEU has declined in the U.S.A. for the period tested, fitting the downward slopping segment of the Kuznets curve. These results imply that energy conservation policies are desirable.

INTRODUCTION

Energy availability and consumption play a key and crucial role in the process of economic growth. At the same time, energy consumption patterns in every country are significantly affected by energy prices. Energy use has been associated with population growth and the expansion of urban centers. Energy use is a key to industrialization and the development of industrial and infrastructural facilities. Roads and transportation networks are among the most energy intensive of these facilities. Energy use is a necessary input to economic growth and is also a function of growth.

Energy has been defined as both a consumer good and an intermediate good (Pierce, 1986). As a consumer good, at the early stages of economic growth, it is possible that consumers will demand and consume more energy as soon as they can acquire the means to do so. It is also possible that the income elasticity of energy demand could become low. This concept can be tested with the intensity of use technique. As an intermediate good, the demand for energy is a derived demand; input factor demand derived from demand for the final product being produced.

The traditional argument is not that energy is merely a consumption good, but that it is an essential input into technological advancement. The substitution of machines and other forms of capital for human labor is an integral part of the process of economic development that requires energy inputs. Thus, one can view the consumption of large amounts of energy as either a cause or a symptom of economic growth.

Economic growth is generally described in terms of the ability of a country to produce more goods and services from one year to another. This concept of economic growth is captured in the evaluation of the gross domestic product (GDP) of a country. The GDP represents the total market value, expressed in dollars, of all final goods and services produced within a country over a certain period. The GDP calculated each year, known as the nominal GDP, is often adjusted for inflation to account for changes in price levels over time, yielding the real GDP. The real GDP is then divided by the population to obtain real GDP/capita. This real GDP/capita has been used to compare standards of living between countries. Thus, another interpretation of economic growth is the ability to increase real GDP/capita over time.

Producing goods and services requires the use of energy inputs. The goal of society is to use energy wisely and efficiently because energy resources are scarce or limited. Energy intensity, known as the intensity of energy use, refers to the amount of energy required to produce a unit of output (GDP). Thus, the energy-GDP ratio is a measure and indication of energy intensity.

A REVIEW OF ENERGY INTENSITY STUDIES

The concept of energy intensity (the ratio of energy consumption to gross domestic product), and energy elasticity (the ratio of the percentage change in energy consumption to that of GDP), have been used frequently in predicting energy needs, in comparing energy use efficiency, and in assessing the impact of energy on the economy.

Energy intensity, as defined above, also represents the amount of energy required to produce one unit of income. It has been considered a global indicator of the link between energy consumption and income. Damstadler, Dunkerly, and Alterman (1977), applied this concept of energy intensity to a comparative analysis of how industrialized societies use energy. They found that there existed complex methodological issues indispensable in making international comparisons. In addition, the task of going beyond the energy consumption GDP ratio, which revealed differences but masked the reasons, proved difficult.

Tabti and Mandi (1985), presented the global evolution of the energy intensity ratio over the previous 35 years. In their work, they did not only give the intensities for total energy and oil, but also provided the intensities for other sources of energy such as coal, gas, and electricity. This enabled them to analyze the behavior of each source separately as well as compare the evolution of each source. The analysis of the evolution of the various intensities by source gives an indication of some of the parameters in their interrelation with energy. Such parameters include technological change in the economy, especially increasing industrialization in the earlier periods and the more efficient use of energy and its conservation in later years. This, however, does not yet suggest the change in economic relation between the gross domestic product and energy demand since this is also affected by several other factors, the most important of which in the last decade has been the energy price.

Yu and Choi (1985), computed both the average and the marginal energy-GDP ratios for selected countries (Poland, South Korea, United States, United Kingdom, and the Philippines), covering the period 1963 to 1976. They concluded that the aggregate energy consumption to GDP ratios are relatively stable in diversified and developed countries. They showed that market economies like the United States, as well as centrally planned economies like Poland at that time, fit this mode. However, the disaggregate energy–consumption–to-GDP ratios exhibited erratic patterns.

In the case of other industrialized and developing countries lacking abundance of energy resources, substitution among various types of energy in use and other primary inputs cause an unstable shift in the composition of energy consumption as well as aggregate energy consumption. According to Yu and Choi, energy intensity becomes an endogenous variable responding to socioeconomic variables in these countries, and that the volatile nature in the energy-GDP ratio renders the ratios useless for forecasting purposes.

Tilton (1985), also provided a critique of the intensity of use technique for forecasting, focusing particularly on its treatment of technological change and material substitution. He noted that when these important determinants of material (energy) demand are adequately assessed, the intensity of use technique loses its advantage and attractiveness as a forecasting tool.

Abodunde, Wirl, and Koesti (1985) tested the hypothesis of constant energy demand elasticities at the sectoral (industry, transport, and others) and international levels (Belgium, France, West Germany, Italy, the Netherlands, United Kingdom, and the United States) vis-à-vis more general assumptions. They applied the analysis of variance tests and suggested that this simple relationship of constant energy demand elasticities was more robust than is often conjectured.

Elias and Grabik (1980) compared the energy intensity and energy elasticity in Eastern and Western Europe. Using a cross-sectoral national data for 1978 and a time series data for the period 1950 – to 1979, they found a higher energy consumption pattern in the Eastern Bloc countries than in the Western European countries. They explained the differences in intensity and elasticity of energy among various countries in the context of stages of economic development, structure of energy consumption pattern, climatic conditions, energy supply, and in the overall economic conditions inherent in political structures.

Adelman (1980) objected to the use of an energy coefficient because of inherent difficulty in interpreting the coefficient. He argues that the elasticity is unstable and confusing, while maintaining that the energy-income ratio is still a valid and useful measure.

Following the dramatic increase in oil prices in the 1970s, decision –making in the energy sector became more complex. This led many nations to reallocate scarce human and financial resources to deal with energy problems. It is quite possible that despite the post 1970s decline in global energy prices, many countries, especially developing countries, still had problems adapting to the burden of imported commercial energy. In recent months, energy prices have been on the rise again, and uncertainty about future supplies exists. Therefore, there will be a need to improve the efficiency of energy use in many countries.

Ang (1987) studied the relationship between energy consumption and output for six developing countries in Southeast Asia. The changing structure of energy demand by consuming sectors and the effects of this on energy-output ratios were analyzed. It was found that the commercial energy-output ratio increased for most of the period between 1960 and 1982. The five sectors responsible for the increasing ratio of commercial energy to output ratio were; the rising share of industrial output in GDP, the substitution of commercial for noncommercial fuels, the strong demand for transportation energy use, the rise in electricity demand in the household and commercial sectors, and the expansion of the energy conversion industries.

The countries of Southeast Asia have achieved rapid economic growth and growth in energy use over the past 20 – 40 years. It has been observed in these countries that the relationship between energy demand and economic growth is a very strong one, although there are variations in the relationship in different periods of time. It has also been shown that for the developing countries where non-commercial energy consumption is significant; the use of energy elasticities estimated based on commercial energy consumption provides only a partial picture of the overall energy-output relationships. In particular, projection of future commercial energy demand based on these elasticities is likely to be overstated. Therefore much caution must be exercised if they are to be used for energy demand forecasting.

Jones (1991) examined how urbanization affects energy use in developing countries. Industrialization and urbanization accompany each other during economic development, but urbanization exerts a number of independent influences on energy-use. It permits economies of scale in production but requires more transportation. Food must be transported to urbanized populations and relatively smaller agricultural populations must modernize, entailing considerable increases in agricultural energy use. In cities, a number of production activities that were domestically produced in rural areas, using human or animal energy, shift to sources outside the household, using modern energy inputs. The largest single source of change in energy-use is personal transportation, which is heavily weighed towards fuel-using modes, particularly as income increases.

Simon and Levine (1994) studied the changing energy intensity in Chinese industry to determine the relative importance of structural shift and intensity change. They analyzed three different sets of energy consumption and output value data using a Las Peyres index method to determine the relative rates of structural shift and real intensity change in China's industrial sector between 1980 and 1990. They found that real intensity change, the economic intensity of industrial sub-sectors, composed of physical intensity change and other non–structural factors, account for most of the large apparent drop in industrial energy intensity in the 1980's. Real intensity is the primary driver of industrial energy intensity change. China's falling energy intensity is in contrast to that of other developing countries. The results from this study indicate that falling intensity within sub sectors was the key to overall intensity change. Therefore, a deeper understanding of the sources of intensity change can help to improve the quality of energy demand forecasting.

Judson, Schmalensee and Stoker (1999) examined economic development and the structure of the demand for commercial energy. To deepen understanding of the relation between economic development and energy demand, the relations between per-capita GDP and per-capita energy consumption in major economic sectors were estimated, covering up to 123 nations. Time and country fixed effects were assumed, and flexible forms for income effects were employed. They found that there were substantial differences among sectors in the structure of country. In particular, they found that the household sector's share of aggregate energy consumption tends to fall with income, the share of transportation tends to rise, and the share of industry follows an inverse-U pattern.

Miketa (2001) presented an analysis of energy intensity developments in manufacturing sectors in industrialized and developing countries. The studies covered the development of energy intensity over time and its relationship with the sectoral economic development. Three variables were analyzed with respect to their impact on energy intensity, sectoral gross fixed capital formation and industrial energy prices. Panel analysis was conducted for ten manufacturing industries using pooled data of 39 countries between 1971 and 1996. The study found that capital formation has the effect of increasing energy intensity and this effect is stronger where sectoral output is larger.

Murtishaw and Schipper (2001) did a disaggregated analysis of U.S. energy consumption in the 1990's and examined evidence of the effects of the Internet and rapid economic growth. The study decomposed US energy use from 1988 to 1998 and attributed the change in energy use to three underlying factors; activity, structure, and intensity. The study used a bottom–up methodology, by separately decomposing delivered energy use in six sectors; travel, freight, manufacturing industries, non-manufacturing industries, residential and services. The study found that the most commonly used indicator of energy efficiency in the total economy, the ratio of energy consumed to GDP (EC/GDP), can often be misleading. The rapid decline in EC/GDP ratio in recent years has been used to support assertions that the internet and information technologies in general have enabled improvements in energy efficiencies. However, this disaggregate analysis suggests that energy intensities on average are falling more slowly than ever before while actual energy use increased faster than at any time since 1970. They concluded that the decline in the EC/GDP ratio in the mid to late 1990's owes much more to structural changes in the demand for energy services than to falling energy intensities.

Medlock and Soligo (2001) examined economic development and end-use energy demand using panel data consisting of 28 countries from all levels of development. They constructed a "map" of energy use by sector during the course of economic development. They then used this development map to project possible future growth in energy demand by end-use sector, and determined the composition of final energy consumption as a function of the level of development. The relationship between economic development and energy consumption was examined. The development patterns that characterize particular economic sectors were identified and the effects of sector specific-demand growth raters on the composition of final energy demand were analyzed. They found that industrial energy demand increases most rapidly in the initial stages of economic development, but growth slows steadily throughout the industrialization process. Energy demand for transportation rises steadily, and takes the majority share of total energy use at the later stages of development. Energy demand originating from the residential and commercial sector also increases to surpass industrial demand, but long term growth is not as pronounced as it is in the transport sector.

Michnik and Goldemberg (2002) looked at foreign direct investment and decoupling between energy and gross domestic product in developing countries. On a sample of 20 developing countries, they noticed a clear decline in energy intensity as foreign direct investment increased. Probably the reason for this is that foreign direct investments come with modern technologies. Thus, leapfrogging occurs over the old fashioned traditional technologies that were previously in use in these countries.

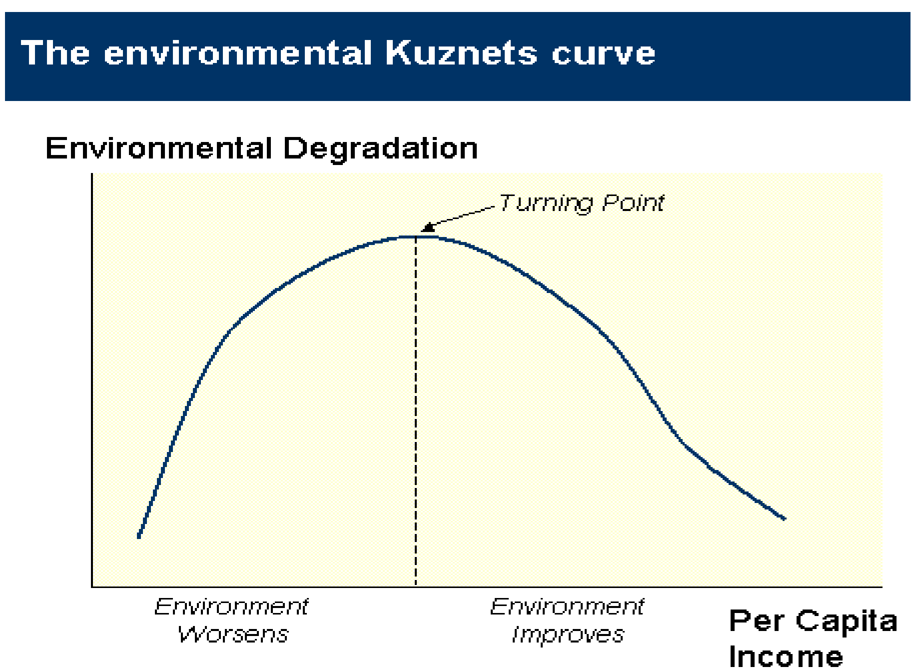
Fisher-Vanden, Jefferson, Lin and Toa (2003), examined what is driving China's decline in energy intensity. Energy intensity in China has been falling since economic reforms were set in place in the 1970's, and beginning in 1996, there has been a striking decline in the absolute level of energy use. Some of the decline was accounted for by falling coal consumption in the industrial sector. Employing a unique set of panel data for approximately 2500 of China's most energy intensive large and medium-sized industrial enterprises during 1997-

1999, they found that rising relative energy prices, research and development expenditures, ownership reform in the enterprise sector, as well as shifts in China's industrial structure, merge as the principal drivers of China's declining energy intensity and use.

SUMMARY: DETERMINANTS OF ENERGY INTENSITY

The following factors are presented from the literature review laid out above. These factors influence the intensity of energy use over time.

1. Technological change in the economy (Tabti and Mandi, 1985)
2. Increasing industrialization
3. Efficiency in the use of energy
4. Energy conservation
5. Energy price(s)
6. Stages of economic development (Elias and Grabik, 1980)
7. Structure of energy consumption pattern
8. Climatic conditions
9. Energy supply
10. Political structure
11. Energy substitution -commercial for non-commercial fuels (Ang, 1987)
12. Strong demand for transportation energy use
13. Rise in electricity demand in the household and commercial sectors
14. Expansion of energy conversion industries
15. Extent of urbanization (Jones, 1991)
16. Extent of capital formation (Miketa, 2001)
17. Structural changes in the economy (Murtishaw and Schipper, 2001)
18. Foreign direct investments (Michnik and Goldemberg, 2002)
19. Research and development expenditures (Fisher-Vanden et al, 2003)
20. Ownership structure in the enterprise sector.



The environmental Kuznets curve (EKC) is a hypothesized relationship between various indicators of environmental degradation and income per capita. It is held that in the early stages of economic growth, degradation and pollution increases. However, beyond some level of income per capita, (which will vary for different indicators), the trend reverses so that at high per capita income levels, economic growth leads to better environmental quality. Thus, the EKC implies that the environmental impact indicator is an inverted U-shaped function of income per capita. Typically, the logarithm of the indicator is modeled as a quadratic function of the logarithm of income. The EKC is named for Simon Kuznets (1955) who hypothesized that income inequality first rises, and then falls as economic growth increases.

The EKC is essentially an empirical concept, but most of the EKC literature is econometrically weak. The EKC concept rose to prominence because little attention was paid to econometric diagnostic statistics. Very few paid any attention to the statistical properties of the data used, such as serial dependence or stochastic trends in time series and few tests of model adequacy have been carried out or presented. When such statistics is taken into account and the appropriate techniques are used, it was found that the EKC does not exist (Stern, 2003). Instead, there was a more realistic view of the effect of economic growth and technological changes on environmental quality.

In general, Kuznets curves have been found for some environmental health concerns (such as air pollution) but not for others (such as landfills). However, it is important to note that this does not necessarily invalidate the theory-the scale of the Kuznets curves may differ for different environmental impacts. The EKC concept has also been employed in analyzing the impact of international trade on the environment and has been a contentious issue.

Many types of pollution and natural resources degradation appear to follow the environmental Kuznets curve - air pollution, water pollution, rates of deforestation, the fraction of fish species listed as endangered, and municipal wastes per urban resident. Energy, land, and resource use do not fall with rising income but the ratio of energy consumption per GDP has fallen and total energy use is still rising in most countries.

THE INTENSITY Of ENERGY USE (IEU): APPLYING THE KUZNETS CURVE TO ENERGY CONSUMPTION

The concept of the intensity of energy use (IEU) predicts that the amount of energy consumed in an economy depends on two relationships. The first assumes that the intensity of energy use, or energy intensity ─ defined as the amount of energy, measured in coal equivalents, BTU, or other physical units, that the economy consumes per unit of gross domestic product (GDP), measured in constant terms ─ is a function of its level of economic development as indicated by income per capita (GDP/P), where P is the population.

In any given year, this relationship can be represented by equation (1).

$$IEU = f(GDP / P) \tag{1}$$

Empirically, the exact specification or nature of the above equation can be determined, but would vary from one energy source to another. In general, the basic shape of the intensity of energy use model is represented by Figure 1, with an inverted U-shaped curve, the equivalent of the Kuznets environmental curve. In the IEU model of Figure 1, the horizontal (x) axis of the graph represents real per capita income (GDP/Capita) like the Kuznets curve. However, the difference between the IEU model and the Kuznets curve is in the vertical (y) axis. The vertical axis in the Kuznets curve represents environmental degradation. In the IEU model, the vertical axis represents energy intensity, the amount of energy required to produce a dollar of income (real GDP).

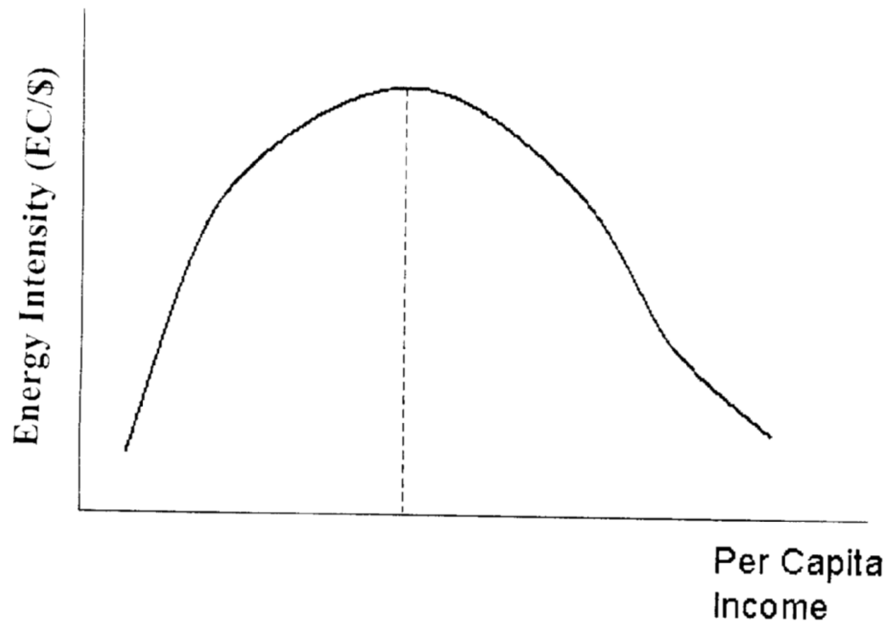


Figure 1

The implication of this basic shape is that at the early stages of economic growth, when per capita incomes are low, energy requirements are also low. This is typical in agrarian societies. As industrialization occurs, investments in basic industry, infrastructure, and other energy – consuming activities will cause energy consumption per unit of income to rise sharply. This implies that developing economies will be represented along the upward – sloping part of the inverted U-shaped curve. As economic growth and development continues, the demand for roads, automobiles, housing, schools, hospitals, and factories are eventually satisfied, and the composition of national output shifts gradually towards services and away from manufacturing.

This shift is presumed to lead to less energy consumption and a lower or declining intensity of energy use. The structural change in final demand will at first slow, then at some higher level of per capita income, reverse the upward trend of the IEU curve.

In addition to this kind of shift in the mix of final goods and services, it is also widely recognized that technological innovations and substitution among energy sources, induced primarily by rising energy prices and other factors, influence the intensity of energy use.

The second relationship advanced by the intensity of energy use concept is the identity that equates a country's consumption of energy (D) in any year t, to the product of intensity of energy use (IEU) and its gross domestic product (GDP), as shown in equation (2).

$$D = (IEU).GDP) \quad (2)$$

The IEU is composed of two determinants, the product composition of GDP (this is the mix of goods and services that the economy produces) and the energy composition of products (the amount of energy it takes the economy to produce the mix of goods and services), which reflects the price of energy. Thus, there are two views on the intensity of energy use.

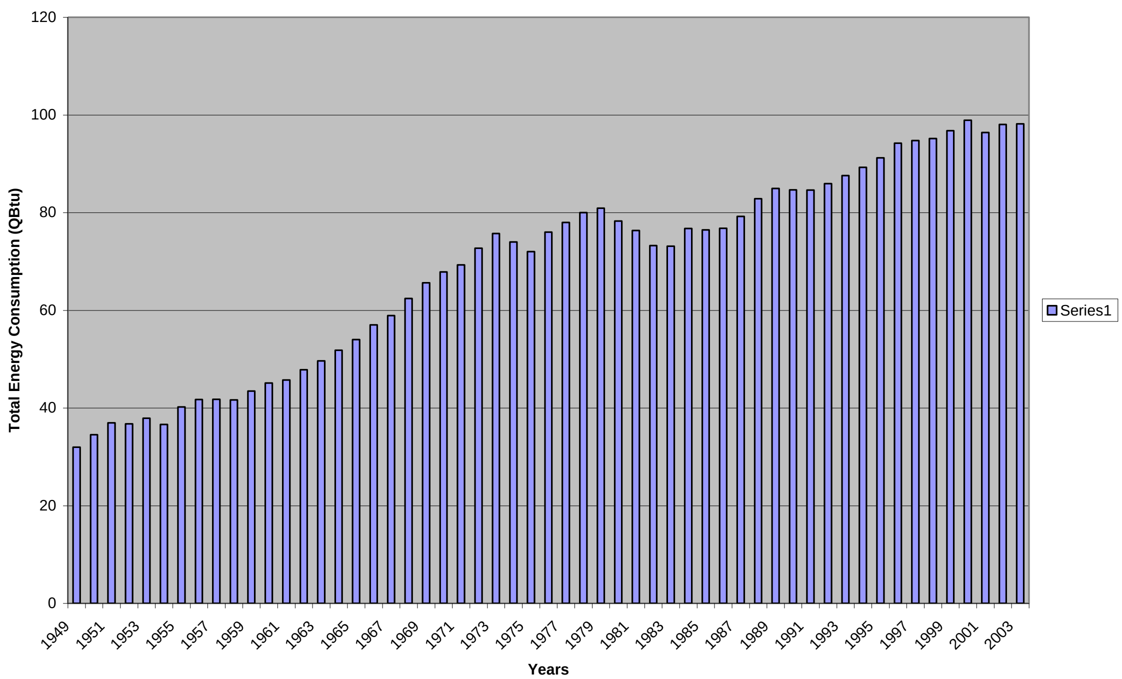
The first view advanced is that the intensity of energy use is mainly determined by the product composition of the gross national product (GDP). As such, developing countries, if they industrialize and grow, will pick up the slack in energy consumption from developed countries that have become service-oriented. The second view is that the intensity of use is equally determined by the energy composition of products. As such new developing countries, because of technological leapfrogging and other factors, will not pick up the slack in consumption from the advanced countries.

ANALYSIS OF DATA FOR THE U.S.A

For the accompanying analysis, energy data was obtained from the website of the U.S. Department of Energy (DOE), Energy Information Administration (EIA), official energy statistics from the U.S. Government. Data for total energy consumption from 1949 - 2003 was taken from the energy overview table. In this study, energy consumption was not decomposed into its various forms. Energy data is expressed in quadrillion BTUs (Qbtu). Data for real GDP, and population were obtained from the website of the U.S. Department of Commerce, Bureau of Economic Analysis, NIPAT tables. GDP data is expressed in billions of dollars, while the population is in millions.

Figure 2, depicts total energy consumption in the U.S., from 1949 – 2003. It shows that energy consumption rose steadily during the time stated with some periods of fluctuations. The fluctuations in energy consumption are related to fluctuations in energy prices. Total energy consumption is very sensitive to energy prices.

Figure 2. U.S. Total Energy Consumption (1949 -2003)

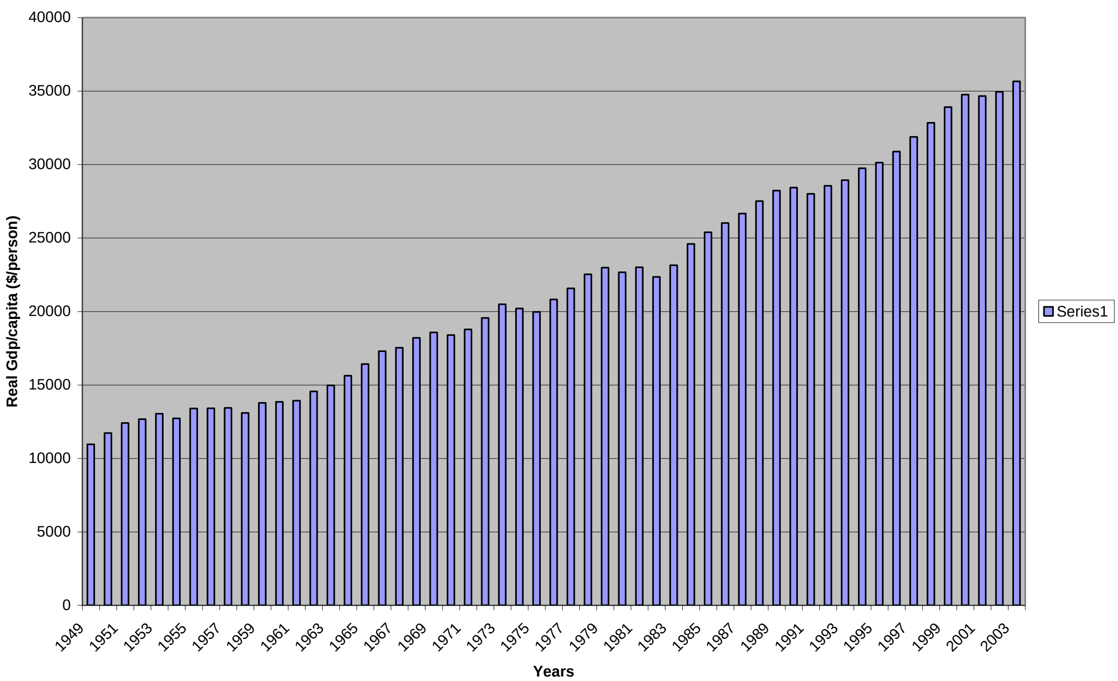


As can be seen from Figure 2, there were small or minor fluctuations in consumption between 1953 and 1959. Thereafter, the graph shows a smooth steady rise in energy consumption from 1959 to 1974. From 1974 to around 1987, there were very significant fluctuations in total energy consumption. This period (1974 – 1987), corresponds to the advent of the oil embargo of the 1970's and the subsequent oil shocks. From 1987 to 2003, the graph shows another period of relatively steady rise in energy consumption with less pronounced fluctuations. Overall, between 1949 and 2003, total energy consumption in the U.S.A. rose from 31.98 to 98.16 Qbtus, an increase of 207%.

Figure 3 is a graph of the real GDP/capita, which is an indication of the standard of living, in the U.S.A. from 1949 – 2003. The data shows a steady rise in the standard of living from approximately $10,957 in 1949 to about $35,664 in 2003. These numbers yield a cumulative increase of 225% over the stated time period.

Although a few dips can be seen in Figure 3, no major fluctuations in the real GDP/capita are observable. Thus, as expressed by the numbers in Figure 3, the U.S. had had a steady and uninterrupted climb in the real GDP/capita.

Figure 3. U.S. Real GDP/Capita (1949-2003)



In Figure 4, the energy/GDP ratio is presented. The data for this graph is obtained by dividing the total energy consumed each year by the real GDP for the same year, yielding energy consumed per dollar of output or income. As noted earlier, this is an indication of the energy intensity, also known as the intensity of energy use, the amount of energy required to produce one dollar of income each year.

As can be seen from Figure 4, energy/GDP ratio has been on the decline in the U.S.A. for the time period stated. The numbers here show a cumulative decline in the energy/GDP ratio of about 50%. This is a very significant decline. Particularly, it shows that the U.S. uses approximately half as much energy in 2003 to produce a dollar of income, as it did in 1949. Alternatively, in 2003, the U.S. produced twice as much income from a unit of energy, compared to 1949.

Figure 5 shows a graph of total energy consumption, versus real GDP on the y-axis. A good look at this graph reveals how energy consumption is influenced by energy prices and how that impacts economic activity. The dots or diamonds in figure 4 represent each of the years covered, from left to right. The small but early fluctuations seen in the 1950's in the energy consumption data is reflected as the first bubble or skew or adjustment in Figure 5. Beyond that point, a gradual linear trend can be observed up to 1974, when the next skew or adjustment can be seen. The curve shifts slightly to the left at this point, denoting a reduction in energy consumption per unit of GDP. This adjustment can be attributed to the oil shocks and the consequent increase in oil prices around 1974.

Figure 4. U.S. Energy/GDP Ratio (1949-2003)

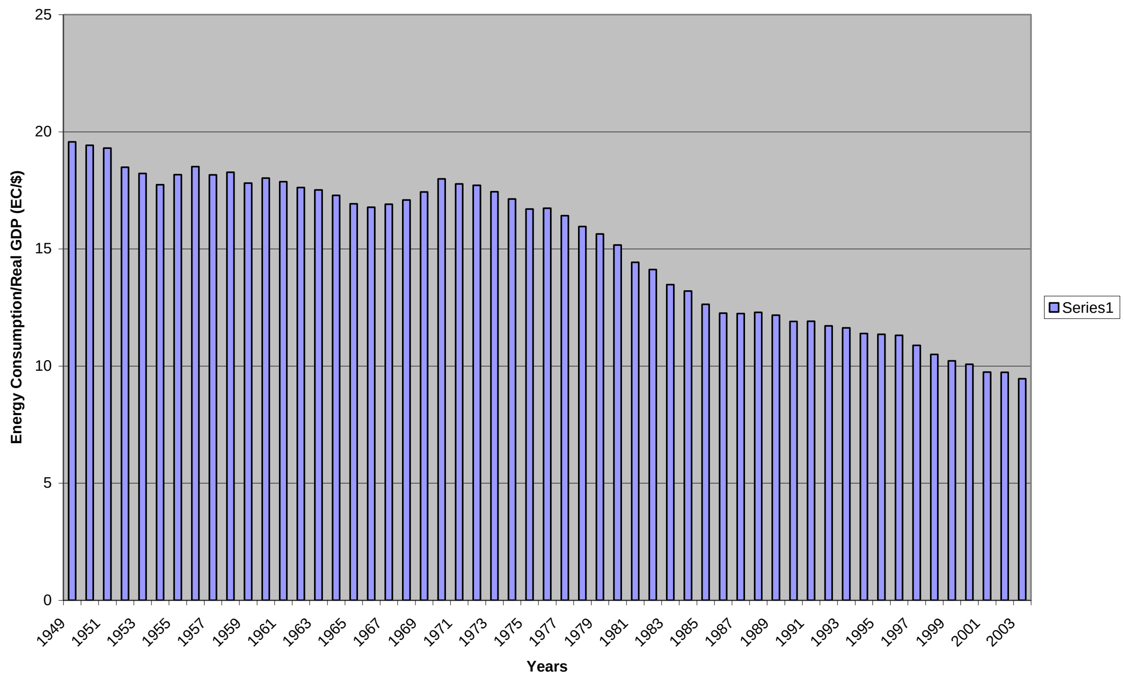
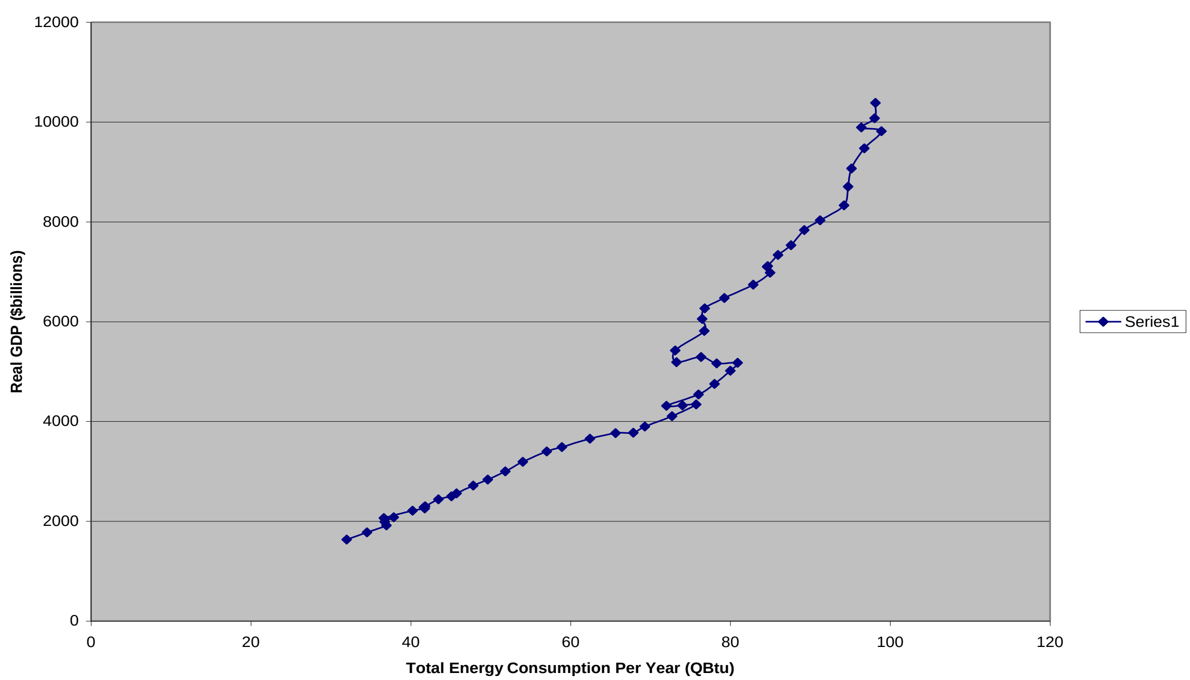


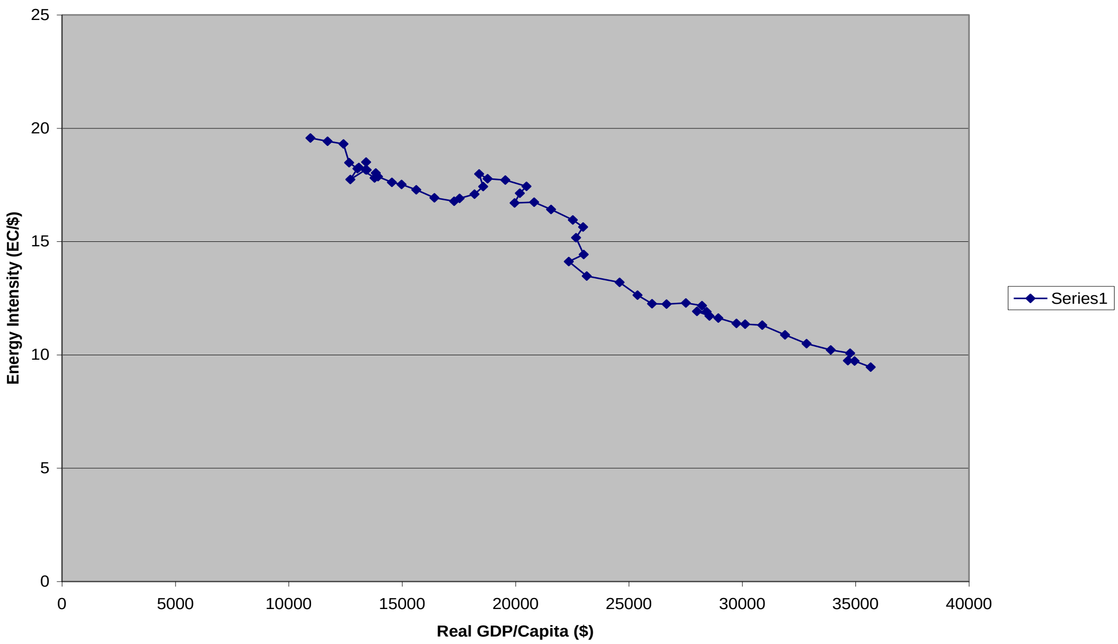
Figure 5. U.S. Energy Consumption v. Real GDP (1949 - 2003)



A careful look at Figure 5 further shows a new, short, but upward tending linear trend from 1976 to 1980, then the curve makes another shift to the left. This adjustment that began around 1980 corresponds to the period of unstable energy markets and rising oil prices stemming from the Iranian crisis. After 1987, the graph continues a new upward trend.

Overall, Figure 5 shows a continuous adjustment in the United States to rising oil prices, resulting in increased level of economic activity with less energy. This data corresponds to the declining energy intensity, or the energy-GDP ratio observed in Figure 4. Figure 5 shows quite clearly that there has been an increase in energy use efficiency. It is significant to note how the graph, following each oil shock, shifts to the left, away from the energy axis.

Figure 6. U.S.A. Intensity of Energy Use Test (1949-2003)



The intensity of energy use concept, the Kuznets curve, was tested for the United States, as depicted in Figure 6. The analysis shows a declining intensity of energy use from 1949 to 2003. This is an indication that the declining trend in energy intensity in the U.S.A. fits the downward slopping segment of the Kuznets curve. That is, the curve in Figure 6 lies on the downward slopping side of the inverted U-shaped curve.

The factors that influence energy intensity were found in the literature. Technological change in the economy, increasing industrialization, efficiency in the use of energy, energy conservation, energy price(s), stages of economic development, structure of energy consumption pattern, climatic conditions, energy supply, political structure, energy substitution-commercial for non-commercial fuels, strong demand for transportation energy use, rise in electricity demand in the household and commercial sectors, expansion of energy conversion industries, extent of urbanization, extent of capital formation, structural changes in the economy, foreign direct investments, research and development expenditures, ownership structure in the enterprise sector. Many of these factors are responsible for the declining energy intensity in the U.S. However, it is important to note that many of these factors are related, and there could be cause and effect reactions amongst several of them.

CONCLUSIONS

Energy availability and consumption are important for economic progress. Because energy inputs are scarce, they must be used wisely and efficiently. Understanding the interactions between energy consumption and economy growth will be very helpful in planning to meet the demand for energy in each country. Increased use of energy inputs contribute to improvements in the quality of life.

Energy intensity has declined in the U.S.A. over the last fifty years. The analysis and results of this study indicate that we can produce more income while being more energy efficient through energy conservation policies, and policies that promote improvements in technology for energy use plus the ability to substitute amongst various forms of energy inputs.

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