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Regional Growth and Energy Supply: Is There an Energy Security Issue?

J. M. Roop, Project Manager
K. A. Freund
P. Godoy-Kain
A. Y. Gu
A. K. Johnson
O. H. Paananen
M. G. Woodruff

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SCOPE NOTE

This study examines how the growth of the developing world might affect energy markets in the future. Two questions of import arise in such a study:

- What are the implications of rapid growth in the developing world on world energy demand, and through increased demand, on price?
- What impact might technology have on mitigating the required energy to sustain this growth?

These two questions are addressed in this study, using the following research strategy:

- The world is divided into six regions: four developing regions (Russia and Eastern Europe, China and Southeast Asia, South Asia [i.e., Indian subcontinent], and Latin America), the developed world, and all other countries (identified as Rest of World [ROW]).
- An examination of each developing region is undertaken by examining past trends for each of the economy's end-use sectors: industry, buildings, agriculture, transportation, and the transformation sector (utilities and other energy transformation).
- For each end-use sector in each developing region, activity measures are defined and historical patterns of energy use are examined. These intensity patterns are then used to construct two scenarios: a Business as Usual (BAU) scenario and an Energy Efficiency (EE) scenario.
- Forecasts are then made for energy requirements for each end-use sector for each developing region for the two scenarios based on a projection of past activity and assumptions about energy efficiency.
- Each region is then aggregated into the BAU and EE scenarios and the six regions are aggregated with the developed region and the ROW to yield two world-energy-demand scenarios. These scenarios are referred to as "energy requirements" since no interaction between demand and supply is evident at this point.
- To introduce that interaction, we use the Edmonds-Reilly-Barnes (ERB) Global Change Impacts model to simulate growth of these developed regions as suggested by the two scenarios. This model tracks the regions economic growth rates, but allows the interaction of supply and demand to determine world energy prices.
- The requirements scenarios are made under the naive assumption that world prices do not change. The ERB solution provides information about how world energy prices would change, under assumed growth rates. Then, each of the developed

regions is re-examined to highlight the implications of higher energy prices on developmental paths that we have projected, absent price impacts.

This study speculates that future growth in the major developing regions of the world will continue as they have in the recent past. If, instead, growth rates slow, price impacts would be moderated.

This work is intended to raise awareness about two issues that are important to the energy security of the United States: energy prices are established globally and the growth of the developing world, should it continue, will sharply increase energy prices in the not-too-distant future. The study does not attempt exhaustively to define how this growth would occur or to understand the factors that could alter the growth path of the developing world.

Accordingly, the following caveats are brought to the reader's attention:

- While there is much inertia in economic activity, events in individual economies can rapidly alter perceptions about future prospects. Any projections based on trends, therefore, must be taken seriously.
- An interesting and dynamic area of the world, here identified as ROW, has been considered only casually. This area includes all of the Middle East and the African continent. Even modest changes in the development pattern of these areas could dramatically affect the results shown here.
- Some regions of the world, especially South Asia and South America, are undergoing fundamental economic restructuring. While our projections try to take this restructuring into account, the extent to which these changes alter the regional development trajectory is highly uncertain. The same is true for the Former Soviet Union.
- Any international study is only as good as the data used, which is notoriously bad. Each country supplies data to the international agency based on domestic collection procedures that may vary conceptually, in coverage, and in collection methodology. Both the energy and economic data for this study are considered weak except for the Organization for Economic Cooperation and Development (OECD) region.
- International comparisons of economic data rely on exchange rates to convert to a standard currency measure. While this is not a very meaningful way to make international comparisons, it is the only one available.

SUMMARY

Based only on recent growth trends, world energy demand could reasonably be expected to grow from about 350 Exajoules (EJ: 1.0E18 = 0.95 Quad) to nearly 1025 EJ by the year 2020, nearly three times current consumption estimates. The introduction of more energy-efficient technologies could reduce this growth by about 17% to 830 EJ.

But one cannot rely exclusively on current trends to forecast future energy demand. The growth of the developing world, while it will put tremendous pressure on current energy capacity, will interact with supply to effect prices, which in turn will mitigate the growth of demand. When these supply/demand interactions are taken into account, growth rates of energy use are much more modest. Under the Business as Usual (BAU) scenario, taking market factors into account, energy demand will grow to 835 EJ by 2020, and this could be reduced a further 15% to 714 EJ through the adoption of more energy efficient technologies. These projections are shown in Table 1.

Table 1. Growth-Based Energy Requirements and Model Results (in EJ)

	Growth Requirements		Model Results	
Year	BAU Scenario	EE Scenario	BAU Scenario	EE Scenario
1990	352.06	352.06	352.06	352.06
2005	581.77	529.94	474.68	439.14
2020	1023.16	830.83	836.49	713.86

One cannot rely on separate regional forecasts to draw conclusions about the effect of that region's growth on world energy prices. Energy prices, especially oil prices, are established on a world basis. In conjunction, all other energy prices move with oil prices, although there are distinct regional and fuel differences that result from different tax regimes and the availability of different fuels. Fuel prices based on model results are shown in Table 2.

Table 2. Energy Prices Based on Model Results (in $/MJ)

	World Oil Prices		World Coal Prices	
Year	BAU Scenario	EE Scenario	BAU Scenario	EE Scenario
1990	5.29	5.29	1.81	1.81
2005	10.16	9.91	1.87	1.85
2020	13.23	12.72	2.86	2.77

The energy security implications of rapid growth in the developing world, after taking into account the interaction of supply and demand, are of little significance. As long as the world relies fundamentally on markets to allocate energy, the developing countries can grow and prosper. This growth will occur despite the fact that world oil prices are expected to increase at about 3.1% per year, on average, over the next 30 years. Price increases will be at a faster rate than this in the early period, with prices moderating in the latter half of the period.

Developing regions without alternative sources of fuel, notably South Asia, will find sustaining growth more difficult because of higher energy prices than some other regions, such as China, with its vast supply of coal. On a region-by-region basis, the key findings are as follows:

- **China** - Recent Chinese history suggests that four major trends will affect the future demand for energy: 1) rapid industrialization and economic growth; 2) fuel substitution; 3) inability of energy fuel suppliers to keep pace with rising consumption; and 4) improved efficiency of energy use, particularly in the industrial sector. While China's energy consumption per capita is currently only one-sixth that of OECD countries, China's population growth and overall demography ensures significant continued pressure on energy demand. Currently 80% of residential energy consumption is provided by non-commercial biomass, mainly cropstalks and fuelwood. However, the expected increase in population from 1.2 to 1.6 billion people by 2030, a rural-to-urban migration with concomitant shift from non-commercial to commercial energy fuels, and improvement of living standards moving the entire population closer to the OECD norm of per capita energy consumption will severely impact energy demand. Thus, final energy requirements are expected to grow exponentially. We project the Chinese final energy requirement will grow by a multiple of 2.4 between 1994 and 2010 and by a multiple of 3.3 between 1994 and 2015, with average growth rates of 5% per year from 1994 to 2000, 5.9% per year from 2001 to 2005, 6.2% per year from 2006 to 2010, and 6.3% per year from 2011 to 2015. In other words, we project the Chinese final energy requirement will grow at an increasing rate in the next 20 years. Still, this is a lower forecast than a recent World Bank study, which projected Chinese energy demand will grow at an average rate of 6.5% per year.

- **South Asia** - South Asia is undergoing a period of transition from one of a strict nationalist policy to decentralization of state control of the economy. It is highly dependent on foreign investment and exports to fuel growth. Numerous barriers still exist that at least initially will slow both foreign investment and export growth. Nevertheless, it is likely that the region will maintain an average growth of close to 5% over the next two decades. This growth will lead to increases in demand for electricity for the services sector, and for most energy types for the industrial sector. There will also be a heavy reliance on the transportation sector, particularly as goods become more readily traded, resulting in a significant increase in the demand for petroleum. Finally, to sustain growth overall, the region will have to invest heavily in new infrastructure, including roads and ports. This type of construction relies heavily on the energy-intensive steel and cement industries, further fueling demand for energy. Under the BAU scenario, total energy requirements for South Asia are projected to increase from 250 Mtoe in 1993 to 891 Mtoe in 2015. Under the energy efficiency (EE) scenario, total energy requirements in 2015 would be approximately 75% of the level projected under the BAU scenario. The EE scenario assumes greater use of energy-efficient technology in all sectors, as well as greater use of natural gas in the industrial and transformation sectors.

- **Russia and Central Europe** - Future energy consumption patterns in the Former Soviet Union (FSU)- Central and Eastern Europe (CEE) region will be heavily influenced by the economic restructuring that has been taking place in that area since the early 1990s. The transition to a market economy will necessitate raising energy prices, enforcing energy efficiency codes, standards and laws, and installing new, energy-efficient technologies. Reform, if fully implemented, will significantly reduce energy demand and intensity in virtually all sectors of the economy. While most FSU-CEE countries have undergone severe recession since 1990, experts believe the worst is over, and the next several years should see an average annual growth rate of over 5%. Energy intensities and final consumption in the FSU-CEE will likely rise in the short-term as the economies recover from recession, but then as new technologies and management practices begin to take hold, both energy intensity and consumption will gradually decline. It is the rate at which this improvement occurs that differentiates the BAU scenario from the EE scenario. Slower changes in restructuring characterize BAU, while more rapid changes are captured in the EE scenario. Under BAU conditions in the year 2015, the FSU-CEE total primary energy supply (TPES) reaches 3,775 Mtoe, while under the EE scenario TPES is 2,675 Mtoe for that year, approximately 30% less than BAU levels. The transformation sector is the largest consumer of energy under both scenarios, followed by the industrial sector. Both scenarios will see increased use of natural gas, though gas penetration will be higher in the EE scenario. Greatest energy efficiency improvements are expected in the buildings sector.

- **Latin America** - The sharp turn-about experienced by the Latin American region since 1990, is expected to continue. Regional economic expansion has been the result of fast increase in private and public investments. Investment growth has been the response to relative political stability and market liberalization. Confidence in the region has also been fueled by major macroeconomic and fiscal reform. There are still significant changes the region must implement in order to maintain the initial path of economic expansion. Investments in the industrial sector have implied job increases, increases in wages, increases in services and thus an overall increase in energy consumption. Due to creation of sub-regional trading blocks and the proliferation of trading agreements, the industrial and transportation sector have experienced the fastest growth. This pattern is expected to continue into the next century. However, to sustain the expected growth, the region will need large investments into the power sector and significant market and pricing reforms. Under the BAU scenario, total final energy requirements to generate projected value of output is estimated at 1,196 Mtoe by 2000 and 1,792 Mtoe by 2015. Under the EE scenario, total final energy requirements are reduced to 1,069 Mtoe by 2000 and 1423 Mtoe by 2015.

- **OECD Countries** - Gross Domestic Product (GDP) growth in most OECD countries is expected to be healthy throughout the remainder of the century, averaging 2.5% a year through 2015. These nations are not expected to be major consumers of energy relative to other, rapidly developing states in the eastern and southern hemispheres. This is because the oil shocks of the mid- and late-1970s forced most OECD countries to begin reducing their dependence on imported oil through conservation and substitution of other fuels as early as two decades ago. The majority now have strong energy efficiency policies in place and have been able to replace old and inefficient capital equipment so that per capita energy consumption has declined substantially since the mid-1970s. In addition, population growth will remain well below 1% a year, which will further help keep demand in check. Because of stable population growth rates and continued improvements in energy efficiency, the OECD's total final energy requirement (TER) under both the BAU and EE scenarios is expected to increase steadily but modestly until 2015. In most sectors, there is little difference between TER for both scenarios, because most OECD countries have already undergone extensive energy efficiency improvements. Thus, by the end of the forecast period, there is only a 5.8% difference in total energy demand between projections for EE and BAU scenarios.

- **Rest of World** - Economic growth in the Rest of World (ROW) region, comprised of Africa and the Middle East, is projected to be less than other regions of the world at about 1% annually through 2015. Population growth in the region will be approximately 3% annually and decrease to 2.5% annually by 2015. Relatively slow GDP growth combined with relatively rapid population growth indicate that per capita GDP will decline in ROW. Total energy consumption in the region is also expected to increase slowly. ROW's TER under both the BAU and the EE scenarios will experience an average of 1% annual growth over the next 20 years. The slow growth in TER results in a decline from 5% of world energy consumption in 1990 to 3% in 2015 for ROW. However, the projected slow economic growth in ROW hides the growth potential of the region. One study indicates that the GDPs of African nations has the potential to grow at 4.8% annually. The Middle East may experience more substantial economic growth if diversification from oil-dependent revenues is successful, or if world oil prices began to rise again.

ABBREVIATIONS AND ACRONYMS

AEEI	autonomous energy efficiency improvement
BAU	Business As Usual
Btoe	billion ton oil equivalent
CEE	Central and Eastern Europe
EE	Energy Efficiency
EJ	exajoules
ERB	Edmonds-Reilly-Barnes (model)
FSU	Former Soviet Union
GDP	Gross Domestic Product
GW	gigawatt
LPG	liquefied petroleum gas
Mtoe	million ton oil equivalent
OECD	Organization for Economic Cooperation and Development
ROW	Rest of World
TER	total final energy requirement
TFC	total final consumption
TPES	total primary energy supply

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1.0 HOW WILL GROWTH AFFECT ENERGY NEEDS?

The growth of certain regions of the world has been spectacular over the past decade. Southeast Asia, in particular, has grown at rates that are the envy of both the developed world and other developing regions. This raises questions about how the energy needs for the region will be satisfied and how this might impact energy prices. But the energy needs of Southeast Asia cannot be considered in isolation.

Energy prices are established on a world basis, so ignoring the rest of the world is simply not adequate. Considered alone, the impact of growth in one region may be negligible. But what if other developing regions that are undergoing restructuring follow along the same path as Southeast Asia, thus impacting energy markets substantially?

This question motivates this study. Rather than focus on Southeast Asia or Russia and Eastern Europe, we examine how the growth of the dynamic developing regions of the world might affect energy markets in the future. We define the "dynamic" developing regions as those that are undergoing a similar structural reform as that which occurred in Southeast Asia prior to, and coincident with, accelerated growth. These regions are Latin America, South Asia (India is undergoing structural reform, but we also include Pakistan and Bangladesh), and the Former Soviet Union and Eastern Europe.

To assure that world markets are adequately covered, two other regions are added to these four developing regions: the developed world and the Rest of World (ROW). But the primary focus, and the bulk of the effort, has gone into the four developing regions. We count the developed world as being those countries that are members of the Organization for Economic Cooperation and Development (OECD). This allows us to draw on OECD forecasts of growth instead of projecting growth for this region separately. For ROW, we extrapolate past growth and energy consumption without the detailed analysis used for the four developing regions, which is described in the methods section that follows.

1.1 METHODS

The growth of the developing world raises a host of questions about how the energy needed for this growth would impact energy prices and, through these prices, energy security. This study examines how the growth of the developing world might affect energy markets in the future. Two questions of import arise in such a study:

- What are the implications of rapid growth in the developing world on world energy demand and especially world oil markets?
- What impact might technology have on mitigating the required energy to sustain this growth?

These two questions are addressed in this study, using the following approach:

- The world is divided into six regions: four developing regions (Russia and Eastern Europe, China and Southeast Asia, South Asia [i.e., Indian subcontinent], and Latin America) the developed world, and all other countries identified as ROW.
- An examination of each developing region is undertaken by examining past trends for each of the economy's end-use sectors: industry, buildings, agriculture, transportation, and the transformation sector (utilities and other energy transformation).
- For each end-use sector in each developing region, activity measures are defined and historical patterns of energy intensity are examined. These patterns are then used to construct two scenarios: a Business as Usual (BAU) scenario and an Energy Efficiency (EE) scenario.
- Forecasts are then made for energy requirements for each end-use sector for each developing region for the two scenarios based on a projection of past activity and assumptions about intensities for each scenario.

The six regions are the following: 1) China and Southeast Asia; 2) South Asia, consisting of India, Pakistan, and Bangladesh; 3) Latin America, consisting of all Central and South America plus the Caribbean. including Mexico; 4) Russia and Eastern Europe (EU) which includes the former Soviet Union states plus the former Eastern European satellites of the USSR, but excluding East Germany; 5) the member states of the OECD, which includes the EU countries, Turkey, Switzerland, North America, Japan, Australia, and New Zealand; and 6) ROW which, mostly, is Africa, and the Middle East. The first four of these get the bulk of the attention. The OECD and ROW do not include any detailed analysis; they are included so that the entire world is covered.

For each of the developing regions, the analysis is conducted at the end-use sector. There are typically five end-used sectors: buildings, industry, agriculture, transportation, and the transformation sector. In many cases, the buildings sector is further disaggregated into a residential and a commercial sector. Energy use in each of these end-use sectors is decomposed into intensity and activity measures that, when multiplied together, yield energy consumption. Then the activity and intensity measures are projected into the future based on recent past trends and foreseeable future events, both economic and political.

The projection of the past trend in energy intensity defines the BAU scenario. The BAU intensity trend is modified in light of possible technology innovations or more rapid restructuring in favor of market mechanisms to define an EE scenario. The forecasts in the World View presented below, are constructed by first multiplying each of the intensity projections by the activity projection and then aggregating like scenarios over all end-use sectors. By adding energy consumption for all five sectors for the BAU scenario, we define the aggregate regional consumption for the BAU scenario and similarly for the EE scenario. We label these projections as regional "energy requirement," to reflect the fact that the projections are made based simply on past consumption trends.

These scenarios are then pulled together to determine the impact of growth in six regions on energy use over the next 20 years. The "requirements" thus defined are then compared to a likely view of what energy supply would be forthcoming in the future to determine what pressures there might be on the world price of oil.

We recognize, however, that just making this comparison does not take into account the dynamic interaction of energy supply and demand. To account for this interaction we have gone one step further. The growth rates implied by our activity measures (usually regional Gross Domestic Product [GDP]) have been incorporated into a model of world energy supply and demand—the Edmonds-Reilly-Barnes (ERB) model. This model reconciles energy supply and demand at the world level, in this case conditioned on GDP growth rates consistent with both the BAU and EE regional scenarios developed. Chapter 7.0 provides a more detailed description of the ERB model and how it was used for this exercise.

1.2 THE WORLD VIEW

Energy consumption in 1990 for the entire world was 371 exajoules (EJ) or about 352 quadrillion Btu (quad).[1] The OECD countries account for slightly less than half of this energy consumption (167 EJ, 45%), with the Former Soviet Union (FSU) and Central and Eastern Europe (CEE) consuming about 87 EJ (23%). Latin America consumes about 50 EJ (13.5%), China about 28 EJ (7.5%), and South Asia about 21 EJ (6%). The ROW thus accounted for another 18 EJ (5%). The distribution of current (1990) energy consumption is shown in the pie chart below (Figure 1.1).

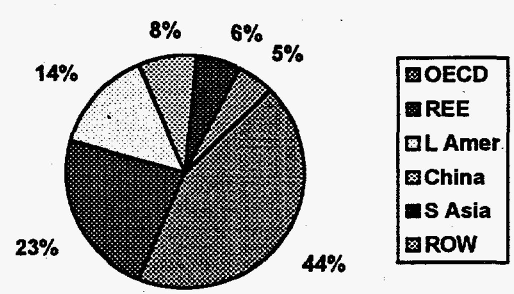


Figure 1.1. World Energy Consumption Shares, 1990, by Region

When these numbers are forecast as described in the methods section above, growth is quite rapid. Under the BAU scenario, world energy requirements grow to 610 EJ (an

[1] A quad is equal to 1.055 EJ.

increase of 64%) in 2005 and reach 1,047 EJ by 2020 (an increase of 182%). These figures are moderated substantially in the EE scenario, reaching 556 EJ (+50%) in 2005 and 871 EJ (+134%) in 2020. The BAU scenario represents a growth rate of 3.5% per year over the 30-year period, which is considerably less than the projected growth rates of GDP, at least in the developing regions. But this overall growth rate conceals the fact that the distribution of energy consumption among regions is altered radically. In the BAU scenario, the OECD countries' share of energy consumption drops from 45% in 1990 to 35% in 2005 and 26% in 2020. The most dramatic relative change is in South Asia, with the world energy share going from 6% in 1990 to over 10% in 2005 and nearly 22% in 2020. China's relative position also grows, from 7.5% in 1990 to 10% in 2005 and over 15% in 2020. Under the EE scenario, energy consumption shifts as well, but not quite as dramatically. The OECD countries decline from 45% in 1990 to 37.5% in 2005 and to 28% in 2020. Again the regions that gain the most are South Asia and China. With efficiency gains, South Asia goes from 6% in 1990 to 10% in 2005 and then to 19% in 2020. China's comparable figures for 2005 and 2020 are 11% and 16%, respectively.

In both the BAU and EE scenarios, Latin America is first expected to gain shares to 2005 on a world-wide basis, but then their relative shares decline from 2005 to 2020. Under the BAU scenario, the relative share goes from 13.5% in 1990 to over 19% in 2005 and then declines to 17.5% in 2020. A similar pattern emerges for the EE scenario: an increase to more than 18% in 2005 that then drops to 16.5% in 2020. For FSU/Eastern Europe the pattern is one of continuous decline. For the BAU scenario, relative shares drop form 23% in 1990 to 19% in 2005 and then to 17% in 2020. This decline is somewhat lower for the EE scenario: shares decline to 17% and 14% in 2005 and 2020, respectively. The distribution for the BAU scenario for the year 2020 is shown in the pie chart below (Figure 1.2).

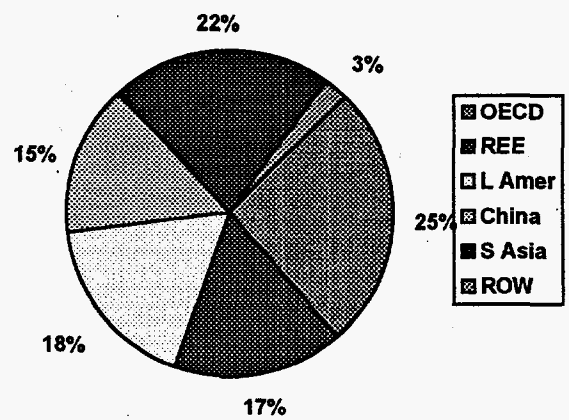


Figure 1.2. World Energy Shares, by Region, for the BAU Scenario, 2020

When the interaction of supply and demand are allowed to reach balance as they do in the ERB model, the projections are substantially lower. Under the BAU scenario, prices moderate energy demand so that total energy use in 2005 and 2020 is only about 84% of the unrestricted forecasts: world totals are 517 EJ in 2005 and 880 EJ in 2020. Under the EE scenario the reduction is not quite as severe, but is still only about 86% of the unrestricted forecast (i.e., 476 EJ in 2005 and 746 EJ in 2020). This slightly lower percentage decline suggests that the reduced pressure on prices, as a result of energy efficient technology adoption, encourages relatively more consumption of energy than would otherwise occur.

The modeling results also change the relative shares by region. China now has the largest relative growth, going from 7.5% in 1990 to 20.5% in 2005 and 31% in 2020 under the BAU scenario. Under the efficiency scenario the increase is even larger—21% in 2005 and 32.5% in 2020. South Asia, which had the most rapid relative growth without the model feedback, now grows relatively less: it captures 10% of world energy consumption in 2005 under the BAU scenario and 14.5% in 2020, but only 9.5% and 12.5%, respectively, under the EE scenario. Latin America shows much the same pattern as before, but the FSU/EE region declines in share to 2005, but then holds steady at that share to 2020. Under the BAU scenario, the FSU/EE region declines to 13% share. Under the EE scenario, the decline is to slightly more than 11%.

1.3 KEY REGIONAL FINDINGS

China

China has the world's fastest growing economy. The average growth rate of GDP from 1979 to 1994 was 9.5%. As a result, China has changed from a net oil exporting country to a net oil importing country. All the rapidly growing economic zones in China are in the coastal areas, which are far removed from the coal mines inland. Transporting coal to needed areas is a serious problem.

Another rapidly expanding social problem has been caused by low-skill migrants moving from rural to urban areas. Over 70% of China's huge 1.2 billion population lives in rural areas. Most of the rural population is low-skill labor doing mostly farming-related work. This large agricultural sector helped China to create employment in the non-state sector while the government was gradually reforming its inefficient state enterprises. This excess labor force, however, has become a lurking disaster. Millions of rural laborers have flooded the urban areas, and with little or no skills for competing in urban job markets, these displaced people have turned to crime.

Because of rapid economic growth and development, the type of energy demanded has gradually shifted to electricity and oil products from burning coal directly. Power supply has become a serious problem in the coastal area; almost all industries in these areas have their own backup power supply, with diesel power generators the most popular choice. With increases in living standards, households in these areas are demanding cleaner and more convenient fuels, such as liquefied petroleum gas (LPG) and natural gas. Thus demand for natural gas and oil products has increased. Since the costs to supply oil products and coal from domestic sources to these areas are very high, these areas end up importing energy from overseas.

Total energy consumption in China doubled in 15 years, from 422 million ton oil equivalent Mtoe in 1980 to 859 Mtoe in 1994. Although the demand for oil products in coastal areas increased, in the country as a whole, coal made up 75% of the total primary energy supply. In 1994, oil made up 17.4% of the total primary energy supply (TPES), natural gas 1.9%, and hydroelectric power 5.7%. Increasing shares of coal are used for generating electricity even though additions are being made to hydroelectric and nuclear generation.

China's total energy requirement is projected to increase 3.3 times from 859 Mtoe in 1994 to 2,852 Mtoe in 2015. The industry sector will continue to be the largest energy user, but its share of final energy requirements will fall from 64% in 1994 to 60% in 2015. The commercial buildings sector is projected to have the largest percentage increase in growth of all the sectors; the final energy requirement share of commercial buildings will increase from 2.7% to 7.3% from 1994 to 2015. The tremendous increase in road usage will spur a 5.2% per year growth in energy consumption in the transportation sector.

South Asia

South Asia is undergoing a period of transition from one of a strict nationalist policy to decentralization of state control of the economy. It is highly dependent on foreign investment and exports to fuel growth. Numerous barriers still exist that at least initially will slow both foreign investment and export growth. Nevertheless, it is likely that the region will maintain an average growth of close to 5% over the next two decades. This growth will lead to increases in demand for electricity for the services sector, and for most energy types for the industrial sector. There will also be a heavy reliance on the transportation sector, particularly as goods become more readily traded, resulting in a significant increase in the demand for petroleum. Finally, to sustain growth overall, the region will have to invest heavily in new infrastructure, including roads and ports. This type of construction relies heavily on the energy- intensive steel and cement industries, further fueling demand for energy. Under the BAU scenario, total energy requirements for South Asia are projected to increase from 250 Mtoe in 1993 to 891 Mtoe in 2015. Under the EE scenario, total energy requirements in 2015 would be approximately 75% of the level projected under the BAU scenario. The EE scenario assumes greater use of energy efficient technology in all sectors, as well as greater use of natural gas in the industrial and transformation sectors.

Former Soviet Union and Central and Eastern Europe (FSU-CEE)

The Soviet Union collapsed in December 1991 and was succeeded by the Russian Federation. Russia's first freely elected president, Boris Yeltsin, began a thorough restructuring of the old Soviet system. He announced his intention to replace Russia's inefficient and financially disabled command economy with free markets and democratic governing institutions. He also sought to integrate the country more fully into the world economy after decades of isolation.

Restructuring has proceeded on several fronts, including decentralization and privatization, price reform, fiscal reform, and openness to foreign investment. While much progress has been made toward these goals over the past five years, Russia has endured significant political and economic strain as a result of the changes. Between 1989 and 1994, for example, total output declined by one-half and consumer price inflation surged, exceeding 1,300% in 1994. Russia also had a large budget deficit that amounted to 8.3% of GDP in 1995 and unemployment was widespread. By late 1995, however, the decline in GDP had begun to stabilize, as had industrial output and inflation. Likewise, after several years of devaluation, the ruble had begun to appreciate in value. Most analysts believe that the Russian economy, having reached its nadir in 1994, is well on the way to recovery and growth. The World Bank predicts an average economic growth rate of 5.4% per year over the next five years.

Population growth is expected to remain at just under one percent for the FSU-CEE area over the next two decades. Unlike various other regions that are developing economically, rapid population growth is not likely to significantly increase demand for energy in the FSU-CEE region. Rather, the primary driver for changing energy-use patterns will be economic restructuring.

Energy consumption and energy intensity levels in Russia have historically been very high, owing to a variety of factors, including access to vast domestic energy reserves; government emphasis on production of energy-intensive capital goods; artificially low energy prices; a harsh climate with long winters; and long transport distances. Waste was rampant, and most enterprises operated very inefficiently, having no incentive to conserve energy. With the introduction of economic reform, however, pricing has become more important, a development which will certainly change how energy is used. Indeed, the region's future energy-demand profile depends largely on the progress of energy price reform. New energy conservation legislation has also been passed. If fully implemented, these laws can further stimulate efficiency.

Russia's TPES in 2015 under the BAU scenario reaches 3,775 Mtoe, while under EE conditions, TPES reaches 2,675 Mtoe, owing to more effective implementation of energy efficiency policies and more rapidly rising energy prices. In both cases, the transformation sector remains the largest consumer of energy, followed by the industrial sector. In 2015 the transformation sector will consume 1,487 Mtoe under BAU and 938 Mtoe under EE conditions. Under both scenarios there will be a move toward more use of natural gas; by 2015 gas is expected to make up nearly 50% of the total energy requirement, with higher gas penetration under EE conditions. Greatest energy efficiency improvements are observed in the buildings sector.

Latin America

The sharp turn about experienced by the Latin American region since 1990 is expected to continue. Regional economic expansion has been the result of fast increase in private and public investments. Investment growth has been the response to relative political stability and market liberalization. Confidence in the region has also been fueled by major macroeconomic and fiscal reform. There are still significant changes the region must implement in order to maintain the initial path of economic expansion. Investments in the industrial sector have implied job increases, increases in wages, increases in services, and thus an overall increase in energy consumption. Due to creation of sub-regional trading blocks and the proliferation of trading agreements, the industrial and transportation sector have experienced the fastest growth. This pattern is expected to continue into the next century. However, to sustain the expected growth, the region will need large investments in the power sector and significant market and pricing reforms. Under the BAU scenario, the total energy requirement to generate the projected value of output is estimated at 1,196 Mtoe by 2000 and 1,792 Mtoe by 2015. Under the EE scenario, total energy requirements are reduced to 1,069 Mtoe by 2000 and 1423 Mtoe by 2015.

OECD Countries

GDP growth in most OECD countries is expected to be healthy throughout the remainder of the century, averaging 2.5% a year through 2015. These nations are not expected to be major consumers of energy relative to other, rapidly developing states in the eastern and southern hemispheres. This is because the oil shocks of the mid- and late-1970s forced most OECD countries to begin reducing their dependence on imported oil through conservation and substitution of other fuels as early as two decades ago. The majority now have strong energy efficiency policies in place and have been able to replace old and inefficient capital equipment so that per capita energy consumption has declined substantially since the mid-1970s. In addition, population growth will remain well below 1% a year, which will further help keep demand in check. Because of stable population growth rates and continued improvements in energy efficiency, the OECD's total final energy requirement (TER) under both the BAU and EE scenarios is expected to increase steadily but modestly until 2015. In most sectors, there is little difference between TER for both scenarios, because most OECD countries have already undergone extensive energy efficiency improvements. Thus, by the end of the forecast period, there is only a 5.8% difference in total energy demand between projections for EE and BAU scenarios.

Rest of World

ROW, which includes the Middle East and Africa, will exhibit slower projected economic growth than the other regions of the world. Much of Africa is experiencing economic stagnation or decline because of restrictive trade barriers, poorly developed infrastructure, excessive tax rates, and political instability. Middle East economic growth has stalled as world oil prices have declined. Projected population growth in ROW is expected to be relatively high at 3%, declining to 2.5% by 2015. The combination of slow GDP growth and rapid population growth indicates decreases in per capita GDP for the region. As a result, projected growth in energy demand is held to 1% annually under both the BAU and the EE scenarios. However, the projected slow rate of economic growth hides the growth potential of the region. One study indicates that Africa has the potential to grow at 4.8% annually if its institutional and political barriers can be overcome. The Middle East GDPs could grow more rapidly if economic diversification is successful, or if world oil prices increase again.

2.0 CHINA

Recent Chinese energy history suggests four trends affecting demand for energy fuels: 1) rapidly growing commercial energy consumption spurred by the rapid pace of economic growth, industrialization, and improving living standards; 2) fuel substitution in industry and home use; 3) inability of energy fuel suppliers to keep pace with rising consumption; and 4) improved efficiency of energy fuel utilization, particularly in the industrial sector.

While China's energy consumption per capita is currently only one-sixth that of OECD countries, China's population growth, which is projected to grow at 0.6% annually over the next two decades, and overall demography ensures significant continued pressure on energy demand. Currently 80% of residential energy consumption is provided by non-commercial biomass, mainly cropstalks and fuelwood. However, the expected increase in population from 1.2 to 1.6 billion people by 2030, a rural-to-urban migration with concomitant shift from non-commercial to commercial energy fuels, and improvement of living standards moving the entire population closer to the OECD norm of per capita energy consumption will severely impact energy demand.

China has the world's fastest growing economy. China's GDP grew at an average annual rate of 9.5% during 1979 to 1994, far outstripping population growth (Figure 2.1).

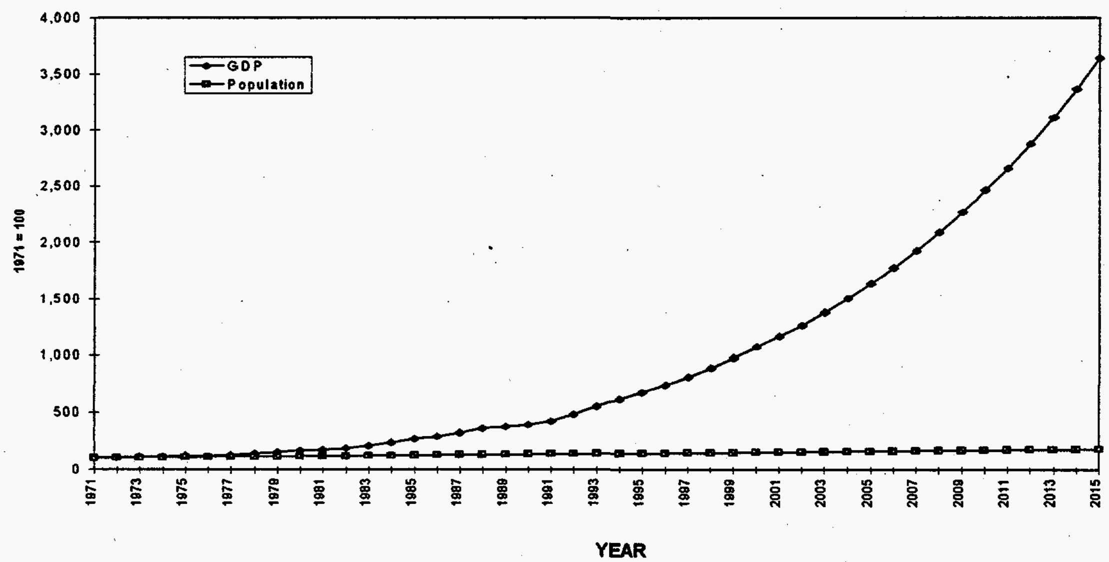


Figure 2.1. China GDP and Population Growth, Projected to 2015

Already, increases in the standard of living have resulted in an influx of home appliances, accompanied by an increase in demand for new energy fuels, such as electricity and natural gas, as substitutes for coal. Meanwhile, rail traffic is saturated, resulting in more heavily traveled roads for both freight and personal transportation, significantly increasing traffic and motor fuels consumption. This demand for oil and gas from the residential and transportation sectors has caused China to switch from a position of net exporter to net importer of these fuels within the last four years. Demand for electricity is so high that China operates electric power grids with standard load factors far above operational norms in the United States.

The aggregate efficiency of Chinese energy consumption has improved in recent years. However, energy consumption per dollar of GDP remains more than ten times higher than OECD countries. Thus, China has an opportunity to relieve some pressure on energy fuels demand by further increasing the efficiency with which energy is used. Studies show that 80% of the reduction in energy intensity, defined as the value of total energy consumption per unit of GDP between 1980 and 1985 was due to industry. Of this 80%, 91% is due to real efficiency improvement, and only 9% to structural changes (Levine et al. 1992). China could do more. Although the government has promoted energy conservation and accelerated the supply of energy through the use of market mechanisms, energy use is still inefficient due to 1) high dependency on coal, 2) inefficient industry, and 3) incomplete price liberalization (Ishiguro and Akiyama 1995).

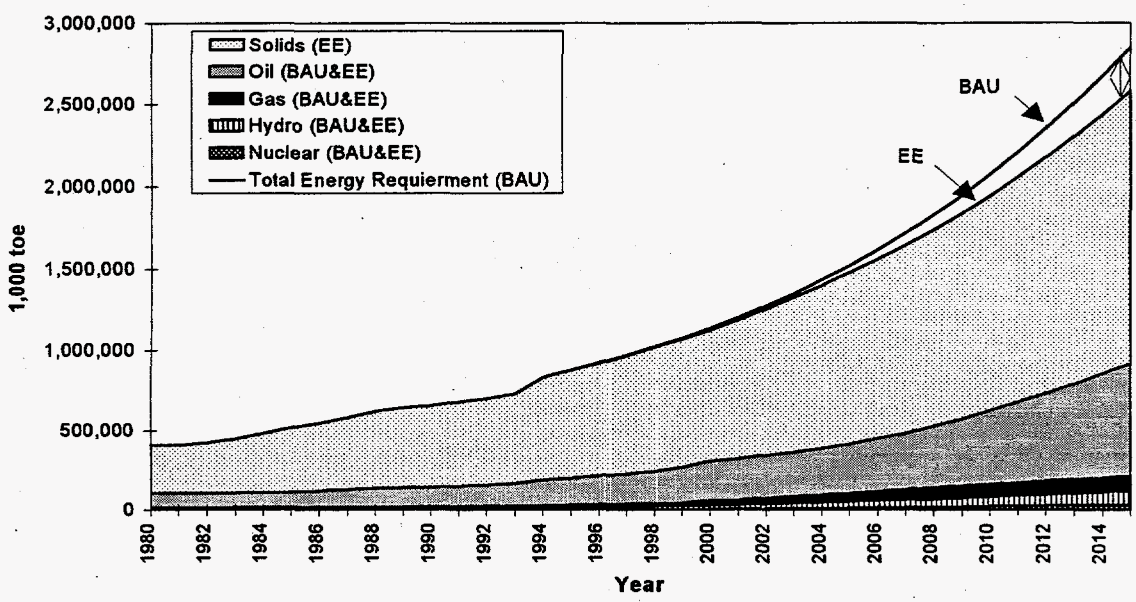
As China's most abundant and accessible energy source, coal made up 75% of the 1994 consumption (including coal used in electric power generation), with oil constituting 17.4%, natural gas 1.9%, and hydroelectric power the remaining 5.7% (Figure 2.2). That same year (1994), industry accounted for 61% of the energy consumption by sector, while transportation held a 10% share and the residential/commercial building sector held a 20% share. This composition has been relatively constant over the past ten years.

2.1 KEY FINDINGS

Given China's population growth and industrial trends, final energy requirements are expected to grow exponentially. Under the BAU scenario, China's total final energy requirement will increase by a factor of 3.3 to 2,077 Mtoe between 1994 and 2015, with annual growth rates of 5.3% from 1994 to 2000, 6% from 2001 to 2005, 6.4% from 2006 to 2010, and 6.6% from 2011 to 2015 (see Figure 2.2).

The industrial sector will continue to be the largest energy user, but its overall share of total energy consumed will decrease (Figure 2.3). Industrial energy intensity is projected to continue to decline, albeit at a slower rate, as industry continues to shift from heavy to light industry and machinery and equipment is modernized. After industry, transformation will continue to be the second largest consumer of energy.

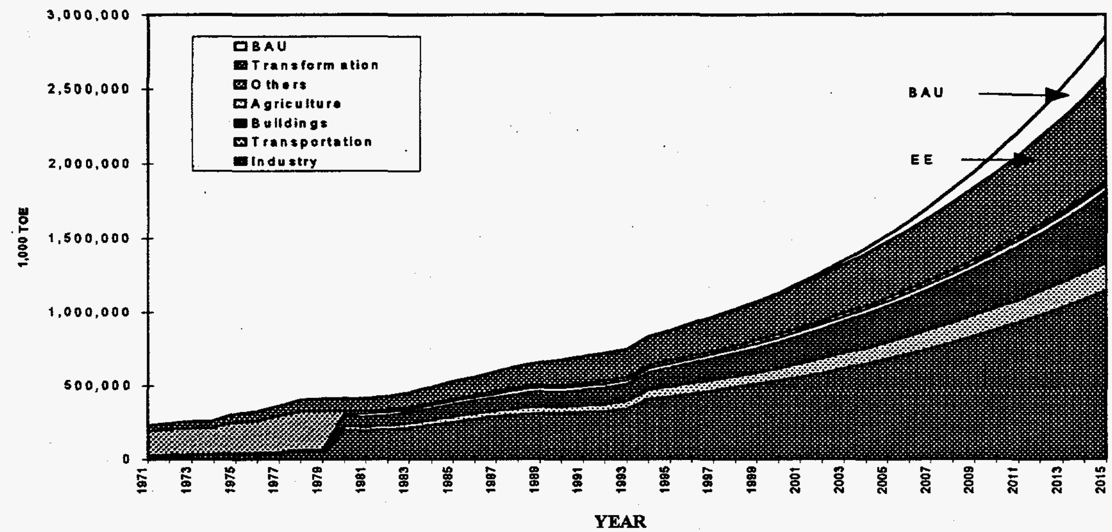
The commercial building sector is projected to have the largest percentage increase in growth, fueled by the double-digit growth in the service sector. The service sector is expected to increase its share in the economy from 25% in 1994 to nearly 40% by 2015.



Note: Solid fuel for BAU is the sum of the solid fuel for EE and the gap under the Total Energy Requirement (BAU) curve.

Figure 2.2. Projected Energy Requirements for China by Fuel Type Under the EE Scenario and by Total Under the BAU Scenario

China's transportation infrastructure, typically a major energy consumer, makes up less than 10% of the total final energy consumption. While the energy consumption is expected to increase in the transportation sector, it will increase at a slower rate than total GDP growth, resulting in decreasing energy intensity during the 1994 to 2015 period.



Note: The "Other" category includes agriculture and buildings data prior to 1980.

Figure 2.3. Projected Energy Requirements for China by Sector Under the EE Scenario and by Total Under the BAU Scenario

2.2 Sector Requirements

Industry

The industrial sector has been growing rapidly, with average annual GDP growth of 10% since 1980. At 350 Mtoe, its share of final energy consumption in 1993 was 64%. In 1993, direct use of coal made up almost 69% of all final energy used in this sector, followed by electricity (12.7%) and petroleum products (10.5%). The electricity share has been increasing quite rapidly, while the share of direct coal use has gradually been declining.

The industrial sector has a high energy intensity, because most industries are still using old equipment in smaller plants that preclude economies of scale. In addition, up to the early 1990s, energy prices were so low that enterprises had little incentive to try to conserve energy. The amount of energy required to produce a unit of steel, cement, ammonia, or paper is considerably more than what is required in industrialized countries (sometimes twice as much).

The industrial energy intensity[1] in 1993 (as measured by 1,000 toe/1987$ millions), was 1.44, compared with 0.52 in the United States in 1970. Nevertheless, the energy intensity of the industrial sector (Figure 2.4) has been decreasing at an annual average rate of about 6% since 1980.

BAU Scenario

The industrial sector will continue to be the largest energy user, but its share of final energy requirements will fall to 60% in 2015, down from the current value of 64% . Industrial energy intensity will continue to decrease, as production shifts to high value-added and less energy-intensive products, with anticipated improvements in technical and labor efficiency. From 1995 to 1999, it is assumed that energy intensity will decline annually by 6%, from 2000 to 2005 by 3%, from 2006 to 2010 by 2%, and by 1% from 2011 to 2015 (Figure 2.4).

Industry contributes 55% to the total GDP and it is assumed that the sectoral GDP will continue to grow faster than the total. Thus, the industrial sector will remain the dominant sector of the economy. It is projected that industrial final energy requirements will reach 1.24 billion toe (Btoe) in 2015.

EE Scenario

Under the EE scenario, energy intensity will drop only slightly faster than under the BAU scenario, the latter of which is already a high percentage drop for a developing country. Under the EE scenario, it expected that total final consumption for the industrial sector will reach 1.15 Btoe, roughly 93% of the level projected under the BAU scenario.

2.3 Transportation

At 10%, China's transportation infrastructure accounts for a considerably smaller portion of total energy consumption than is typical in other countries. This low percentage can in part be explained by China's planning in the 1950s. China spread its industries to isolated villages, with limited or no road connections. Each of these isolated villages was supposed to be self-sufficient.

[1] Industrial energy intensity is measured in terms of industrial final energy consumption divided by industrial GDP.

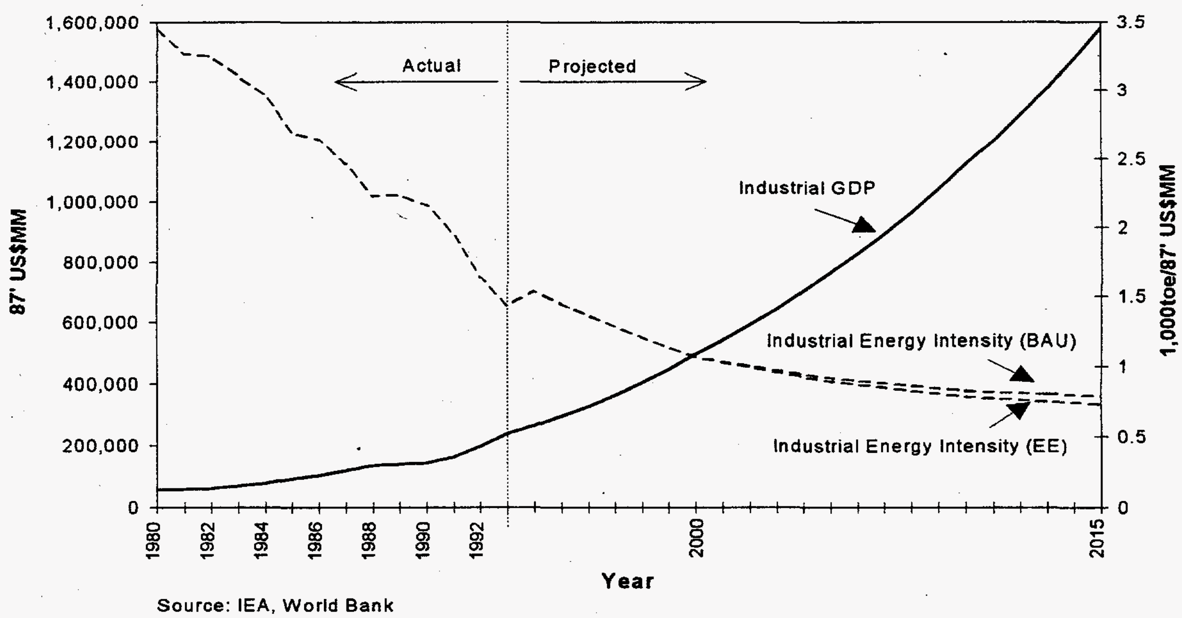


Figure 2.4. Energy Intensity of Industry and Industrial GDP in China Under the BAU and EE Scenarios

Energy consumption for transportation increased from around 25 Mtoe in 1980 to about 56 Mtoe in 1993. Road traffic grew at a much faster rate than overall transportation, 13.3% per year increase for passenger road traffic while road freight grew at double the rate of rail freight. As a result, road passenger traffic as a share of all passenger traffic increased from 32% in 1980 to 49% in 1994.

The energy efficiency of China's road transportation has been increasing. During the 1980s, almost all of China's domestic car manufacturers imported modern technologies from American, European, and Japanese auto-makers. It is expected that China's demand for all kinds of vehicles will increase steadily over the next five years, at an average annual growth rate of 7 to 8%.

The tremendous increase in road usage spurred a 5.2% annual growth in energy consumption in this sector, but this is well below the total GDP growth of 10% per year. Therefore the transportation sector's energy intensity has been decreasing.

Petroleum has increased its relative share of energy consumed in the transport sector, largely as a result of the growth in road transportation and the conversion of rail transport from coal-based steam locomotives to diesel. In 1993, petroleum made up over 78% of all the final energy used in this sector, followed by coal (18.7%) and electricity (2%).

BAU Scenario

The transport sector suffers from insufficient data and even at the simplest level, such as the number of passenger and commercial vehicles, the available data are subject to a wide range of variability in quality. This makes it difficult to calculate meaningful indicators of energy intensity in the sector. For this analysis, energy intensity is defined as total energy consumption divided by total GDP.

The transportation energy intensity has been decreasing at an average annual rate of 3.5%. As the economy slows down, the growth of the transportation sector will catch up. Therefore, it is assumed that the energy intensity for transportation will continue to decrease, but at a slower rate, by 2% per year until 2005, and then at 1% annually until 2015 (Figure 2.5). The total energy requirement of this sector will reach 259.2 Mtoe in 2015.

EE Scenario

For the transportation sector, we assume even more steam locomotives will be replaced by more efficient diesel and electric locomotives and modern technologies will be imported to make the automobile fleet increasingly more efficient. This would allow the transportation sector energy intensity to decrease at a constant rate of 3% annually to 65 toe per million dollars in 2015. The projected energy requirements will reach 186.9 Mtoe under this scenario, roughly 72% of the level projected under the BAU scenario.

Buildings (Residential and Commercial)

Total energy consumption increased from around 67 Mtoe in 1980 to about 113 Mtoe in 1993, and made up more than 20% of total final energy consumption in China in 1993 (not including biomass). Roughly 87% of this consumption was used for residential buildings. The commercial buildings sector accounted for the remaining 13%.

Residential energy consumption in China is dominated by coal and biomass. However, since biomass is not a commercial fuel, it is not considered in our forecast. Cooking and space heating are the chief end uses. About 70% of the population lives in rural areas and relies heavily on biomass for fuel; biomass supplies about 80% of rural household demand. Coal dominates the urban household energy market. In consumption of commercial fuels, rapid economic growth has brought about significant changes in the consumption pattern. Most significantly, household use of electricity increased more than four-fold from 1980 to 1990, due to the increasing use of electric appliances. As part of its effort to join the World Trade Organization, China has been opening its market for imported goods. China has become a market for low-priced, outdated, non-energy-efficient appliances.

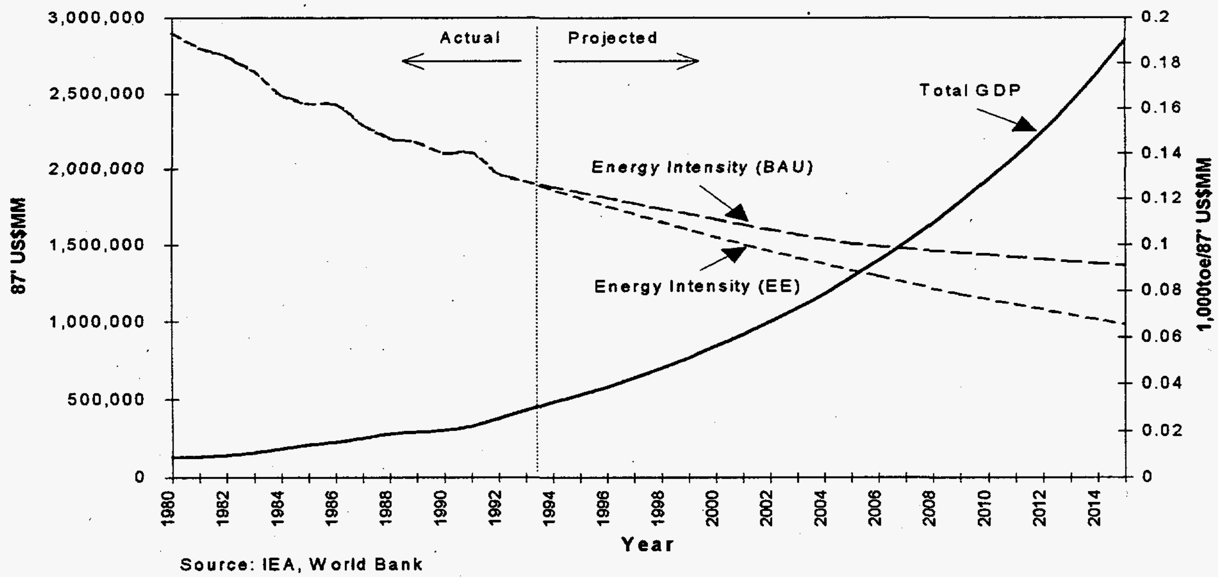


Figure 2.5. Energy Intensity of the Transport Sector and GDP in China Under the BAU and EE Scenarios

The service sector in China has been growing very rapidly, over 11% in 1993, even faster than the industrial sector. Services provided by the service sector (banking, financing, and legal services) are increasingly important for China, sparking demand for electronic office equipment.

BAU Scenario

We project that the residential sector energy requirement will continue to increase, as appliances become even more readily available to the population and electricity consumption increases. It is expected that gas fuel consumption will also increase in urban areas for use in cooking, while coal consumption for residential use will decline.

The residential building energy intensity is defined as commercial energy use (i.e., excluding biomass) divided by the number of households. In 1993, the energy intensity was 0.33 toe/household. It is expected that energy intensity will increase at an annual rate of 4% to 0.78 toe/household in 2015 (Figure 2.6). In comparison, the energy intensity in 1980 for a U.S. household was 2.25 toe/household. It is projected that residential energy consumption will reach 357 Mtoe in 2015.

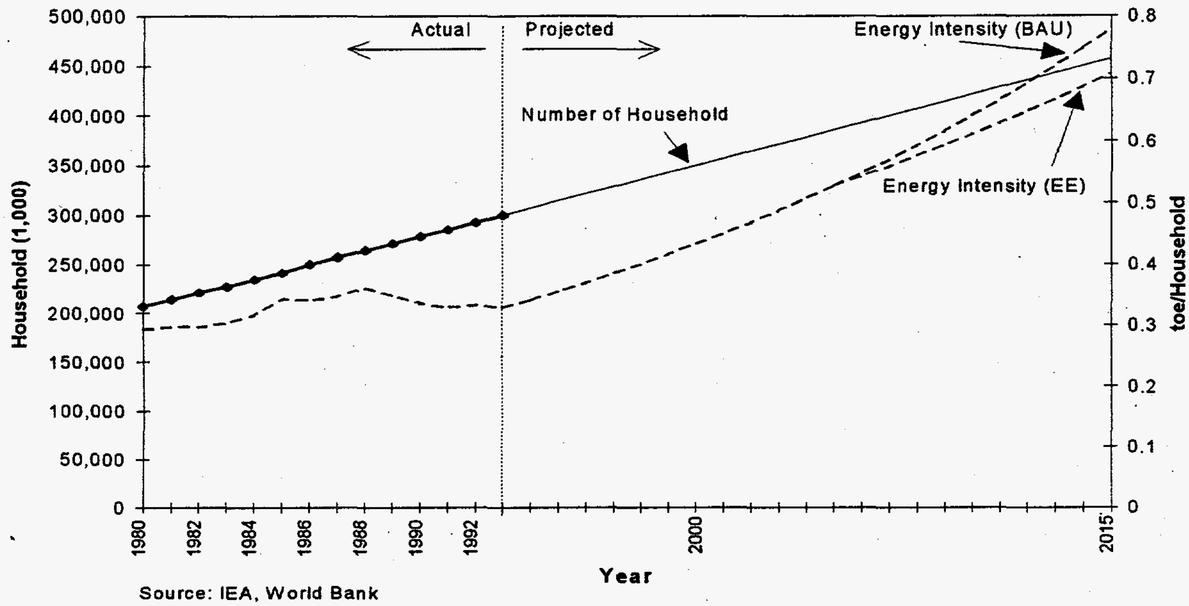


Figure 2.6. Energy Intensity of the Residential Sub-Sector and Number of Households in China Under the BAU and EE Scenarios

The commercial building energy intensity is defined as total commercial energy used divided by service sector GDP. In 1993, the energy intensity was 142 toe/1987$ million. It is expected that the energy intensity will decrease at about 2% annually until 2005 (Figure 2.7). This decrease results from very high rates of GDP growth, which are expected to outstrip energy consumption growth. However, the value of the services will not grow as fast when more and more people enter the sector and provide the same services. Therefore, the energy intensity will start to increase as more office equipment is used in commercial sector, while the value of the services remains the same. Thus, it is expected that the energy intensity will increase from 2006 to 2015 by 2% annually.

It is projected that the commercial building energy requirement will reach 151 Mtoe in 2015.

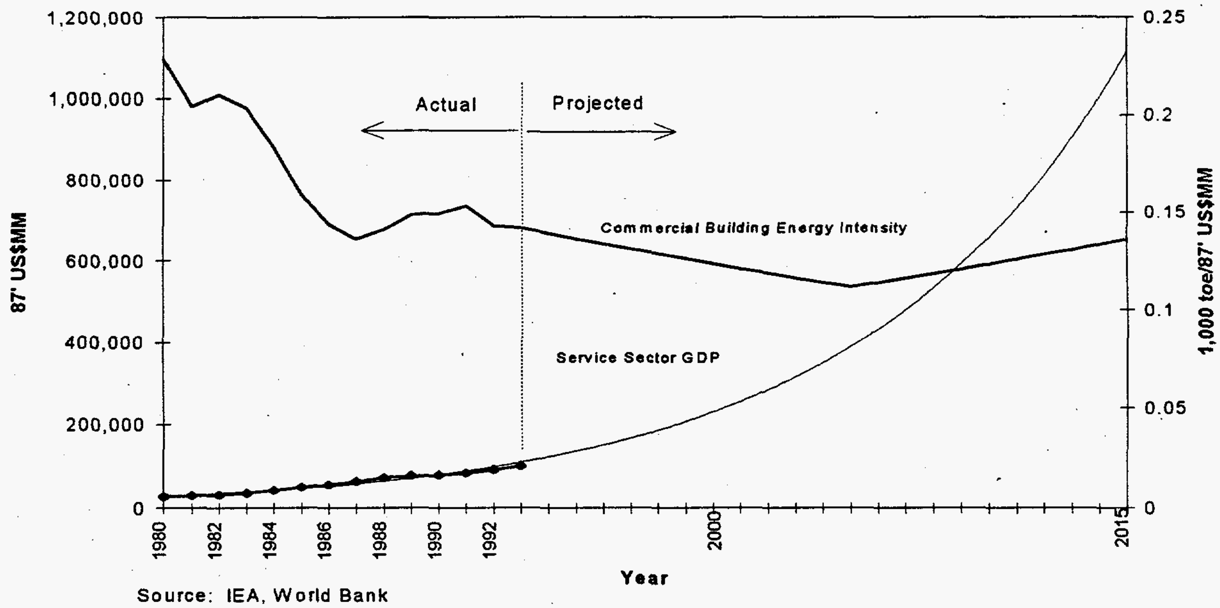


Figure 2.7. Energy Intensity of the Commercial Sub-Sector and Services GDP in China Under the BAU and EE Scenarios

EE Scenario

Under the EE scenario, it is assumed that the energy intensity will increase by 4% annually to 2005, after which it will slow to 3% annually to 2015. The energy intensity will increase to 0.71 toe/household, 91% of the level projected under the BAU scenario. Residential energy consumption will reach 324 Mtoe, 33 Mtoe less than under the BAU scenario.

Since the commercial buildings sector accounted for less than 3% of the total final energy consumption in China in 1993, it is assumed that energy efficient appliances would have little impact on total final energy demand. Therefore, the EE scenario is assumed to be the same as the BAU scenario, with total energy requirements projected at 151 Mtoe in 2015.

Agriculture

Energy consumption in the agriculture sector made up less than 5% of the total final consumption in China in 1993. Direct use of coal accounted for about 44% of energy use in this sector, followed by petroleum (38%) and electricity (18%). The electricity share has been gradually increasing, while the share of coal has been declining.

China hopes to squeeze out badly needed gains in agricultural efficiency by increasing mechanization and encouraging coordination among farms. While efforts to boost output have focused in recent years on easy credit and other incentives, the emphasis is shifting to aiding grain production centers and the farm machinery sector. In addition to wanting to increase output, the government is trying to increase the income of rural residents. Increasing farm efficiency through mechanization is seen as the best answer. Currently, nearly half of the China's large grain farms (100 hectares or more) are not plowed by machinery.

BAU Scenario

Although the Chinese government is working to mechanize the agricultural sector, heavy machines may not work well in the millions of tiny family farms around China. Since agricultural demand accounted for less than 5% of China's total final energy consumption in 1993, no reasonable scenarios would have any significant affect on the total energy requirement projection. Agricultural energy intensity and agricultural GDP are projected based on historical data. The results show that agricultural energy intensity will decrease at a decreasing rate from 0.94% in 1994 to 0.44% in 2015 (Figure 2.8). The projected energy requirement for the agricultural sector will increase from 26.5 Mtoe in 1994 to over 40.5 Mtoe in 2015.

EE Scenario

The EE scenario is assumed to be identical to the BAU scenario, because China is still in its early stages of mechanization the agricultural sector. Even if it is assumed that China is able to successfully mechanize its farms in the next 25 years, the primary effort will be on increasing production. Farm machinery are expensive capital investments and once they are purchased, it will take some time before they are replaced with more efficient equipment.

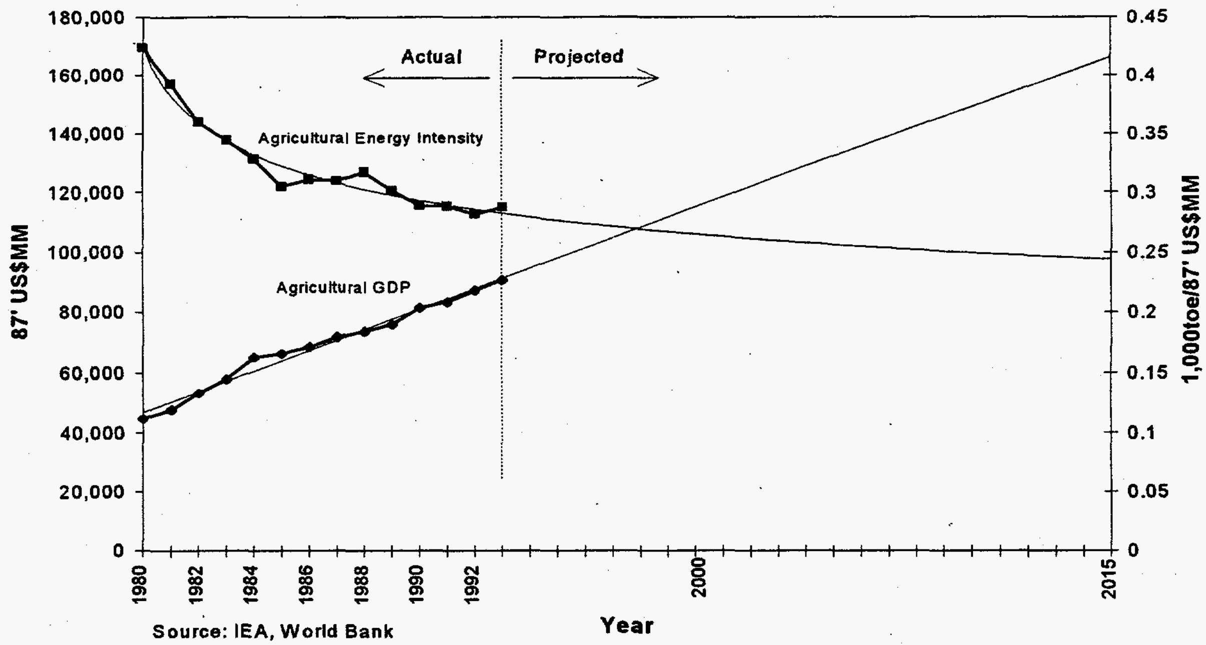


Figure 2.8. Energy Intensity of the Agriculture Sector and Agricultural GDP in China

Transformation

For each sector, energy consumption and an activity measure for energy consumption was baselined. A typical activity measure used was value added for that sector, such as industrial value added. We then calculated the energy intensity of each sector by dividing the energy consumption by the activity measure.

We estimated future energy requirements by forecasting the activity and energy intensity measures to 2015. We then multiplied the activity measure by the energy intensity measure for an estimate of energy requirements. We calculated the total predicted energy requirements by summing the energy requirements for all the sectors, and multiplying this total by the projected TPES/TFC ratio[2] (Figure 2.9), as shown in the equation below:

$$TER = (ER_I + ER_{RB} + ER_{CB} + ER_T + ER_A) * R$$

where

TER = total energy requirements

[2] TPES/TFC ratio is the ratio of Total Primary Energy Supply (TPES) and Total Final Consumption (TFC). TPES is the sum of indigenous production and imports minus exports and international marine bunkers and +/- stock changes. TFC is the sum of final consumption by the different end-use sectors.

ER = energy requirements

I = industrial sector

RB = residential buildings sector

CB = commercial buildings sector

T = transportation sector

A = agricultural sector

R = projected TPES/TFC ratio.

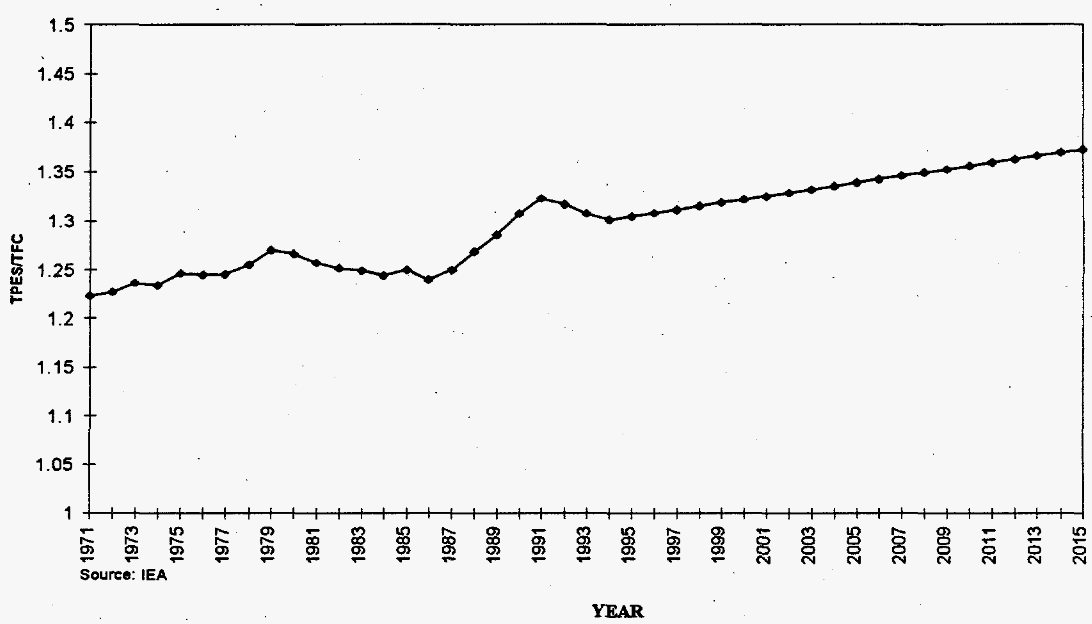


Figure 2.9. Energy Intensity of the Transformation Sector in China

3.0 FORMER SOVIET UNION AND CENTRAL AND EASTERN EUROPE

This chapter describes the energy consumption patterns of the FSU and Central and Eastern Europe (CEE), a geographic region encompassing approximately 23,441,059 square miles and inhabited by nearly 400 million people. For the purposes of this study, Russia consists of the Russian Republic as well as the fourteen independent countries which formerly comprised the Soviet Union.[1] Central and Eastern Europe is understood to consist of the following countries: Albania, Bulgaria, the Czech Republic, Hungary, Poland, Romania, the Slovak Republic, and the five states of the former Yugoslavia (Bosnia-Herzogovina; Croatia, Serbia and Montenegro, and Slovenia). Because all of these states have similar economic structures, are geographically close together, have many cultural similarities, and began the transition away from central planning at approximately the same time, it is appropriate to treat all 21 countries as one region. Since Russia is by far the region's largest consumer and producer of energy, however, greater attention is devoted to developments in that country.

3.1 Economic Restructuring Key to Changing Energy Consumption Patterns

The Soviet Union collapsed in December 1991 and was succeeded by the Russian Federation. Russia's first freely elected president, Boris Yeltsin, began a thorough restructuring of the old Soviet system. He announced his intention to replace Russia's inefficient and financially disabled command economy with free markets and democratic governing institutions. He also sought to integrate the country more fully into the world economy after decades of isolation.

Restructuring has proceeded on several fronts, including decentralization and privatization, price reform, fiscal reform, and openness to foreign investment. While much progress has been made toward these goals over the past five years, Russia has endured significant political and economic strain as a result of the changes. Between 1989 and 1994, for example, total output declined by one-half (IMF 1994), and consumer price inflation surged, reaching as high as 1,354% in 1994. Russia also had a large budget deficit that amounted to 8.3% of GDP in 1995 (EIU 1995) and unemployment was widespread.

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[1] Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kirghizia, Latvia, Lithuania, Moldova, Tadzhikistan, Turkmenistan, Ukraine, and Uzbekistan

to appreciate in value. Most analysts believe that the Russian economy, having reached its nadir in 1994, is well on the way to recovery and growth. They predict an average economic growth rate of 5.4% a year over the next five years (World Bank 1996).

Energy consumption and energy intensity levels in Russia have historically been very high, owing to a variety of factors, including access to vast domestic energy reserves; government emphasis on production of energy-intensive capital goods; artificially low energy prices; a harsh climate with long winters; and long transport distances. Waste was rampant, and most enterprises operated very inefficiently, having no incentive to conserve energy. With the introduction of economic reform, however, pricing has become more important, a development which will certainly change how energy is used. Indeed, the region's future energy demand profile depends largely on the progress of energy price reform. New energy conservation legislation has also been passed. If fully implemented, these laws can further stimulate efficiency.

3.2 Key Findings

Figure 3.1 illustrates Russia's TPES in 2015 under the BAU and EE scenarios.[2] Under the BAU scenario, TPES reaches 3,775 Mtoe, while under EE conditions, TPES reaches 2,675 Mtoe, owing to more effective implementation of energy efficiency policies and more rapidly rising energy prices. In both cases, the transformation sector remains the largest consumer of energy, followed by the industrial sector. In 2015 the transformation sector will consume 1,487 Mtoe under BAU and 938 Mtoe under EE conditions. Under both scenarios there will be a move toward greater use of natural gas; by 2015 gas is expected to make up nearly 50% of the total energy requirement, with higher gas penetration under EE conditions (Figure 3.2). Greatest energy efficiency improvements are observed in the buildings sector.

[2] Unless otherwise indicated, all energy data is based on OECD estimates, and all economic data is based on World Bank sources. Some data has been interpolated owing to questionable quality of source data.

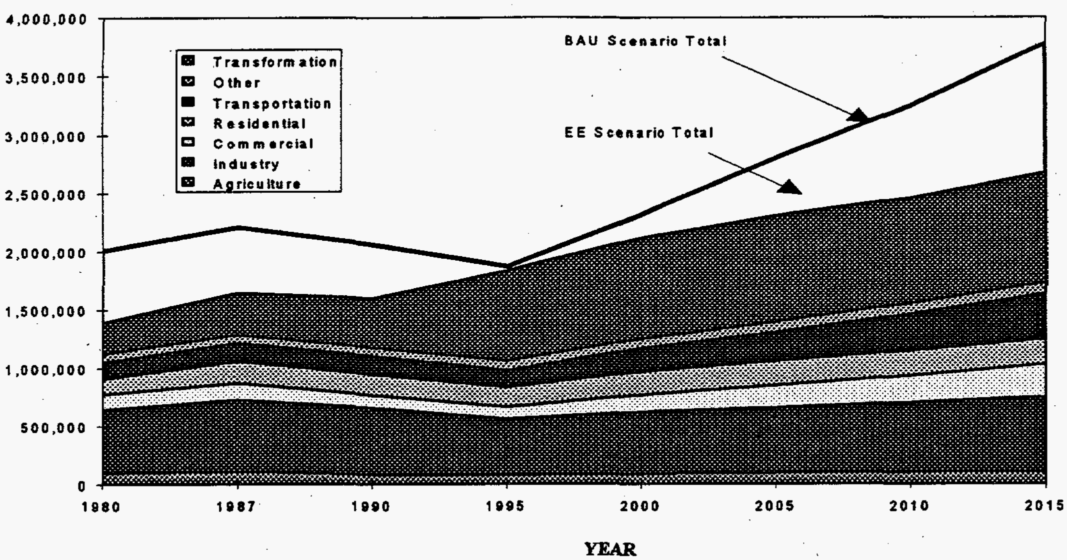

Figure 3.1. BAU and EE Projections for FSU-CEE Total Energy Requirement and Supply By Sector to 2015

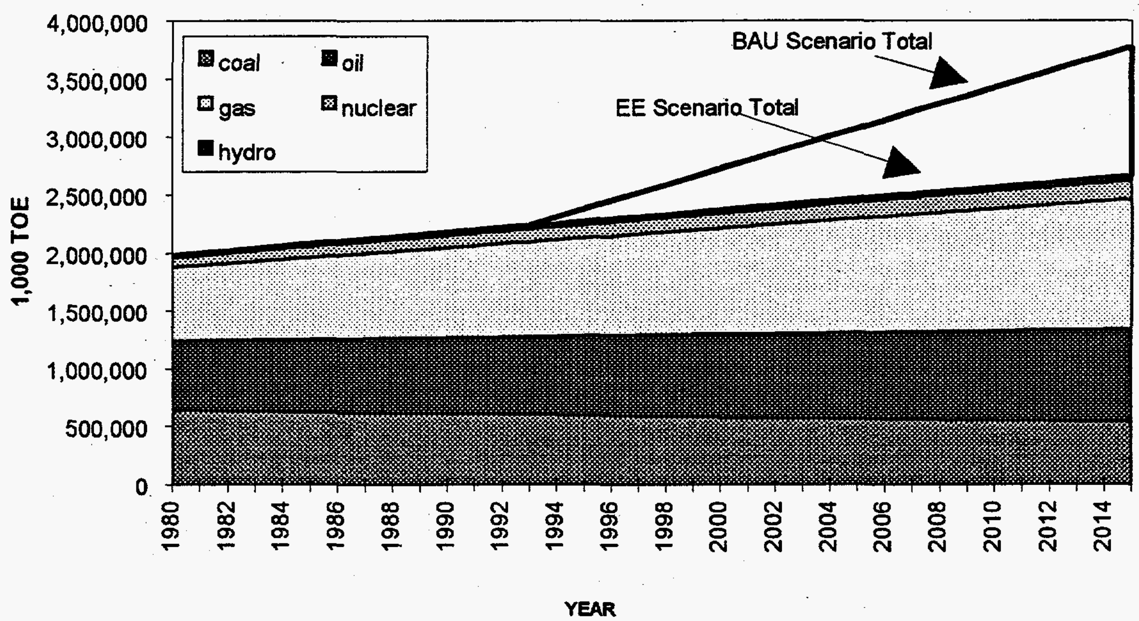

Figure 3.2. BAU and EE Projections for FSU-CEE Total Energy Requirement and Supply By Fuel Type to 2015

Population growth is expected to remain at just under 1% for the FSU-CEE area over the next two decades. Unlike various other regions that are developing economically, rapid population growth is not likely to significantly increase demand for energy in the FSU-CEE region. Rather, the primary driver for changing energy use patterns will be economic restructuring. Figure 3.3 depicts projected population and GDP growth in the FSU-CEE region.

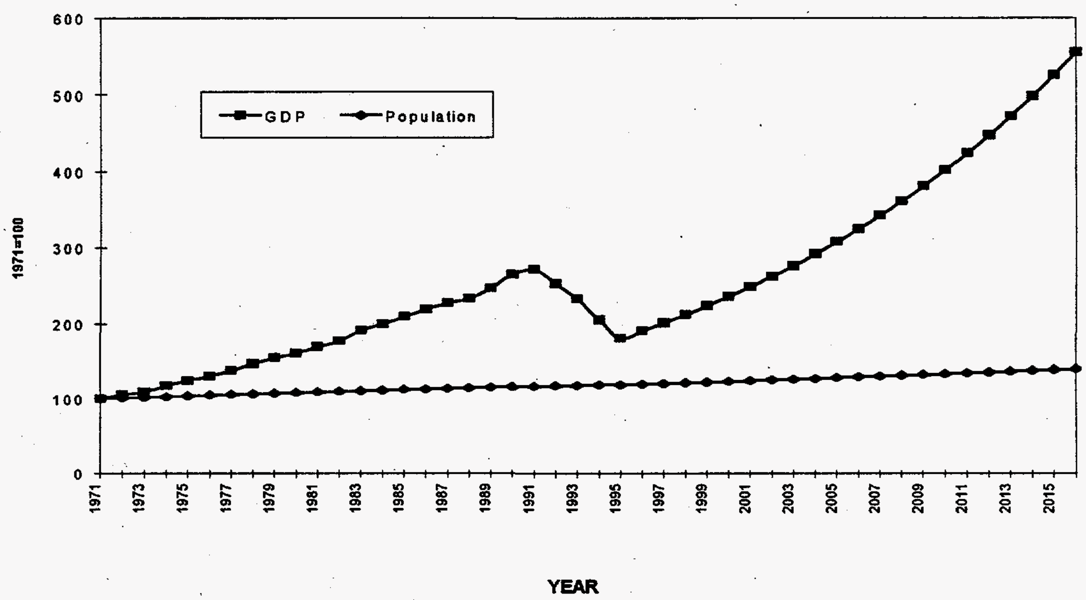

Figure 3.3. Historic and Projected GDP and Population Growth in the FSU-CEE[3]

3.3 Sector Requirements

Industry

By the late 1980s, industry comprised close to 50% of Soviet GDP. The Soviet government had traditionally emphasized energy-intensive industries such as iron/steel and non-ferrous metals, cement, paper, chemicals, and building materials. Much of this production served the defense industry, which comprised approximately 20% of GDP. The industrial sector experienced a severe decline in the early 1990s when the Russian economy went into recession and military production slowed.

Despite the steep decline in output during this time, energy intensity rose because energy was still consumed to keep factory equipment running. In addition, energy prices fell during the early 1990s, which kept demand high even though overall economic output was declining (OECD 1994).

[3] GDP data for 1991-1994 have been interpolated based on World Bank estimates.

Since early 1995, however, the Russian economy has begun to stabilize. The coming decades will see reductions in energy intensity and consumption in the Russian industrial sector. Some of the most inefficient plants have already been shut down, and others will continue to close. Heavy industry's share of GDP will continue to decline. As the country converts from military to civilian production, demand for consumer products will grow, expanding the share of less energy-intensive light industry in the Russian economy. In addition, increasing decentralization and privatization of the economy will enable foreign companies to invest in Russian industry, supplying more efficient management techniques and replacing aging capital stock, thereby reducing energy intensity. Russia is currently developing laws to attract foreign investors.

Another important factor impacting future energy consumption patterns is that the international community is pressuring Russia to raise energy prices, bringing them more closely in line with world levels. Higher energy prices will force industry to become more energy-efficient; Russian plant managers will develop a greater understanding of cost accounting procedures, which will change how they make investment decisions, presumably forcing them to consider cost—rather than expediency or national plans—when purchasing fuel (OECD 1995b).

Further energy efficiency improvements will result from the replacement of coal and oil in industry with natural gas. Increased use of gas in the power sector will also help replace some of the nuclear capacity that will be lost when Russia shuts down some of its old and potentially dangerous nuclear reactors (OECD 1995b).

BAU Scenario

Under this scenario, economic reform makes steady progress, but obstacles to complete market transformation exist. Energy intensity in the industrial sector rises slightly until the turn of the century, and then, as old plants are gradually retired, intensity declines 1% per year until 2015. Total final consumption of energy for this sector under the BAU scenario in 2015 is 783 Mtoe, 43% above 1993 levels.

EE Scenario

While energy intensity under the BAU scenario begins to decline in the next century, the declines under the EE scenario occur earlier and are somewhat more dramatic. For example, the EE scenario assumes that the economy will successfully transition away from heavy industry a few years earlier than it would under a BAU scenario. Intensities begin to decrease in the late 1990s, resulting in a total energy requirement of around 647 Mtoe in 2015. Figure 3.4 illustrates energy intensity and energy requirement for the industrial sector under BAU and EE conditions.

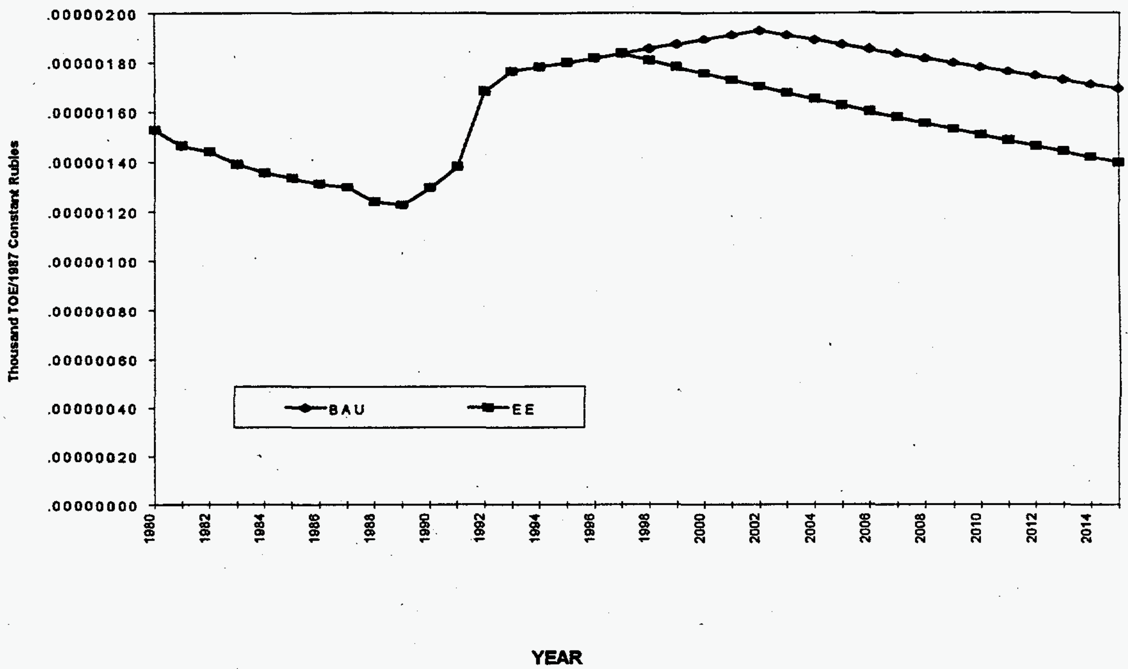

Figure 3.4. BAU and EE Projections for FSU-CEE Industrial Sector Energy Intensity to 2015

Transportation

The transportation sector in the FSU-CEE region will expand rapidly as the country develops. In the tradition of most developing economies, moreover, the FSU-CEE's primary mode of transportation will shift from rail to road and air (OECD 1995c). Use of private automobiles has already begun to climb. Over the short-term, the additional cars on the road will be older, less efficient, second-hand models from western countries, increasing intensity for passenger traffic in the near-term. However, over time, many western automobile manufacturers will establish a presence in FSU-CEE countries, bringing with them advanced technologies that can significantly reduce energy intensity. The region will also gradually transition to western-type fuel efficiency standards.

Because of poor maintenance and budget shortfalls, the FSU-CEE area's railroad network has deteriorated greatly since the early 1990s. Infrastructure deficiencies will plague the region for some time to come, since most governments currently lack the capital necessary to properly maintain the road and rail systems. This will be a huge detriment to energy efficiency until well into the twenty-first century.

While transportation will clearly be a high growth, high demand sector in the FSU-CEE over the next few decades, there will also be some improvements in energy efficiency that which will have a mitigating impact. For example, trucks, which currently run on gasoline, will be switched over to run on more fuel-efficient diesel fuel. In addition, Russia's transition away from heavy industry means that trade in bulk raw materials will decline. Also, load factors of future road transport will be higher.[4] Some infrastructure improvements will also be made. Russia's notoriously leaky and inefficient oil and gas pipeline system, for example, will be properly maintained and upgraded, resulting in energy intensity decreases. In the longer term, improvements will also be made in road and rail quality.

Finally, as in all other sectors, higher overall energy prices will result in further declines in transportation sector energy intensity and consumption. Changes in consumption will of course depend on the extent to which prices have been adjusted.

BAU Scenario

The BAU scenario for the FSU-CEE transportation sector assumes that the economic growth is sufficient to allow a 20% increase in the number of automobiles on the road by early in the next century. As with the other sectors under BAU conditions, effective laws governing transportation efficiency standards are lacking, and those policies that are enacted are not rigorously enforced. The population has still not developed a sensitivity for efficiency concerns and is unwilling to pay more for more energy-efficient vehicles. As a result, energy intensity for the sector rises until 2005. Total final consumption of energy is approximately 505 Mtoe in 2015.

EE Scenario

Under this scenario, energy efficiency improvements occur in the short-term. Energy intensity in the sector rises until about the turn of the century, and then begins a gradual decline. While final energy consumption continues to climb to 391 Mtoe, it nonetheless remains 23% below BAU levels. Not only are new policies in effect in the transportation sector, but people are also purchasing better quality vehicles and are paying higher prices for energy. Energy efficiency policies under this scenario are also boosted by environmental regulations aimed at reducing emissions of carbon dioxide from automobiles. Figure 3.5 depicts energy intensity and energy consumption patterns for both scenarios.

[4] While under the Soviet system, enterprise-owned trucks often returned to the plant empty after making deliveries, private trucking companies under a market-based system will have incentive to maximize their load efficiencies.

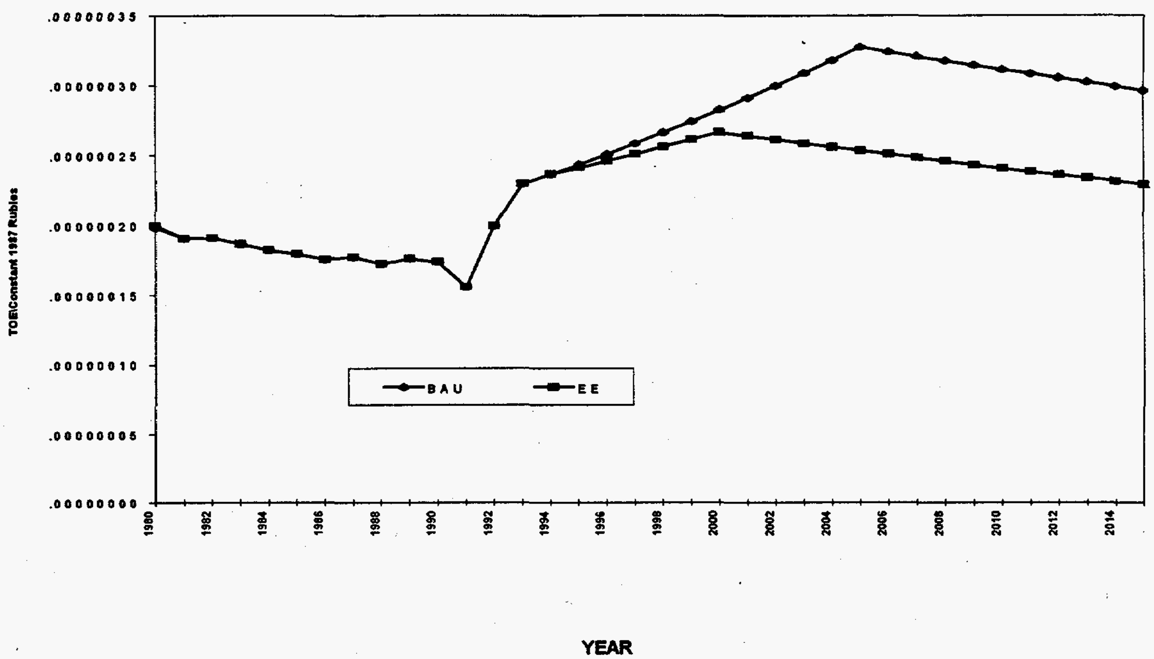

Figure 3.5. BAU and EE Projections for FSU-CEE Transportation Sector Energy Intensity to 2015

Buildings (Residential and Commercial)

Commercial

The commercial/services sector in the FSU made up a very small share of GDP. In 1991, for example, it comprised only 22% of GDP, compared to 50% in the United States (CIA 1994). Beginning in the early 1990s, this sector expanded rapidly, making up 42% of GDP by 1993 (World Bank 1995). Today, retail stores, hotels, restaurants, real estate agencies, banks and other financial institutions are increasingly common in the region. At the same time, hundreds of western entrepreneurs have established a presence in the area as investment conditions have become more favorable.

BAU Scenario: Under this scenario, the commercial sector will make up well over half of GDP value-added by 2015, approaching levels common in the OECD. Rising incomes will mean more money is available to spend on commercial and leisure activities. The Russian business class continues to thrive and grow, and passage of legislation conducive to foreign investment will bring additional western franchises to Russia. Floor space in the commercial buildings sector will grow significantly, and new lighting will be installed; computers and other electricity-consuming appliances will proliferate. Unlike in the past, however, new business enterprises will be built according to code, equipped with more energy-efficient lighting, space heating, and insulation. Western investors will be particularly sensitive to energy costs. Under BAU conditions, energy consumption will reach 438 Mtoe in 2015, more than quadrupling

1990 levels of 105 Mtoe. The commercial sector is non-energy-intensive relative to other sectors; despite rapid growth, energy intensity in 2015 will still be below that of the industrial and agricultural sectors.

EE Scenario: The EE scenario assumes that energy efficiency standards and regulations are quickly updated and enforced. It also assumes that a strong market for energy-efficient building supplies emerges. Under these conditions, total consumption for the sector will reach 278 Mtoe, approximately 64% of the projected BAU value. Figure 3.6 shows these trends.

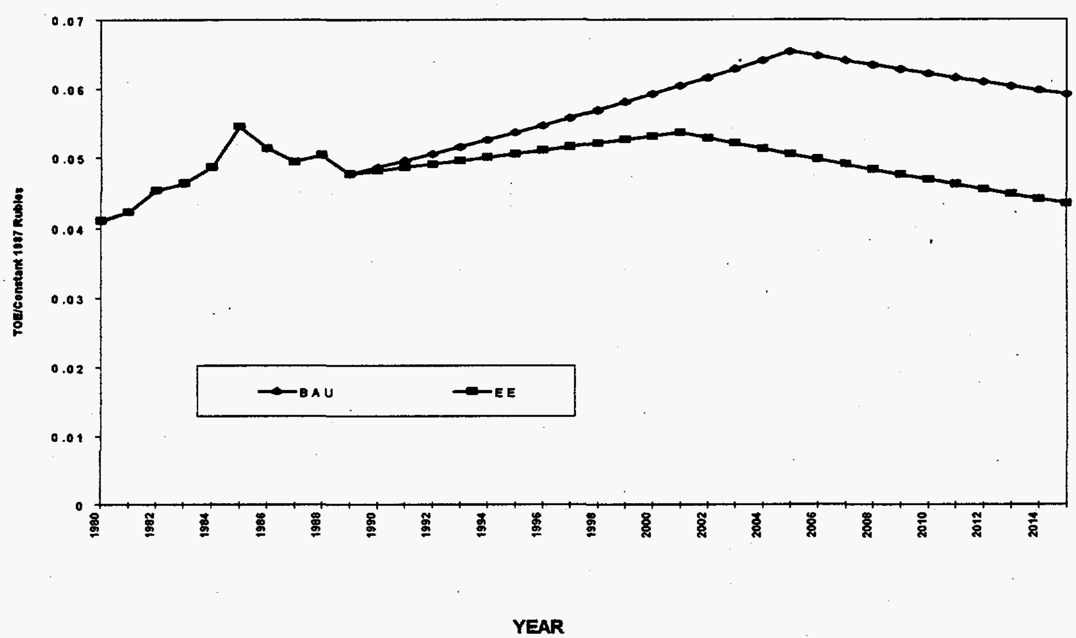

Figure 3.6. BAU and EE Projections for FSU-CEE Commercial Sector Energy Intensity to 2015

Residential

The FSU-CEE residential sector, like the other sectors, has no tradition of energy efficiency. There are many reasons for this, including artificially low energy prices; disregard for existing standards and regulations; poor construction practices; the absence of adequate insulation; lack of metering and control equipment; limited availability of advanced, energy-efficient equipment or capital to purchase such equipment; poor payment discipline on the part of energy consumers; and a monopolistic energy supply system (OECD 1995a). While these conditions are expected to improve over time, other factors will cause energy consumption and intensity to increase in this sector for some years to come.

The residential sector will grow rapidly as the economies of the FSU-CEE region evolve and people seek to escape from the traditionally cramped living conditions.

As Russia's heavy industry declines, moreover, people will move away from the company towns, where they have lived and worked for decades, to seek opportunities in other cities. They, too, will require new housing. These factors imply a boom in the residential construction industry, and thousands of new homes and luxury apartments will be built over the next couple of decades. Additional housing will be accompanied by an increase in demand for space heating, hot water, and new appliances. Sales of refrigerators, washer/dryers, television sets, CD players, and other electric equipment will rise along with people's incomes. This means that demand for electricity will also rise, particularly since Russian consumers are not used to purchasing appliances on the basis of their energy-efficiency qualities. It will take some time before Russian consumers develop the necessary "green" attitudes (OECD 1995a).

BAU Scenario: The above conditions suggest that energy consumption and energy intensity in the residential sector will increase over the next several years. Construction of new homes grows at 2% a year, but because housing is so scarce, few of the older, inefficient apartment buildings will be torn down in the short-term. However, over the course of the next decade or so, transition to a market economy will result in higher energy prices and less subsidization, which means that residential sector energy consumption will decrease as consumers are faced with full responsibility for energy costs. In addition, insulation and metering and control devices will be installed in homes, leading to more efficient use of energy. The BAU scenario assumes that energy intensity will rise until about 2004, when it begins a gradual decline. Total final consumption of energy in this sector in 2015 is 292 Mtoe, approximately two-thirds above 1990 levels.

EE Scenario: The main difference between the BAU and EE scenarios, once again, is that greater progress has been made in implementing energy efficiency policies, and new energy-efficient technologies are installed in each new home constructed. In addition, many older homes are retrofitted with energy-saving devices under a federally-subsidized program (based on the government's successful efforts to raise revenue through taxation). Energy intensity begins to decline around the year 2000, dipping 21% below peak 1985 levels. Total final consumption of energy in this sector is approximately 214 Mtoe in 2015, compared with 292 Mtoe in the BAU scenario. Figure 3.7 illustrates energy intensities and energy requirements for the FSU-CEE residential sector to year 2015.

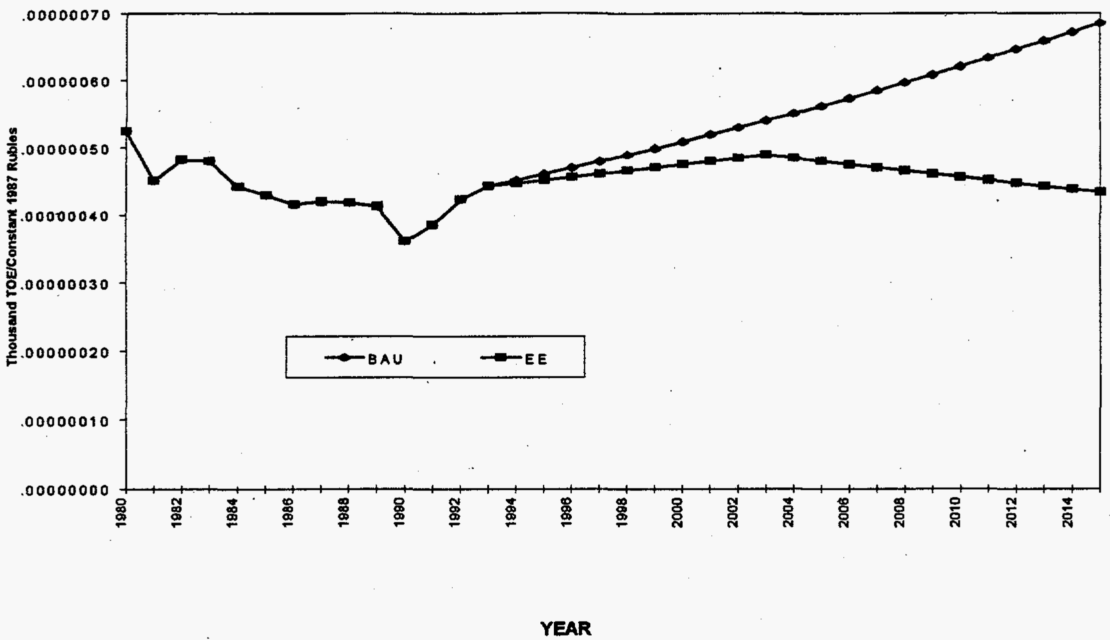

Figure 3.7. BAU and EE Projections for FSU-CEE Residential Sector Energy Intensities to 2015

Agriculture

Because prices and costs have traditionally been meaningless to most Russian farmers, the FSU's agricultural sector has been characterized by misallocation, waste, inefficient distribution, and low returns on investment (Informatics 1993).

In 1991 agriculture made up 12.9% of Russian GDP, compared with less than 2% in the United States (CIA 1994). Since 1992 vigorous efforts have been underway to reform this sector. Privatization has been a major component of this strategy, though this program has only been a qualified success.

BAU Scenario

Under the BAU scenario, energy intensity rises gradually because privatization is slow to take off. As a result, many farms are operated inefficiently until early in the next century. Output grows slowly and constantly, but farms become increasingly mechanized and electrified, which raises energy demand, and hence intensity. Energy consumption reaches 146 Mtoe by 2015, nearly 40% above 1990 levels.

EE Scenario

This scenario assumes that energy intensity declines as farms are privatized at an accelerated rate, and farmers, motivated by profits, will become more productive, getting goods to market (as opposed to in the past, when an inefficient distribution system meant that many crops rotted in silos). As countries develop, the percentage of farmers in the population generally declines. Those farmers who remain will adopt more energy-efficient methods and technologies. Hence, both energy intensity and consumption in the sector decline relative to the BAU scenario. Figure 3.8 shows the projected energy intensity of this sector for both the BAU and EE scenarios. Final consumption of energy in 2015 is 108 Mtoe, 26% lower than BAU projections.

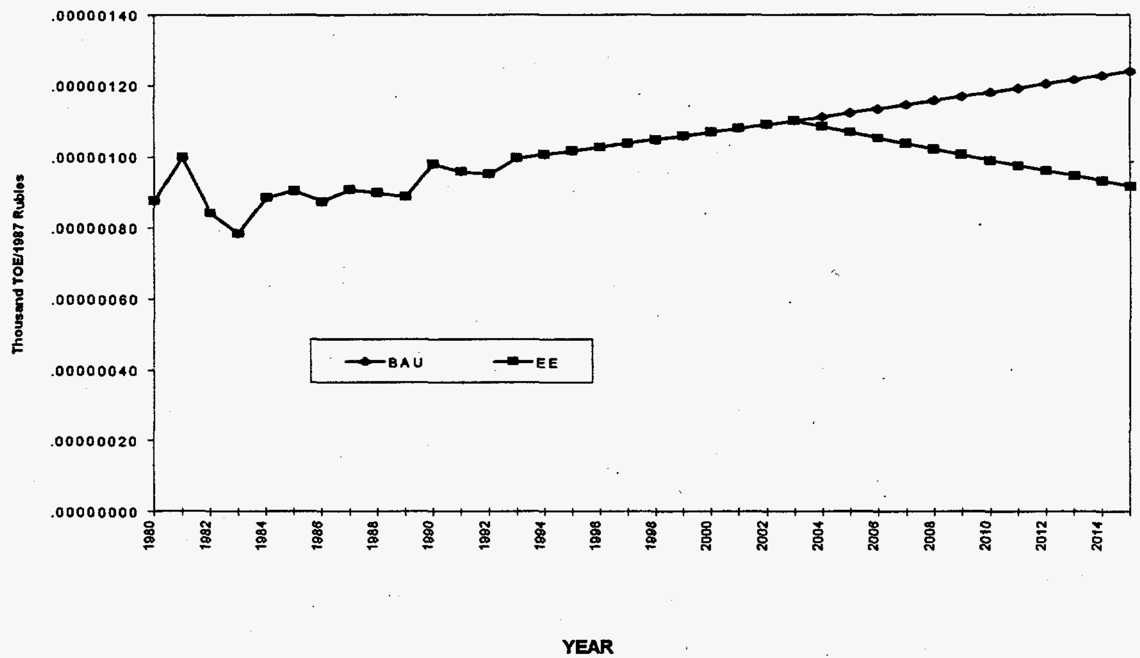

Figure 3.8. BAU and EE Projections for FSU-CEE Agricultural Sector Energy Intensity to 2015

Transformation

Electricity grids in the FSU-CEE are old and poorly maintained, as are Russia's petroleum refineries. Indifference to cost has further contributed to inefficiency. In addition, enormous distances lie between fuel coal and gas fuel reserves in the east and the major demand centers in the western part of the country. Fuels must thus be shipped over great distances, which means that much energy is lost in route. Limited access to capital also prevents plant managers from investing in state-of-the art technologies that could reduce demand. The challenges to efficiency in this sector are great, but overall, economic reform will probably result in the introduction of new, more energy-efficient technologies similar to those already common in OECD countries, and price increases will keep demand in check.

Electricity demand has fallen recently, owing to the region's declining industrial production. Because of the rapidly expanding housing sector and rising demand for consumer goods, electricity's share of the country's total fuel mix will rise. However, electricity will be increasingly generated from natural gas rather than from coal and oil. Indeed, most future capacity growth will be gas-fired. (At present approximately 41% of electricity is generated using natural gas). Additional energy savings will come from a revised price structure, equipment overhauls, and implementation of equipment standards and demand-side management programs.

BAU Scenario

Under this scenario, TER for the transformation sector in 2015 is 1,487 Mtoe. The TPES/TFC ratio energy improves by 10% between 1975 and 2015. Declines are modest because price adjustments have been slow to materialize. Little money is available for investment in the equipment necessary to make the needed efficiency improvements.

EE Scenario

Under the EE scenario, transformation TER is 938 Mtoe in 2015, representing a 37% improvement over BAU levels. The TPES/TFC ratio improves by 16% (Figure 3.9).

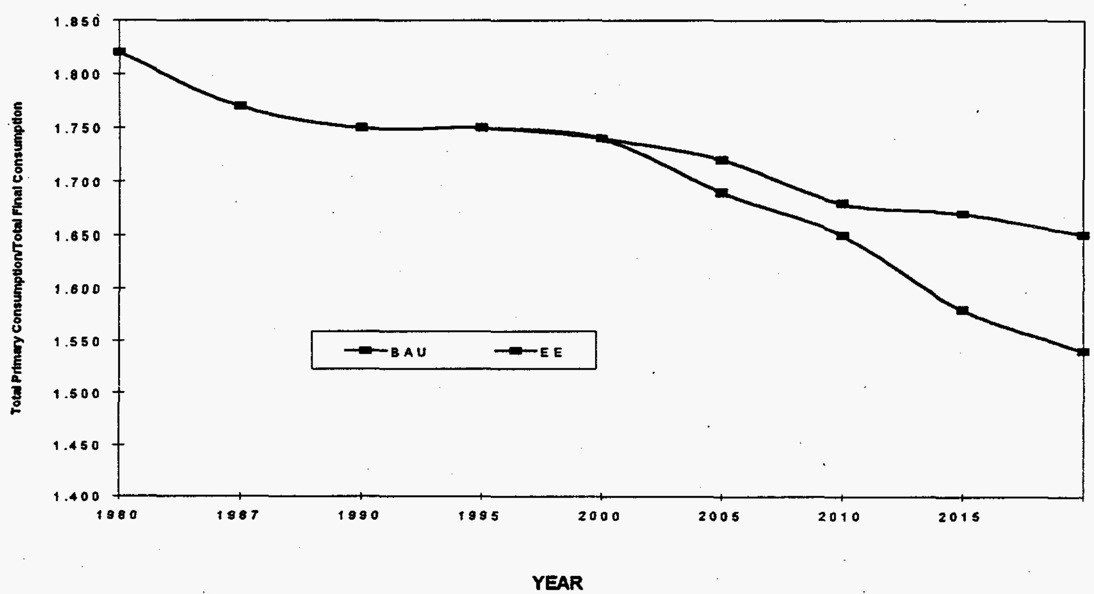

Figure 3.9. BAU and EE Projections for FSU-CEE Transformation Sector Efficiency to 2015

4.0 SOUTH ASIA

South Asia, comprising India, Pakistan, and Bangladesh, accounts for roughly 20% of the world's population, roughly equivalent to China. India, the economic leader of the region, is undergoing a period of transition from one of a strict nationalist policy to decentralization of state control of the economy. It is highly dependent on foreign investment and exports to fuel growth. Yet numerous barriers exist that likely will slow both foreign investment and export growth. The inadequate state of the infrastructure, in particular, will likely slow export growth, and the political uncertainty in India will likely inhibit some foreign investment, as least initially. Nevertheless, India will continue opening up its economy by pursuing policies more attractive to foreign and private investors.

Even during the 1970s and 1980s, when India pursued a strict nationalist policy, the real GDP growth rate maintained a respectable 3% annual average. The services and industrial sectors in South Asia are conservatively projected in this study to grow by at least 5.7% on annual basis to 2015. In 1994, these two sectors accounted for about two-thirds of GDP. It is likely that the region will maintain an average growth of close to 5% over the next two decades. In comparison, population growth is expected to average roughly 1.5% during the period (Figure 4.1). GDP and population growth reflect measures of activity that influence energy consumption.

The growth in GDP in particular, will lead to increases in demand for electricity for the services sector, and for most energy types for the industrial sector. There will also be a heavy reliance on the transportation sector, particularly as goods become more readily traded, resulting in significant increase in the demand for petroleum. Finally, to sustain growth overall, the region will have to invest heavily in new infrastructure, including roads and ports. This type of construction relies heavily on the energy-intensive steel and cement industries, further fueling demand for energy. Thus, even with all the restructuring obstacles to overcome, South Asia will become an important player in world energy markets within the next 20 years.

4.1 Key Findings

Under the BAU scenario, total energy requirements for South Asia are projected to increase from 250 Mtoe in 1993 to 510 Mtoe in 2005. By 2015, total energy requirements are projected to reach 891 Mtoe. It is expected that natural gas will increase its relative share of total energy required as the region continues to develop and exploit its natural gas supplies.

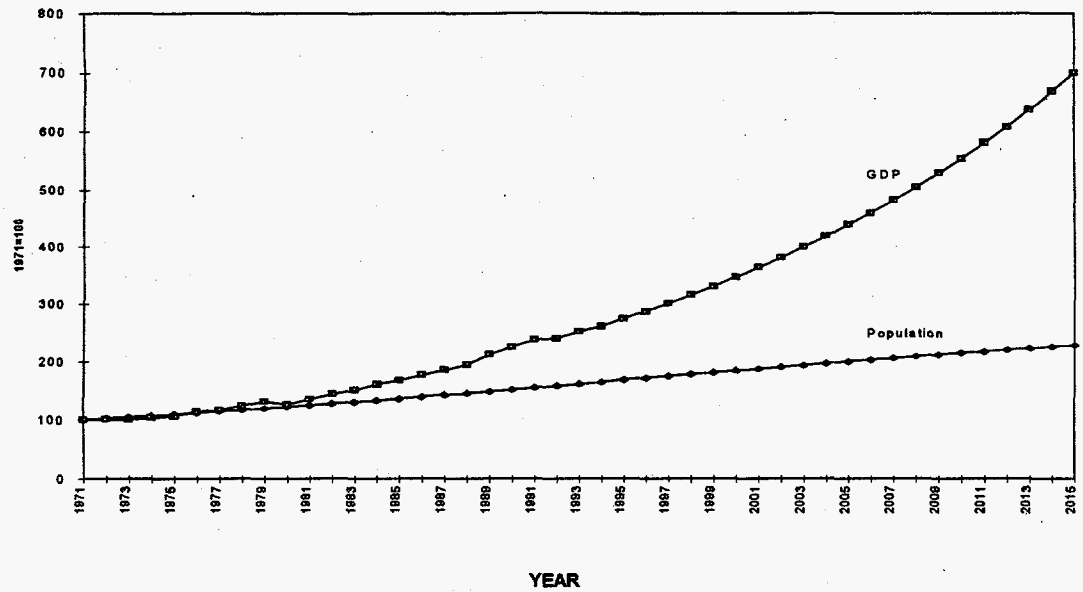

Figure 4.1. South Asia GDP and Population Growth, Projected to 2015

Increases in transportation, as well as the importance of kerosene and other petroleum products in the residential sector, will fuel the demand for petroleum based products. The current dominant fuel type, coal, will begin to reduce its relative share of total energy requirements.

Industry will continue to be the largest final consumer of energy, but its share of total energy requirements will fall. The buildings sector is projected to have the largest percentage increase in growth of all the sectors, reflecting a likely transition from the overwhelming predominance of non-commercial fuels (biomass) to the use of more commercial fuels. The buildings sector will also increase its relative share of total energy requirements from 10% in 1993 to an estimated 16% in 2015.

Under the EE scenario, total energy requirements are projected to be roughly 15% below the BAU level in 2005, and over 25% lower in 2015 (Figure 4.2). Under this scenario, coal and oil would still predominate, but at lower levels than that predicted under the BAU scenario. Nevertheless, the EE scenario assumes that South Asia will make greater use of its more energy efficient natural gas supplies in the transformation and the industrial sectors.

The EE scenario assumes that the transformation sector would make greater use of natural gas, and improve the energy efficiency of existing operations. Transformation would use a relatively smaller share of total energy consumed under the EE scenario than under the BAU scenario. Nearly 45% of the projected energy savings in the EE scenario would come from the transformation sector.

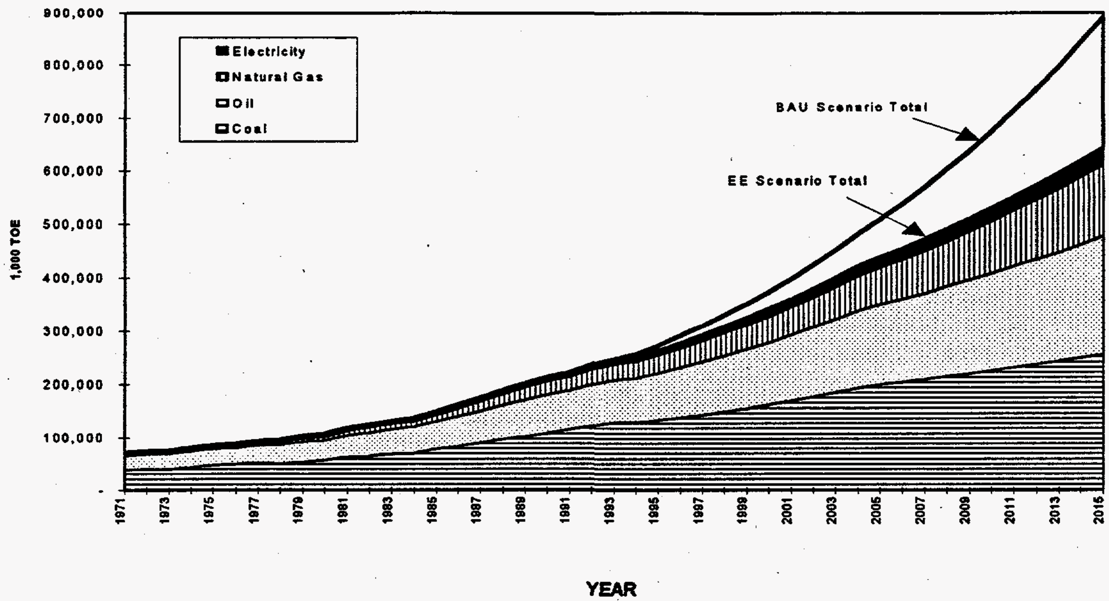

Figure 4.2. Projected Energy Requirements By Fuel Type for South Asia By Sector Under the EE Scenario and by Total Under the BAU Scenario, 1971-2015

While industry will be the dominant final consumer of energy, the transport and buildings sectors will increase their relative share over the period (Figure 4.3). Industry is expected to make modest, non-process modifications to improve energy efficiency, resulting in energy consumption levels in 2015 of roughly 78% of that under the BAU scenario. Greater use of more energy efficient vehicles, and greater use of electricity in the rail sector will result in a roughly 25% energy savings under the EE scenario. Improvements in lighting, increased insulation in building, and more energy efficient appliances would result in roughly a 28% energy savings.

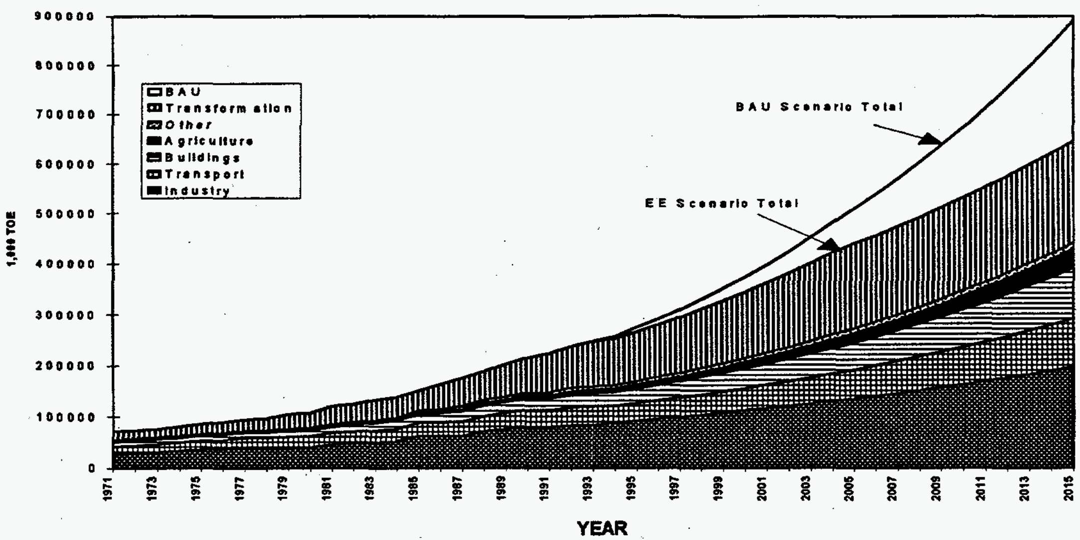

Figure 4.3. Projected Energy Requirements for South Asia By Sector Under the EE Scenario and by Total Under the BAU Scenario, 1971-2015

4.2 Sector Requirements

Industry

Until 1993, the industrial sector has been the largest consumer of energy in South Asia. Industrial growth has been a major driver behind GDP growth in the region between 1971 and 1993. Industrial value added was used as an activity measure for the industrial sector. South Asia's industrial sector is characterized by both heavy and light industry. The energy intensity level of the industrial sector is highly dependent on the structure of the industrial base. Steel and chemicals, for example, are highly energy intensive, whereas, garment manufacturing (sewing) is relatively less energy intensive. India, in particular, has a substantial heavy industry component. In India, three energy-intensive industries (iron and steel, non-metallic minerals, and chemicals) account for 58% of total energy consumption in the industrial sector, with the iron and steel industry alone accounting for 30% (Ishiguro and Akiyama 1995). The energy efficiency of these industries is low compared with industrialized countries.

BAU Scenario

Under the BAU scenario, it is assumed that industrial value added will increase at an average annual rate of 5.7%, a rate comparable to the 1971 to 1994 period. Energy intensity is projected to decrease by 0.8% per year to a level slightly below that of 1971 (Figure 4.4). It is assumed that for the purposes of the BAU scenario, the energy intensity will decrease as India further diversifies its industrial base into more light industry, such as electronics. Also, new industrial construction and plants will be more

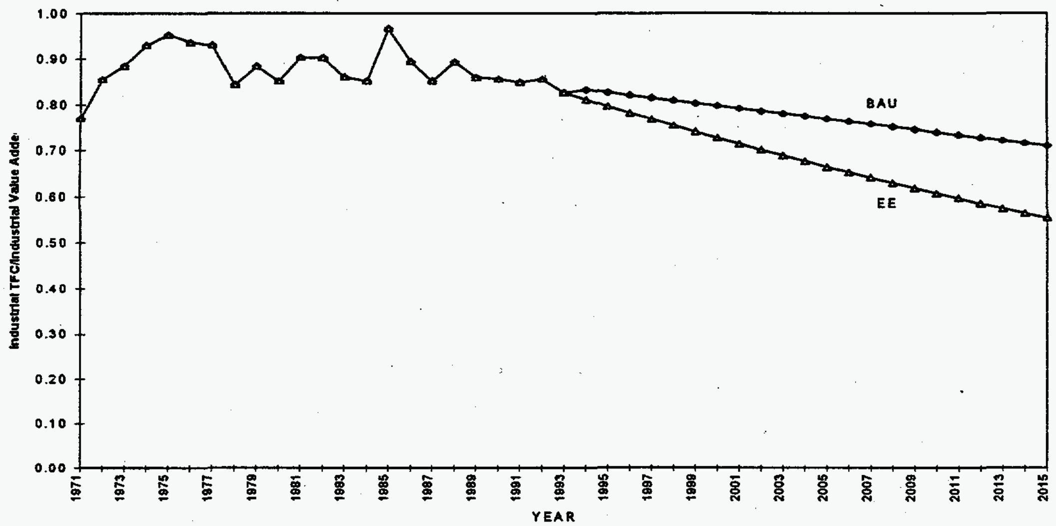

Figure 4.4. Energy Intensity of Industry in South Asia Under the BAU and EE Scenarios

energy efficient than older plants. In addition, it is assumed that industry will have more incentive to improve energy efficiency measures as government subsidies on electricity are removed. Given the projected increase in industrial value added and decrease in energy intensity, the total energy required is projected to increase at an annual average rate of 5% to 254 Mtoe.

EE Scenario

Under the EE scenario, it is assumed that the energy intensity will decrease at 1.8% per year, which equals 60% of the drop achieved in energy intensity (energy consumption per unit of gross output) in China during 1980 to 1990. Roughly 60% to 80% of the energy intensity decline in China was attributed to improvements in energy efficiency (Levine et al. 1995). Under the EE scenario, industry in India would make even larger energy efficiency improvements than under the BAU scenario, including making greater use of natural gas technologies. It is estimated that non-process technologies could improve the energy efficiency of the iron and steel industry by as much as 20% (TERI). Total energy required for the industrial sector is projected to reach 198 Mtoe in 2015, roughly 75% of the level forecast under the BAU scenario.

Transportation

The transportation sector is the third largest energy consumer in South Asia, after the transformation and industrial sectors. The major modes of transportation in India are road and rail. Road has surpassed rail as the major mode of freight transportation, and its share of passenger transportation has increased as well. While the kilometers of roads increased by 75% from 1971 to 1991, the actual density of traffic increased.

In 1971, the transportation sector relied on oil for roughly one-half of its energy requirements. In 1993, 96% of the energy requirements were met by oil. This dramatic shift highlights in part, the increasing importance of road traffic relative to rail. It also reflects a shift in the primary fuel type used for the rail sector from coal to petroleum based products, particularly diesel.

The future of the transportation sector, as well as the industrial sector, will be dependent in part on the success of the Indian Government policies to improve the transportation infrastructure base. India's port facilities are inadequate to handle large volumes of trade that might be expected as a result of opening the economy. Until 1994, container freight traffic was limited almost exclusively to rail shipments in India. The rail system consists of tracks containing multi-gauge widths, limiting long-haul traffic, and the quality of roads is poor, and inadequate to handle the future demands of a growing economy. India has taken numerous steps to open its transportation infrastructure base to foreign and domestic private investment. The government has instituted several initiatives to attract private investment to build and upgrade its highway, railway system, and ports.

Road and rail account for over 90% of energy use in the transport sector. Therefore, the projections for the transportation sector are based on activity levels and energy intensities for road and rail combined. The energy consumption was calculated separately for all freight traffic (road and rail) and all passenger traffic (road and rail).[1]

BAU Scenario

Under the BAU scenario, growth in vehicle passenger and freight traffic is assumed to grow at a slower rate than the 6.8% and 5.5% achieved during the baseline period. Much of the growth in passenger traffic in the baseline period was fueled by construction of new automobile plants in India. This new production met much pent up demand. While it is likely that passenger traffic will continue to increase, it is unlikely that it will be able to maintain the same high levels achieved during the earlier period.

As shown in Figure 4.5, the energy intensity of passenger traffic is projected to increase by 4.3% annually as a result of a shift away from non-motorized modes of

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[1] The data used to calculate the activity and intensity measures for the transportation sector were based on data for India only. This data was extrapolated to estimate energy consumption for freight and passenger traffic for all of South Asia. The activity measure used for freight was "freight ton kilometers (freight t-km) and for passengers was "passenger kilometers." Energy intensity for freight was measured in terms of estimated energy consumption for freight traffic (1,000 TOE) as a share of estimated freight traffic (billion freight t-km.) Similarly, passenger energy intensity was measured in terms of estimated energy consumption for passenger traffic (1,000 TOE) as a share of passenger traffic (billion passenger-km.)

transportation to motorized transportation. On the other hand, the energy intensity of the freight sector is projected to decline at an annual average rate of 1.5%, as coal-powered steam trains continue to be supplanted and converted to diesel engines or electric track systems, and as road transport continues to increase relative to rail. Diesel trucks and trains, and especially rail powered by electricity, are more energy efficient than the old steam trains. Energy requirements for the transportation sector are projected to grow to 128 Mtoe by 2015.

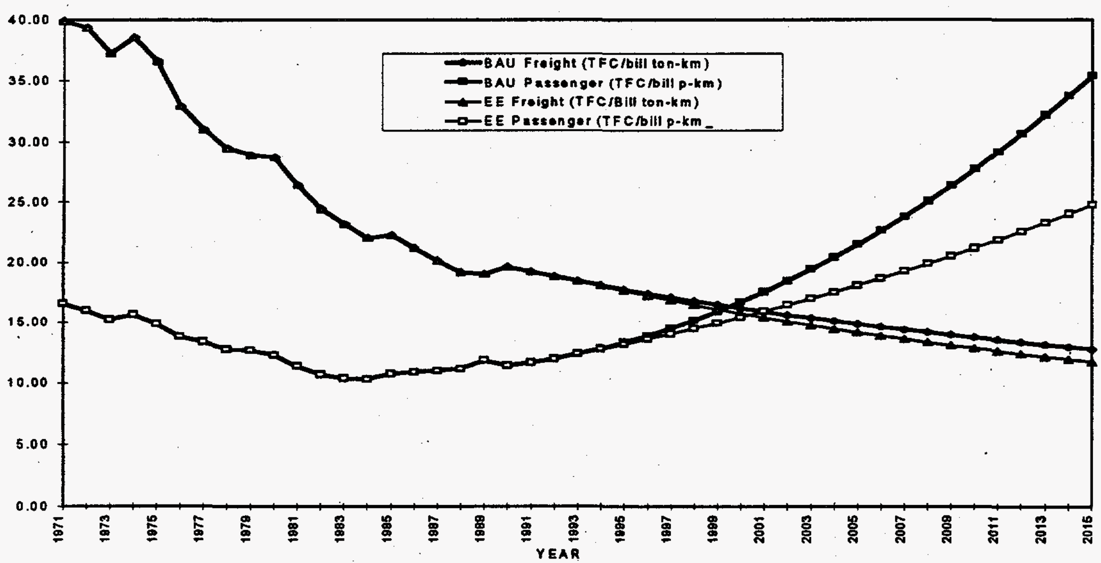

Figure 4.5. Energy Intensity of the Transport Sector in South Asia Under the BAU and EE Scenarios

EE Scenario

For both freight and passenger traffic, it was assumed that gains of at least 25% could be attained if the energy efficiency of the vehicle fleet was improved to a level equivalent to that of Korea or Indonesia. Passenger cars were used as a proxy for the relative level of fuel efficiency of vehicles in India compared with other countries, even though the large share of vehicles in India is comprised of motorcycles. The energy efficiency of a new passenger vehicle in India was roughly 12 to 14 liters/100 kilometers in the early 1990s, compared with an on-road rate of 10/100 kilometers in Indonesia and South Korea in 1985 and 1987, respectively (IEA 1994).

Under the EE scenario, it is assumed that the energy intensity of freight will decrease at a rate of 25% greater than current rates, and that the energy intensity level of passenger traffic will increase at a rate 25% less than is projected under the BAU scenario. It is assumed that the energy intensity of freight traffic under the EE scenario will remain at BAU levels until 1996, and then decrease at average annual rate of 1.9% annually during 1996- 2015. The affect of improving the energy intensity ratios of passenger and freight traffic will result in EE projected energy consumption of roughly 81 Mtoe, two-thirds the level of that under the BAU scenario.

Buildings

The buildings sector is comprised of the residential and commercial subsectors. The building sector accounted for 16% of total commercial energy consumed in South Asia in 1993. Virtually all the energy consumption in the building sector is residential energy consumption. It is likely that much of the small shops in the commercial sector are actually counted as part of the residential sector.

If biomass is included, residential energy demand accounted for roughly 40% of total energy consumed in South Asia 1993. South Asia relies heavily on biomass as its source of energy for the residential sector. In India, only one-third of residences have electricity (World Resources 1995).

Cooking and water heating account for the bulk of rural energy household use. Biomass is the primary energy source used for cooking. Kerosene is the major source of energy used for lighting. Kerosene is also used in cooking. In residences that have electricity, electricity is primarily used for lighting and appliances, such as refrigerators.

As electrification increases and household incomes rise, enabling people to purchase appliances, it is likely that the demand for electricity and other commercial energy sources will increase significantly. For cooking, other forms of fuel, such as natural gas, kerosene, or other forms of oil, will likely replace biomass as the fuel of choice.

Similarly, as opportunities for expanding the commercial sector increase, it is likely that commercial energy demand will increase significantly. Air conditioning systems and lighting will likely be the largest energy consumers. Office equipment, such as computers and printers, will also increase the demand for commercial energy.

The projections for the buildings sector were estimated by projecting the residential sector and the commercial sector separately, then adding them together. The activity measure used for the residential sector was number of households and for the commercial sector, it was services value added (1987$/millions).[2]

[2] The energy intensity measure used for the residential sector was residential energy consumption (TOE) divided by the number of households. For the commercial sector, the energy intensity used was commercial energy consumption (1,000 TOE) divided by services valued added (1987$ millions.)

BAU Scenario

It is expected that the number of households will increase at an average annual rate of just over 1.3%, reflecting a slower projected population growth than achieved during the 1970s and 1980s.[3] The energy intensity rate for the residential sector is projected to increase at a slightly higher rate than that of 1981-1993 (Figure 4.6).

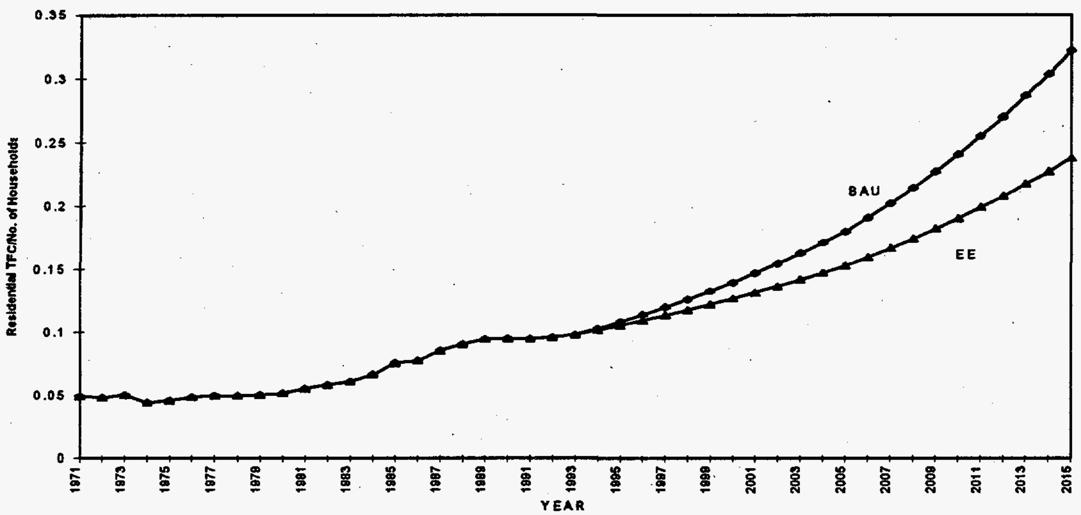

Figure 4.6. Energy Intensity of the Residential Sub-Sector in South Asia Under the BAU and EE Scenarios

Services valued added is projected to grow at a comparable rate to the 1981 to 1994 period. The energy intensity ratio for the commercial sector (Figure 4.7) is projected to increase at the same rate as that for the residential sector, though it could realistically increase at an even greater rate. The energy intensity ratio for both the residential and commercial sectors is assumed to increase at such a high rate largely because of a switch from non-commercial to commercial fuels. As incomes rise and the population shifts from rural to urban, the demand for commercial fuels will increase in both the residential and commercial sectors. Energy consumption in the buildings sector is estimated to increase to 140 Mtoe overall, with the residential sector accounting for roughly three quarters of the total energy requirements.

[3] The World Bank projects population to grow at an average annual rate of 1.3% during 1993-2015 (World Bank 1995).

EE Scenario

Under the EE scenario, it is assumed that new building construction in both the residential and commercial sector would incorporate more energy efficient lighting, and commercial building construction would take advantage of energy saving insulation and energy efficient air conditioning systems. In addition, it is assumed that new purchases of appliances, such as refrigerators, would be more energy efficient than the older models currently in use.

For the purposes of the energy efficiency scenario, it assumed that annual average growth in energy consumption for both the residential and commercial sectors would grow at 20% less than that under the BAU scenario. Under the EE scenario, energy consumption overall for buildings would increase to 99 Mtoe, roughly 70% of the BAU level.

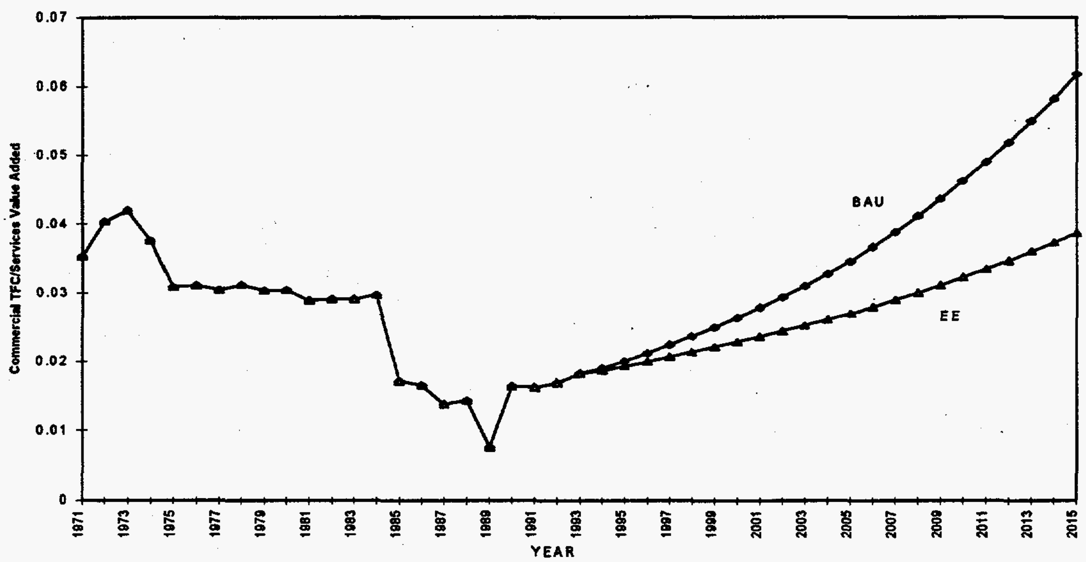

Figure 4.7. **Energy Intensity of the Commercial Sub-Sector in South Asia Under the BAU and EE Scenarios**

Agriculture

Approximately 60% of India's economically active population is engaged in agricultural production, compared with 71% for Bangladesh and 51% for Pakistan. This compares with 28% for South Korea, and 3% for the United States (TERI 1992). Agriculture's share of GDP in South Asia was 26% in 1994, down from 40% in 1970.

Only one-third of India's cultivated land is irrigated. The pumps used for irrigation are generally either electric, diesel, or animal-powered. The number of electric pumps in use in India more than doubled from 1980 to 1990 (TERI 1992). Electricity tariffs for agricultural pumping have been historically low, and have contributed to huge losses for the state electricity boards (World Resources 1995). The average crop yield for irrigated land is generally below its potential, in part because of poor water management, and the inexperience of farmers switching from rain-fed to irrigated agriculture (World Resources 1995). The other major source of energy use in the agricultural area is for land preparation and harvesting equipment. Diesel is the major fuel source of mechanized farm equipment (TERI 1992).

BAU Scenario

The energy intensity of agriculture is assumed to grow at an annual average rate of 5.1%, reflecting the increasing use of energy for irrigation and tractors (Figure 4.8). It is likely that this region will expand its use of energy as it strives to increase its agricultural output. Crop yields in India, though up substantially in real terms from 1971, are still below that of China in terms of yields per hectare (World Resources

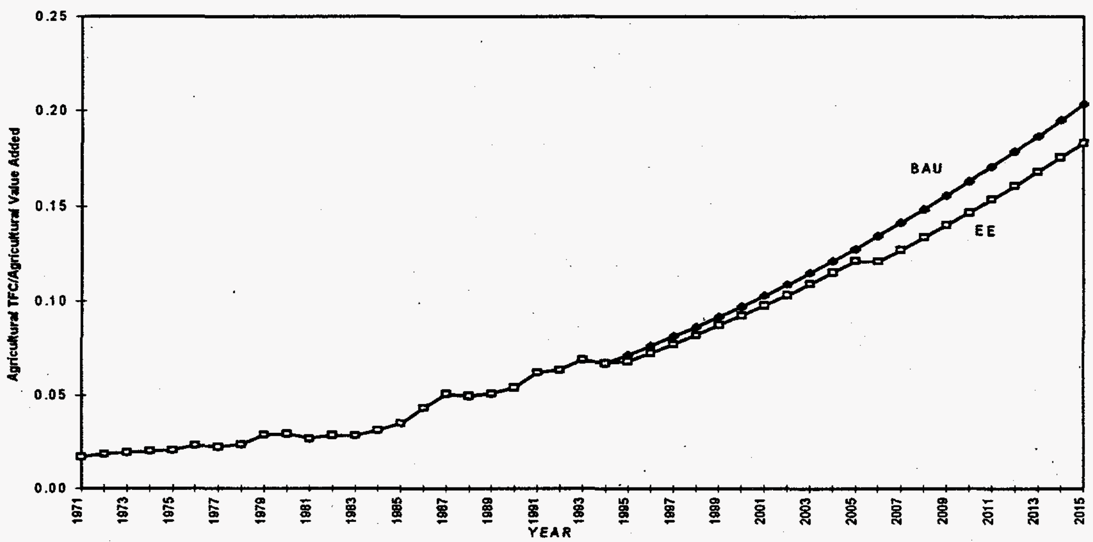

Figure 4.8. Energy Intensity of the Agricultural Sector in South Asia Under the BAU and EE Scenarios

1994). Agricultural value added, the activity measure used for this sector, is projected to grow at 3.2%, slightly above the 3.0% annual rate achieved during 1981 to 1994. Energy consumption is predicted to grow by an annual average rate of 8.4% to 44 Mtoe, compared with an annual rate of 10.7% during 1981 to 1993.

EE Scenario

Under the EE scenario, it is assumed that the energy intensity in agriculture will increase, but at 5% less per year than under the BAU scenario for the first 10 years, and by 10% less during the second 10 years. It is assumed under the EE scenario that better water management practices will be implemented, thereby requiring the use of less water and less energy to run pumps to obtain water. Under this scenario, it is assumed that new pumps will use more energy efficient motors than those currently in place. It is likely that widespread efficient water management practices would take a number of years to implement, hence the step change in the relative energy intensity for the first 10 and last 10 years predicted. Energy consumption is predicted to grow to 39 Mtoe by 2015, 88% of the level projected under the BAU scenario.

Transformation

The generation and distribution of electricity accounts for roughly 90% of the total net energy use for transformation sector. Oil refining also accounts for a significant share of primary energy consumption, but actual energy used in the transformation of oil to refined petroleum products is relatively small compared with the generation and transmission of electricity.

South Asia's electricity generation is highly inefficient. The energy efficiency of this sector (total electricity generated divided by total energy consumed for electricity generation and transmission) decreased from 40% in 1971 to 34% in 1993. The transmission of energy is also very inefficient. In 1993, distribution losses equaled 17% of total electricity generated.

The energy intensity of this sector increased during the 1970s and 1980s, reflecting a shift to greater use of coal-generated power, compared with much more energy efficient hydroelectric power. In 1993, hydroelectric power had an efficiency of close to 100% (based on energy generated as a share of energy consumed,) compared with efficiencies of 27% for coal, 33% for oil, and 40% for natural gas.[4]

In an effort to increase badly needed capacity, the government opened the electricity sector up to private investment in 1992. Since then, the government has offered tax holidays for new projects, as well as a guaranteed rate of return on investments. In addition, in 1994, the Indian Government ended the extensive subsidies to electricity sales. A number of foreign investors are examining or have agreed to major new power projects in India. Nevertheless, the electricity sector is still governed by numerous

[4] Based on IEA energy consumption for electricity generation and electricity generation data for South Asia.

central and state government regulations, creating numerous hurdles for foreign investors.

Like the electricity sector, India is seeking new investment to expand the capacity of its refining sector. Numerous new projects and expansions of existing refineries have been approved by the government, which could expand the refining capacity in India by over 60% to nearly 1.7 million b/d. The Indian government is also in the process of privatizing existing government-owned refineries. It is likely that the refining capacity will continue to increase to try to keep pace with the fast growing transportation sector and to reduce or minimize the country's reliance on imports.

BAU Scenario

Energy intensity in the transformation sector is assumed to increase until 2004, based on the assumption that India will continue to exploit its large coal reserves (Figure 4.9). It is expected that the share of coal-based power will continue to increase, while the relative share of hydroelectric power will decrease. Starting in 2005, it is expected that energy intensity will begin to decline, as natural gas begins to play a larger role in the electricity sector. One new major power project that was recently approved, for example, will use coal in the initial years of start-up, and when the natural gas infrastructure is in place, will switch to natural gas. Energy consumption is expected to jump to 195 Mtoe in 2005 and 313 Mtoe in 2015.

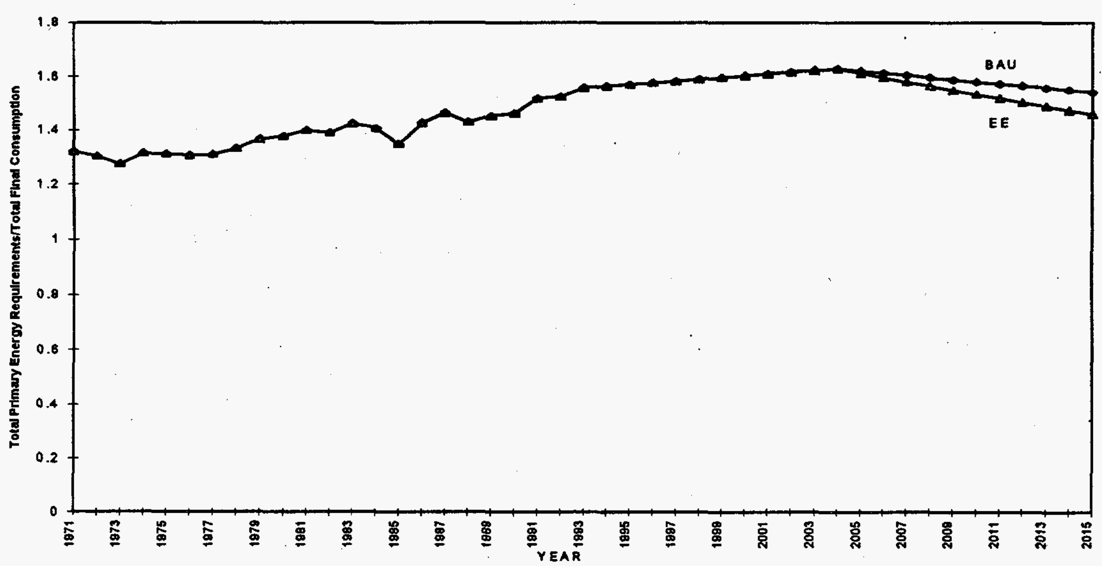

Figure 4.9. Energy Intensity of the Transformation Sector in South Asia Under the BAU and EE Scenarios

EE Scenario

Under the EE scenario, it is assumed that hydroelectric plants will increase capacity, either through modernization or new plants. The increase in hydroelectric capacity would likely not exceed the growth in coal-based electricity generation, but might at least in the long run be expected to maintain its current share. Natural gas-based power generation could be expected to increase its relative share of electricity generation. It is unlikely that this would be significant for at least 10 years, until India has had time to improve its natural gas pipeline infrastructure.

Finally, it is assumed much of the new power generation will be based on private investment and will be operate at higher efficiency levels than is currently the norm. Efficiencies for the coal sector, for example, could be expected to increase from its current level of 27% to about 30% or more. Similarly; as India continues to dismantle subsidies for electricity, power plants might have more incentives to improve their levels of efficiency.

Thus, for the EE scenario, it is assumed that the energy intensity levels will continue to increase at the same rate as the BAU scenario until 2004, allowing time for new power plants to be built and existing plants to be refurbished. During this interim period, it is expected that coal will continue to increase its relative share of power generation, resulting in higher energy intensities overall. From 2005 to 2015, it is assumed new higher energy efficiency plants will start coming on line, resulting in a decrease in the energy intensity levels, back to a rate close to that in 1990. Energy consumption is predicted to increase to 203 Mtoe in 2015, roughly 35% less than the level predicted under the BAU scenario.

5.0 LATIN AMERICA

Overall economic changes during the past 25 years in Latin America have been the result of large fluctuations in economic activity, political reforms, investment, debt generation, and debt restructuring and productivity. During the 1970s GDP grew at an annual average rate of 5.7% (Inter-American Development Bank 1993). A substantial contribution to total regional development during this period was made by Brazil and Mexico, whose GDP grew at an annual average rate of 8.6% and 6.4%, respectively.

In the decade of the 1980s, all gains previously experienced eroded at a fast pace. The region suffered a major blow with high levels of inflation and negative or low growth rates in GDP for most countries. Inflationary pressures and lack of confidence in regional economic performance resulted in an annual average GDP growth rate of only 1.2%. At the same time, regional population continued to grow at an annual average of 2.1% following a 2.4% growth in the previous 10 years, resulting in a continuation of rural-urban migration and its respective pressure on all public services.

Political instability accompanied by nationalization of key industries and limitations on foreign ownership rights created an environment of capital flight and a sharp decline on domestic and foreign investment in the region. Annual average growth of domestic investment went from 7.2% in the 1970s to -3.2% in the 1980s.

The 1980s are often referred to as the lost decade. But in another sense, this decade laid the groundwork for the turn around of the region that started at in the 1990s. By the middle of the 1980s, there was regional acceptance of the need for change in political systems and in macro and micro economic policies. Most countries in the region embraced the recommendations of the major international financial institutions to undertake structural change. This required refocusing of government expenditures, free elections, privatization of key sectors in each country including the financial and energy sectors, and changes in the laws associated with foreign investment and ownership. This was considered necessary to restore confidence in the region and attract foreign private investors.

These changes laid the foundation for the healthy economic growth experienced in the 1990s. Regional GDP from 1990 to 1993 grew at an annual average rate of 3.3%. To date, overall consumption increased on average by 4.2% and domestic investment increased by 9.2%. One of the policies that has fueled regional growth is the elimination of restrictions associated with capital movements. This resulted in a capital injection to the region of US $60 billion in 1992. This was three times as large as the capital inflows received in 1990. These investments have largely gone to the modernization of the industrial sector and the privatization of financial and energy sectors, which in turn resulted in faster growth in energy demand.

Total energy consumption in Latin America region steadily increased at an annual average rare of 4.7% from 304 Mtoe in 1970 to 878 Mtoe in 1993. Total energy use was greatest during the 1970s when high levels of government and private expenditures fueled economic growth. Energy use increased at an annual average rate of 6.9%. The following decade, energy use slowed down to an average of 2.8%.

Recent fast growth in regional investment has resulted in demand expansion, surges in imports, higher real wages, increases in energy use, and a deficit in the balance of payments. Since 1987, total energy use has outpaced both population and GDP growth. The change in this relationship from the previous decade is partly the effect of increased investment which has spurred increases in intra-regional trade as well as increases in the demand for durable goods. GDP is expected to grow at an annual average rate of 2.5% from 1995 to 2015 (Figure 5.1).

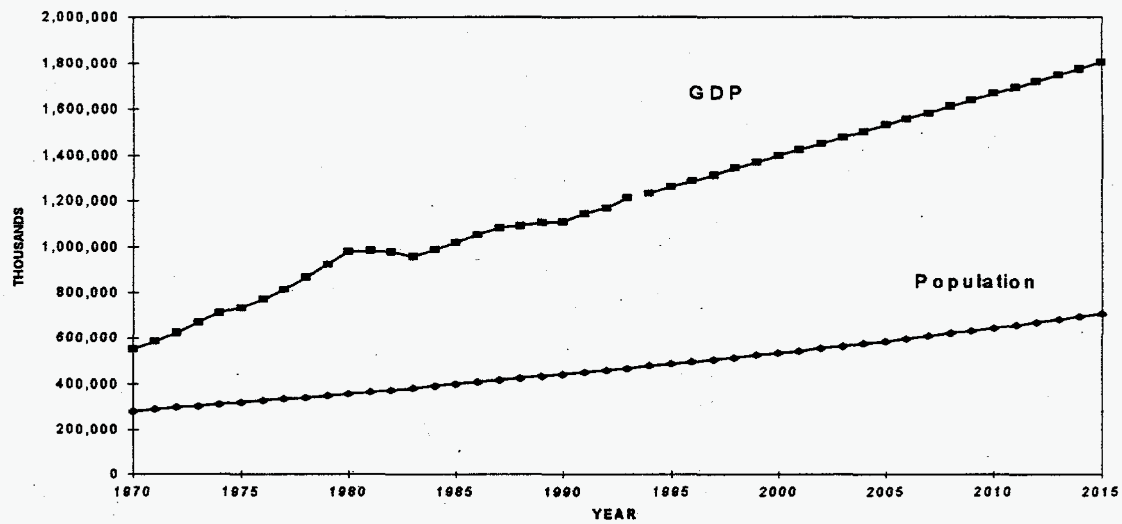

Figure 5.1. Latin America GDP and Population Growth, Projected to 2015

5.1 KEY FINDINGS

The Latin America region is expected to continue down the path of economic expansion experienced since 1990. Under the assumption of continued market liberalization, intra-regional trade agreements, and macro-economic and fiscal reforms, increased real wages and trade are the most likely outcomes. On the other hand, sustainable economic growth for the next 20 years will have to be accompanied by major reforms and investments in all sectors of the economy. Investment requirements for the power sector are estimated at US $19 billion, which is likely unachievable. So, in order to provide the region with the required energy for continued economic growth, creative and alternative financing for power generation is necessary.

Under the BAU scenario, total final energy requirements to generate projected value of output is estimated at 1,196 Mtoe by 2000 and 1,792 Mtoe by 2015. Under EE scenario, total final energy requirements are reduced to 1,069 Mtoe by 2000 and 1,423 Mtoe by 2015.

Total final energy requirements by major sectors of the economy is expected to continue growing as overall investment increases, real wages rise, and demand for goods and services remains strong. Figure 5.2 shows energy requirements by sector under EE scenario, with the BAU additional requirements shown above the EE scenario. The EE scenario represents an overall reduction in requirements of around 6.5%.

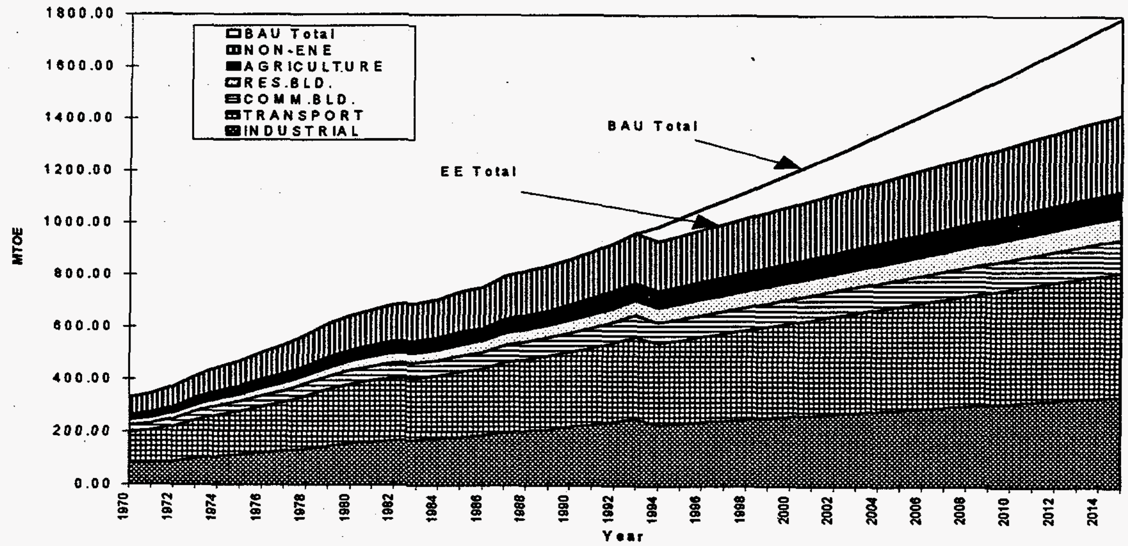

Figure 5.2. Total Final Projected Energy Requirements for Latin America By Sector

Energy intensity under the BAU and EE scenarios is not expected to experience major reductions in the next 20 years. The existent infrastructure in all sectors of the economy will unlikely introduce energy efficient equipment unless the real cost of energy reaches the end user through electricity rates that are closer to market value. Figure 5.3 shows total final energy requirements by fuel type under the EE scenario, with the BAU total on top.

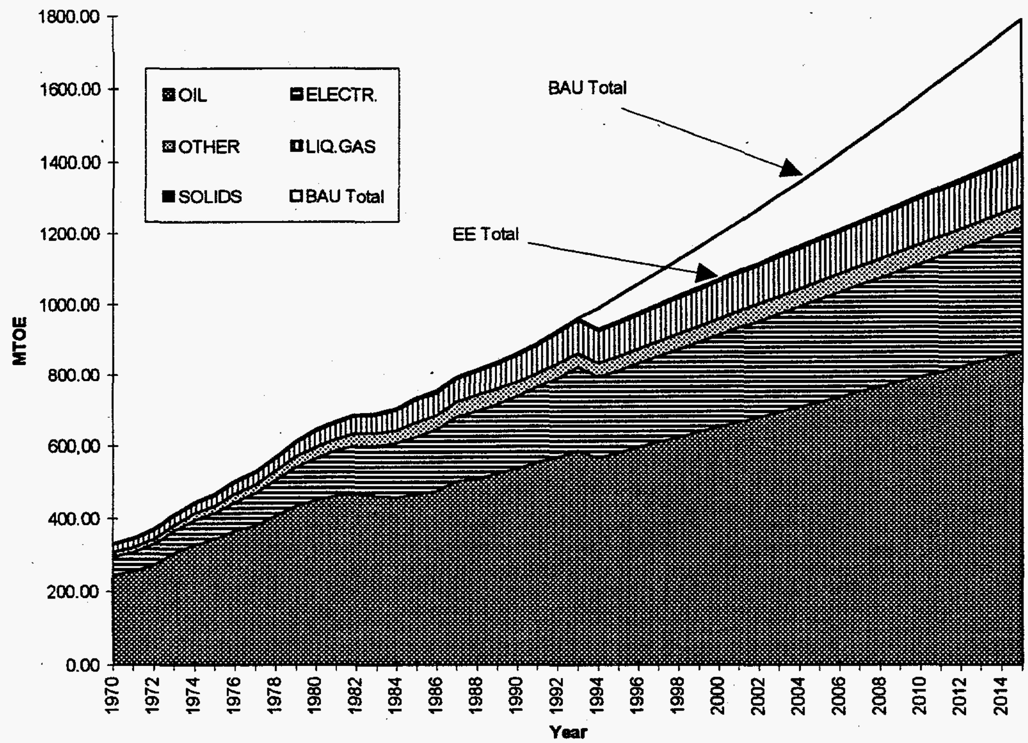

Figure 5.3. Projected Energy Requirements for Latin America by Fuel Type Under the EE Scenario and by Total Under the BAU Scenario

5.2 Sector Requirements

Industry

Total primary energy use in the industrial sector grew from 20 Mtoe in 1970 to 30 Mtoe in 1993. At the same time, total final energy delivered to the industrial sector grew from 81 Mtoe to 254 Mtoe. The average annual growth in the three decades reflected the cycles experienced in inflation and investments. The average annual rate of increase in the 1970 to 1993 period has remained substantial at 5.1%.

While energy intensity in this sector has increased throughout the period, its rate of change moved in the opposite direction of sectoral GDP. When industrial GDP was growing substantially in the 1970s and investments were flowing into the region, sectoral intensity maintained an annual average growth of 1.7%. During the 1980s overall economic slow down, lack of investment and nationalization of key industries created the environment for inefficiencies in the market place and inefficiencies in production. This inefficiency meant annual average increases in energy intensity of 3.4%. Throughout the period of analysis, intensity growth has averaged 2.3%. This has resulted in an increase from 281 Mtoe/US $1 million total regional GDP in 1970 to 481 Mtoe/ US $1 million total regional GDP in 1993.

Since 1970, the industrial sector has steadily increased the use of electricity relative to fuel oil and kerosene. Electricity share has gone from 27% of total final energy use in 1970 to 46% in 1993. At the same time, industrial use of liquid gas has increased its share from 12% of total to 18%. Total final energy used in this sector increased from 54 Mtoe in 1970 to 169 Mtoe in 1993.

BAU Scenario

Consistent with the study methodology, future energy requirements in the region are projected based on both GDP and energy intensity. Future energy intensity for all scenarios were estimated by projecting past trends into the future for the 1994 to 2015 period. Under the BAU scenario, industrial intensity was estimated to grow at an average annual rate of 1.7%. Given the large inflow of private investment to the industrial sector of the region, it is very likely that industrial intensity will continue to increase in the near and mid term. Under the BAU scenario, projected intensity implies that in 2015, 1,015 Mtoe will be necessary to generate US $1 million in real industrial output. Figure 5.4 illustrates the projected path of industrial intensity from 1994 to 2015, under both the BAU and EE scenarios.

Under the BAU scenario energy required by the industrial sector in the year 2000 is estimated at 314 Mtoe, at 426 Mtoe in 2010, and at 489 Mtoe in 2015.

EE Scenario

Industrial energy intensity was estimated to grow at an average annual rate of 0.5% under the EE scenario, less than one-half the rate of growth under the BAU scenario. Some slow down in intensity would be obtained by introducing energy efficient production process into the existent regional industrial infrastructure. This would most likely happen as a result of increasing environmental regulations and the rise of electricity prices as the privatization of the energy sector occurs.

Under the EE scenario the annual average growth rate in projected energy required decreases to 1.9%, compared with 3.1% under the BAU scenario. This implies that the industrial sector, with greater use of energy efficient technologies and guided by energy efficiency policies, could achieve a reduction in requirements to generate the same level of output. It is projected that requirements could be reduced to 264 Mtoe in 2000, 318 Mtoe in 2010, and to 345 Mtoe in 2015.

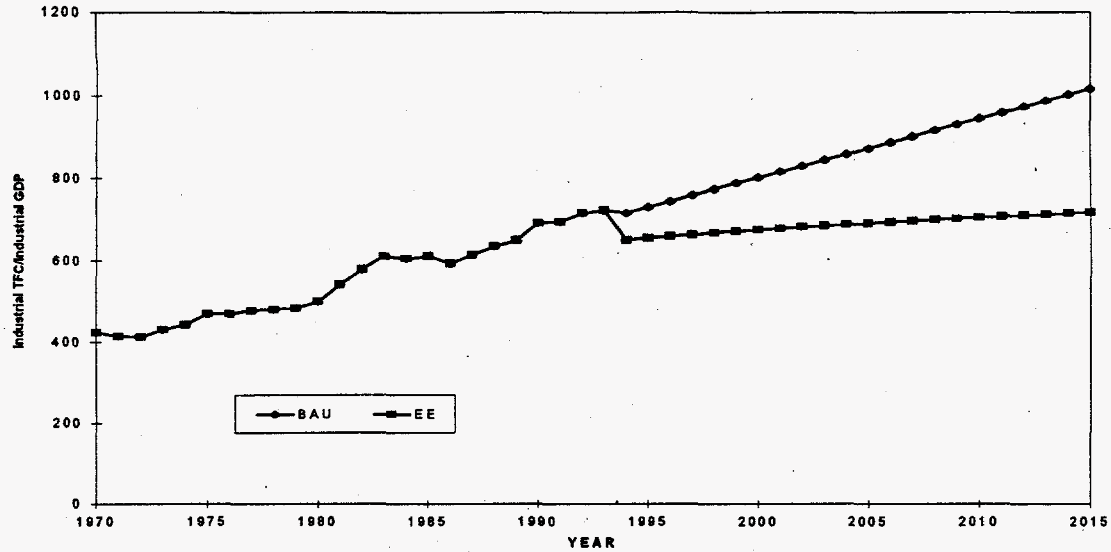

Figure 5.4. Latin America Projected Industrial Energy Intensity

Transportation

The transportation sector in the region has also experienced some structural changes in the past 25 years. Rural-urban migration has increased demand for business and public services in urban centers. The continued growth in total population in the urban centers has and will require more city public transportation, as well as rural-urban transportation. Almost all of the transportation development in the region has been by road. Even in the countries where the railroad was once part of the passenger and freight transportation, investments in the rail infrastructure has been replaced with highways and its respective truck and bus systems.

Total final energy use by the transportation sector since 1970 has almost tripled from 115 Mtoe to 312 Mtoe. The differences in annual rates of growth in final energy use in the three decades are evident of the cycles experienced in inflation, trade, and investments. While this sector's consumption of final energy grew at an average 6.9% in the 1970s, the following decade its average consumption slowed down to 2.3%. However, its average annual rate of consumption increases in the 1970 to 1993 period remained strong at 4.4%. The overall use of oil increased from 81 Mtoe in 1970 to 173 Mtoe in 1993. Here, oil includes gasoline, kerosene, diesel oil, and fuel oil. In 1993 this represented 56% of total final energy used by the sector, compared with 73% in 1970. Overall use of electricity has increased significantly from 17 Mtoe to 76 Mtoe in the 1970 to 1993 period. The share of electricity use in this sector went from 14% to 24% of total.

Energy intensity in this sector has moved parallel to total GDP. Throughout the period of analysis, energy intensity increased on average 0.9% annually, with more recent slower growth showing some evidence of technology improvements in fuel efficiency in vehicles. Over the entire period, energy intensity increased from 236 Mtoe/US $1 million total regional GDP in 1970 to 292 Mtoe/US $1 million total regional GDP in 1993.

BAU Scenario

Under the BAU scenario, transportation intensity was estimated to grow at an average annual rate of 0.7%. Given the large inflow of private investment to the region and its impacts on trade, it is very likely that transportation intensity will continue to increase in the near and mid future, even though it will slow down its rate of growth compared to the 1980s. Under this scenario, projected intensity implies that, in 2015, 344 Mtoe will be necessary to generate US $1 million total GDP. Figure 5.5 illustrates the transportation intensity from 1994 to 2015 under both the BAU and EE scenarios.

Under the BAU scenario, projected energy required by the transportation sector in the year 2000 is estimated at 381 Mtoe, at 491 Mtoe in 2010, and at 550 Mtoe in 2015.

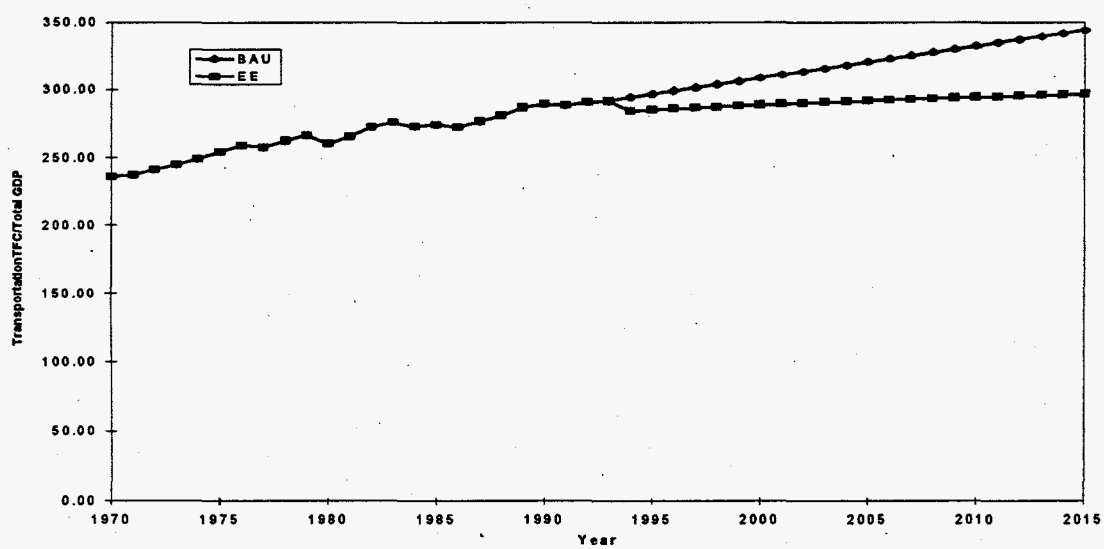

Figure 5.5. Latin America Projected Transportation Energy Intensity

EE Scenario

Under the EE scenario, transportation intensity was estimated to grow at an average annual rate 0.2%, compared with 2.6% under the BAU scenario. Energy intensity is projected to grow to 297 Mtoe/US $1 million total regional GDP. Lower energy intensities could be obtained through improvements in roads and highways and the continued path of increasing fuel efficiency in vehicles. Some incentives will be created as trade liberalization brings more competition into the region and more efficient ways of providing the service become necessary.

Under the EE scenario, the annual average growth rate in projected energy required decreases to 2%. This implies that the transportation sector under energy efficiency policies, such as fuel efficient vehicles and improved highways and roads, could achieve a reduction in requirements, down to 357 Mtoe in 2000, 434 Mtoe in 2010, and 473 Mtoe in 2015.

Buildings (Residential and Commercial)

Residential

The residential sector of the region has experienced a structural change in terms of 1) growth in housing demand and its respective electricity use and 2) people per household. As the rural-urban migration took place, demand for housing in urban centers increased and so did their demand for public services. The continued growth in total population and the decline in the number of people per household has also maintained the steady growth in energy use.

Total final energy delivered to the residential sector almost tripled from 19 Mtoe to 55 Mtoe. The average annual growth rate during the 1970 to 1993 period overall remained strong at 4.8%.

The use of electricity and liquid gas in this sector increased continuously, while the use of kerosene has dropped dramatically. Of the total final energy used in the household in 1970, 28% was electricity, 35% was liquid gas, and 27% was kerosene. By 1993, the share of kerosene had dropped to 6% of the total, while electricity and liquid gas had increased to 41% and 48%, respectively.

Throughout the period of analysis, growth in energy intensity remained relatively stable (1.5%). The increases reflected changes in household activities and increases in the use of electrical appliances. This has resulted in an increase from 0.33 Mtoe per household in 1970 to 0.47 Mtoe per household in 1993.

To estimate future energy requirements to meet the projected increase in residential energy consumption, per-household energy intensity for the next 21 years was estimated.

BAU Scenario: Under the BAU scenario, residential intensity was estimated to grow at an average annual rate of 1.2%. Given the large inflow of private investment to the region and its impacts on wages and employment, it is very likely that household intensity will continue to increase in the near and mid term. As per capita income increases, so does the number appliances that use electricity as a source of energy for operation. Projected intensity implies that, in 2015, 0.68 Mtoe will be necessary to satisfy the annual demand of the average household. Under the EE scenario, energy intensity is projected to grow to 0.49 Mtoe. Figure 5.6 illustrates the projected path of household energy use from 1994 to 2015 for both the BAU and EE scenarios.

Under the BAU scenario, energy required by the residential sector in the year 2000 is estimated at 77 Mtoe, 103 Mtoe in 2010, and 120 Mtoe in 2015.

EE Scenario: Under the EE scenario, residential intensity was estimated to grow at an average annual rate of 0.4%, one-third the rate of growth under the BAU scenario. Some slow down in the intensity may be obtained by introducing energy efficient appliances and building insulation in future housing. It is assumed that demand-side management programs will be implemented in response to rapid increases in energy demand and electricity rates. These type of programs will be better received by the public as electricity rates increase. Rates will likely increase in response to environmental regulations and restructuring and privatization of the power sector.

Under the EE scenario, the annual average growth rate in projected energy required decreases to 2.1%, compared with 3% under the BAU scenario. This implies that the energy requirements for the residential sector could be reduced through energy efficiency policies such as demand-side management to 63 Mtoe in 2000, 78 Mtoe in 2010, and 86 Mtoe in 2015.

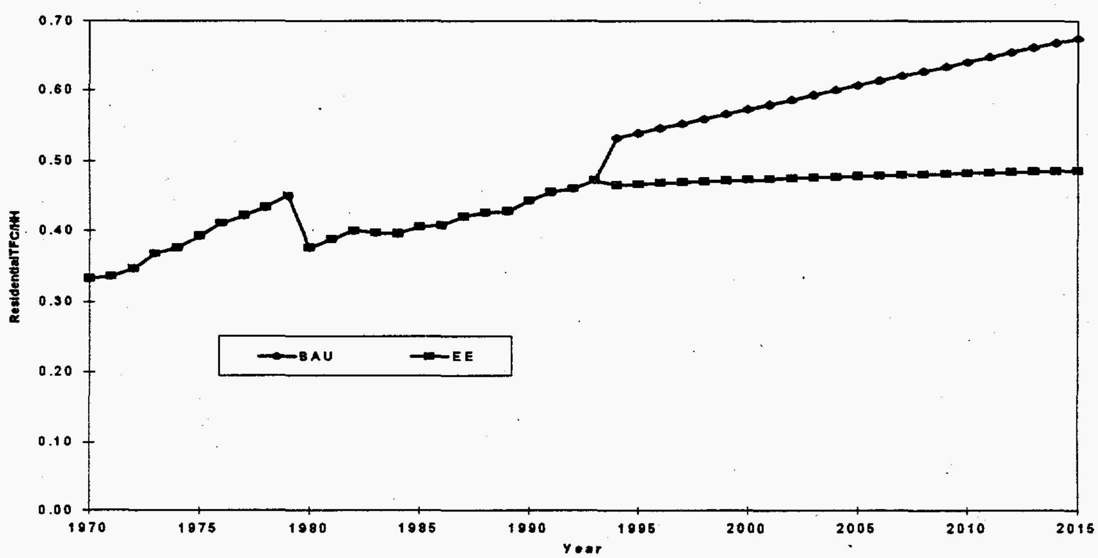

Figure 5.6. Latin America Projected Residential Energy Intensity

Commercial

The commercial sector of the region has experienced a structural change in terms of growth in the services industry and its respective demand in electricity use. As the rural-urban migration took place, demand for business services in urban centers increased and so did their demand for public services. The continued growth in total population in the urban centers increased the need for more retail centers, financial centers, and food services. The introduction of modern buildings with the need for controlled environmental systems and lighting added to the energy needs of the sector. The construction of tall buildings requires elevator systems for internal mobility adding to the overall use of energy. As the computer age has moved into the work place at a fast pace, additional energy requirements have been added to daily operations.

Total final energy delivered to the commercial sector tripled from 27 million Mtoe to 84 Mtoe. The differences in annual rates of growth in final energy use in the three decades illustrate the cycles experienced in inflation and investments. Overall, the average annual rate of growth in consumption during the 1970 to 1993 period remained strong at 5.1%.

Energy intensity in this sector has moved parallel to total GDP. Throughout the period of analysis, intensity growth has been low (1.7%) showing the evidence of technology improvements in the construction of buildings and the use of more efficient ventilation equipment. This has resulted in a small increase in intensity from 111 Mtoe/US $1 million total regional services GDP in 1970 to 137 Mtoe/US $1 million total regional services GDP in 1993.

BAU Scenario: Future energy intensity under all scenarios for the commercial sector were estimated by projecting likely trends from 1994 to 2015. Under the BAU scenario, commercial intensity was estimated to grow at an average annual rate of 0.8%. Given the large inflow of private investment to the region and its impacts on wages and employment, it is very likely that commercial intensity will continue to increase in the near and mid term, albeit at a slower rate of growth. The projected energy intensity implies that in 2015, 155 Mtoe will be necessary to generate US $1 million of commercial goods or services. Figure 5.7 illustrates the projected path of commercial intensity from 1994 to 2015 under both scenarios.

Under the BAU scenario, energy required by the commercial sector will grow at an annual average rate of 2.8% to 100 Mtoe in 2000, 131 Mtoe in 2010, and 149 Mtoe in 2015.

EE Scenario: Under the EE scenario, commercial intensity was estimated to grow at an average annual rate of 0.2%, one-fourth the level of growth projected under the BAU scenario. Energy intensity is projected to grow to 130 Mtoe/US $1 million of commercial goods or services. Improvements in intensity may be obtained by introducing energy efficient ventilation equipment and building insulation in future financial and retail establishments. Some incentives will be found for demand-side management programs as increasing electricity prices are passed through to the consumer in response to environmental regulations and as the privatization of the energy sector begins to take hold.

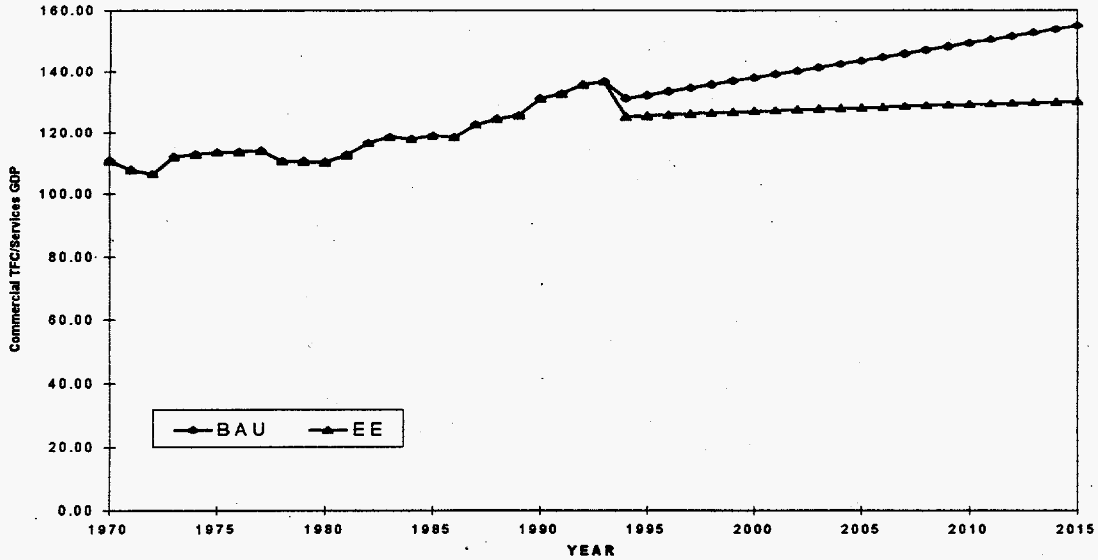

Figure 5.7. Latin America Projected Commercial Energy Intensity

Under the EE scenario, the annual average growth rate in projected energy required decreases to 2.2%, from 2.8% under the BAU scenario. This implies that the commercial sector could reduce energy requirements using energy efficiency policies, such as energy efficiency lighting, improved insulation and ventilation, down to 92 Mtoe in 2000, 114 Mtoe in 2010, and 125 Mtoe in 2015.

Agriculture

The agricultural sector has been the most stable of all sectors in terms of output during the period studied. Annual average growth in output fell to 2% in the 1980s from 3.4% in the 1970s. In the 1990s the recovery in this sector has led to annual average growth rate of 2.6%. The relative stability of the agricultural sector is a by-product of the importance placed on it by governments for political and financial reasons. The region already has a had its major rural-urban migration. In 1980, 65% of the population already lived in urban centers. Urban population has continued to increase and reached 73% in 1992. To minimize the effects of labor losses and the risk of food security, there has been an increase in the mechanization of food production.

During the 1970 to 1993 period, total final energy delivered to the agricultural sector almost tripled from 24 Mtoe to 69 Mtoe. The agricultural sector, like the other major economic sectors in the region, steadily increased the use of electricity, and liquid gas since 1970. The share of electricity in total final energy use went from 25% to 38%, while liquid gas went from 28% to 38%. The use of kerosene has declined dramatically from 24% to 5%.

Growth in energy consumption in the agricultural sector remained strong at 4.7% during the 1970 to 1993 period. Throughout the period of analysis, intensity growth averaged 1.8%, showing evidence of technology insertion and its corresponding productivity enhancements. This has resulted in an increase from 422 Mtoe/US $1 million total regional GDP in 1970 to 637 Mtoe/US $1 million total regional agricultural GDP.

To estimate future energy requirements, agricultural GDP and energy intensity were estimated for the next 21 years based on their past trends.

BAU Scenario

Under the BAU scenario, agricultural intensity was estimated to grow at an average annual rate of 1.2%. Given the large inflow of private investment to the industrial sector of the region, it is very likely that agricultural intensity will continue to increase in the near and mid term in response to continued mechanization of the sector.

Under the BAU scenario, projected intensity implies that, in 2015, 131 Mtoe will be necessary to generate US $1 million of agricultural output. Under the EE scenario, energy intensity is projected to grow to 103 Mtoe. Figure 5.8 illustrates the projected path of agricultural intensity from 1994 to 2015 under both the BAU and EE scenarios.

Under the BAU scenario, energy required by the agricultural sector in the year 2000 is estimated at 86 Mtoe, 115 Mtoe in 2010, and 131 Mtoe in 2015.

EE Scenario

Under the EE scenario, agricultural intensity was estimated to grow at an average annual rate of 0.4%, one third the rate of growth under the BAU scenario. Some slow down in the intensity may be obtained by introducing energy efficient irrigation and harvesting technologies. This could happen as result of trade liberalization and increased intra-regional trade. Also, increasing costs of production resulting from higher electricity prices could also help moderate the demand for energy.

Under the EE scenario, the annual average growth rate in projected energy required decreases from 2.9% to 2.1%. Thus, energy requirements could be reduced to 77 Mtoe in 2000, 94 Mtoe in 2010, and 103 Mtoe in 2015.

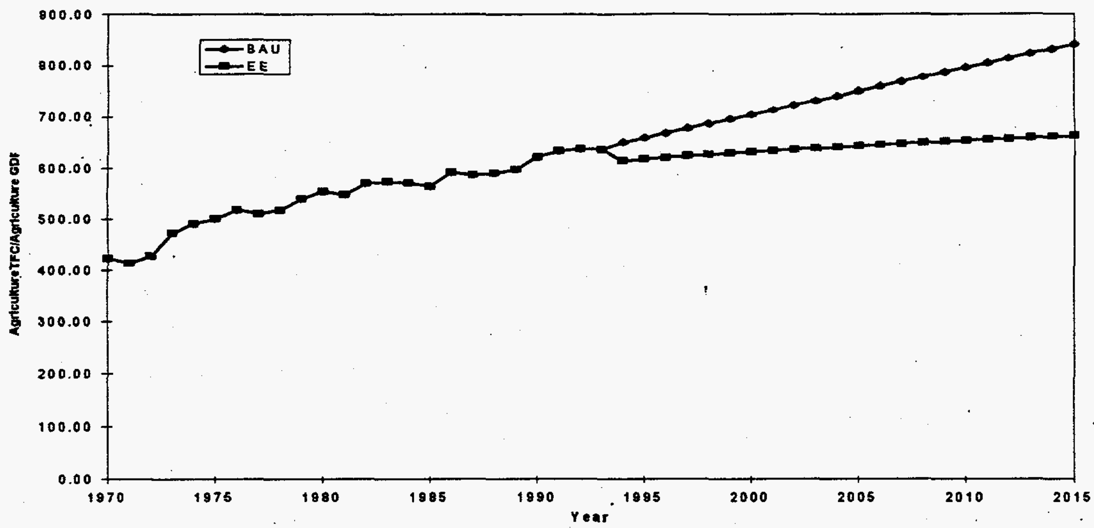

Figure 5.8. Latin America Projected Agriculture Energy Intensity

Transformation

Electricity generation in the region has steadily increased in the past 25 years in response to steady growth in population and the needs associated with it. Although regional economic expansion and contraction have heavily influenced the level of investment and production in all sectors of the economy, demand for electricity generation has continued to increase.

In the past 25 years, the power sector of Latin America has suffered from extensive institutional, financial, and management problems. In the 1970s, economies of scale and lack of capital made it viable to have governments in charge of the generation and distribution of power. These circumstances generated institutions that were used for political purposes rather than for the provision of a service. Governments used power companies to soften some of the inflationary effects by subsidizing the cost of electricity to all end users. As the power companies did not recover the operating or construction costs from end users and construction of plants continued, the sector kept on falling deeper into debt. Because the priority was on increased installed capacity, no attention was paid to inefficiencies already built into the system.

In 1970, the overall region had 39.3 gigawatts (GW) of installed capacity. By 1980, it had increased to 92.4 GW and by 1993 it had nearly doubled to 167 GW. This growth has altered the reliance on primary fuels. At the beginning of the period, 48% of generating plants were hydroelectric, while another 45% were steam plants (mostly oil). Throughout the 1980s a large number of hydroelectricity projects were constructed throughout the region. These projects resulted in an increase in share of hydroelectric power to 59% in 1989. This share has been maintained. Steam generating plants fell to 33% of the total. While gas plant capacity increased from 1.4 GW to 16.1 GW, it only represented an increase in share from 2% to 4%.

For the future of the region, the transformation sector is a key element for continued economic growth, productivity increases, and overall increases in value of output. The transformation sector will also be key for the introduction of energy efficiency policies. Regional increases in population will continue to challenge the production capacity of electricity generation installations.

At the same time, institutional reform and changes in pricing mechanism and privatization of the power sector will add to the challenge of providing additional electricity while major functional changes in the sector are implemented. The heavy debt acquired by the power sector in the region during the 1980s will continue to slow down the pace of improvements in market efficiencies and in the production and distribution of energy to end-use sectors. However, there is no doubt that regional installed capacity will continue to increase at a fast pace to meet expected energy requirements by all sectors of the economy.

Under any scenario, the structure of the electricity generation sector is not expected to change significantly by the year 2015 from 1993. Hydroelectric power is still expected to be the largest single source for electricity generation. Its share of total capacity is projected to decline slightly from 59% in 1993 to 54% in 2015. Hydroelectric installed capacity is unlikely to continue increasing at past rates due to the large financial costs of dam construction and the ecological impacts/costs already experienced in the region. The international lending institutions are discouraging hydroelectric plants and encouraging gas infrastructure development as well as some renewables. The region as a whole has a policy for the future to increase the use of coal in power generation to decrease its dependence on oil. Steam plants are expected to increase their share significantly from 33% in 1993 to 42% in 2015. Steam plants are presently coal and oil-fired; although historically the majority have been oil-fired, the number of coal-fired plants as well as gas-fired plants are expected to increase faster in response to present investments in gas pipelines/infrastructure.

BAU Scenario

Under the BAU scenario, electricity losses of 17% were added to estimate the total primary energy requirement. Total primary energy requirements were estimated by multiplying projected final energy requirements by a transformation ratio. The transformation ratio was calculated by the weighted sum of total installed capacity. Installed capacity was weighted by the energy conversion efficiencies by type of plant.

With the inclusion of losses, total primary energy required under the BAU scenario is projected to be 2,429 Mtoe by the year 2000, 3,282 Mtoe by 2010 and 3,789 by 2015.

EE Scenario

Under the EE scenario, it was assumed that a 5% improvement in energy losses would be achieved through the implementation of energy efficiency policies, including improvements in the generation, transmission, and distribution of electricity. Under the EE scenario total primary energy requirements are reduced to 2,223 Mtoe, 2,775 Mtoe and 3,087 Mtoe, respectively.

6.0 ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT AND REST OF WORLD

6.1 Organization for Economic Cooperation and Development

The Paris-based Organization for Economic Cooperation and Development (OECD) consists of 23 member countries, representing the world's most developed economies.[1] The total population of this geographically diverse region in 1993 was 974 million. Together, the OECD nations account for approximately 20% of the world's total population.

While the economies of the OECD are large, the region is not expected to be a major source of growth of energy in the next century. On the contrary, energy consumption in the OECD will likely grow only modestly. However, the region is important to study because it can serve as an analog for possible future development paths in other regions. In other words, it is reasonable to expect that China, India, and other industrializing countries will emulate the OECD's historic energy use patterns, characterized by high consumption during times of rapid economic expansion, followed by a reduction in demand as a result of more energy-efficient technologies and national energy conservation policies (Figure 6.1).

Key Findings[2] - Moderate, Stable Growth Expected

After an economic recession in Europe and the Pacific region (Japan, Australia) during the early 1990s, most OECD economies are growing again, and GDP growth in most countries is expected to be healthy throughout the remainder of the century, averaging 2.5% a year through 2015. Despite economic growth and restructuring in the energy sectors of many OECD countries, these nations are not expected to be major consumers of energy relative to other rapidly developing states in the eastern and southern hemispheres. This is because the oil shocks of the mid- and late-1970s forced most OECD countries to begin reducing their dependence on imported oil through conservation and substitution of other fuels as early as two decades ago. The majority now have strong energy efficiency policies in place and have been able to replace old and inefficient capital equipment so that per capita energy consumption has declined substantially since the mid-1970s. In addition, population growth will remain well below 1% a year, which will further help keep demand in check.

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[1] OECD member countries include Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.
[2] Projections in this chapter are based largely on OECD forecasts found in OECD (1995b).

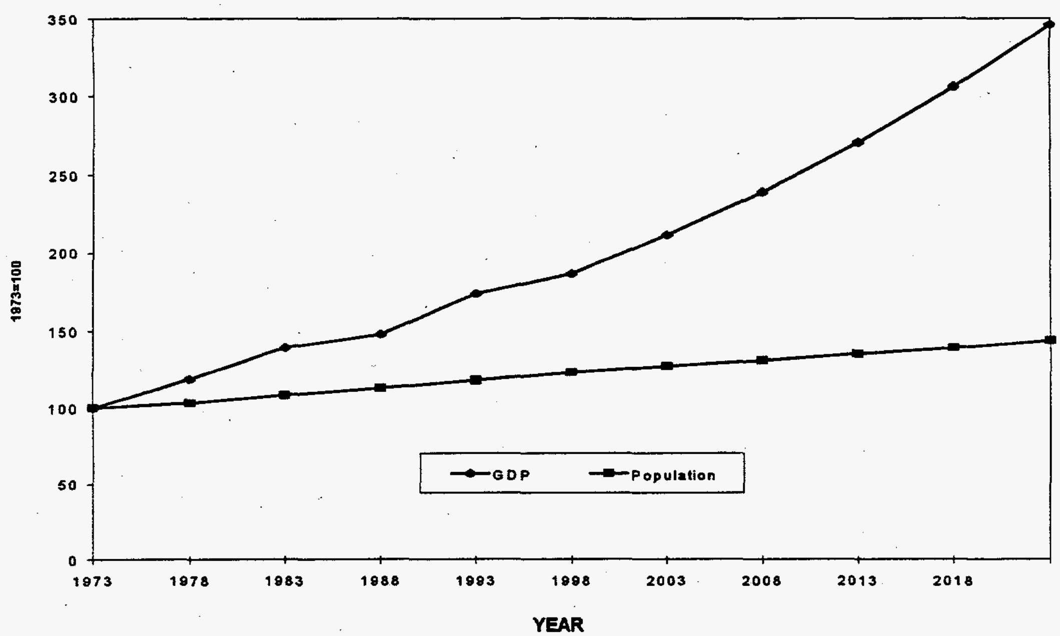

Figure 6.1. Historic and Projected GDP and Population Growth in the OECD

Because of stable population growth rates and continued improvements in energy efficiency, the OECD's TER under both the BAU and EE scenarios is expected to increase steadily but modestly until 2015. In most sectors, there is little difference between TER for both scenarios, because most OECD countries have already undergone extensive energy efficiency improvements. Thus, by the end of the forecast period, there is only a 5.8% difference in total energy demand between projections for EE and BAU scenarios. Under BAU conditions, for example, TER is 4,254 Mtoe in 2015, while under EE conditions, TER is 4,008 Mtoe. Figure 6.2 illustrates projected energy supply and requirements under both scenarios.

With respect to projected fuel breakouts, coal consumption continues to decline relative to other fuels, a result primarily of economic recession, the downsizing of coal mining industries in many OECD countries, and a general OECD-wide concern with reducing global carbon dioxide emissions (OECD 1995a; EIA 1994). While overall consumption of oil increases through 2015 under both scenarios, oil loses some of its market share to natural gas. In 1971 oil claimed close to 53% of the market; it is projected to make up no more than 42% of primary energy by 2015 (OECD 1995b). Both scenarios show increasing market penetration by gas. Under the EE scenario, renewable energy resources in 2015 are double BAU shares.

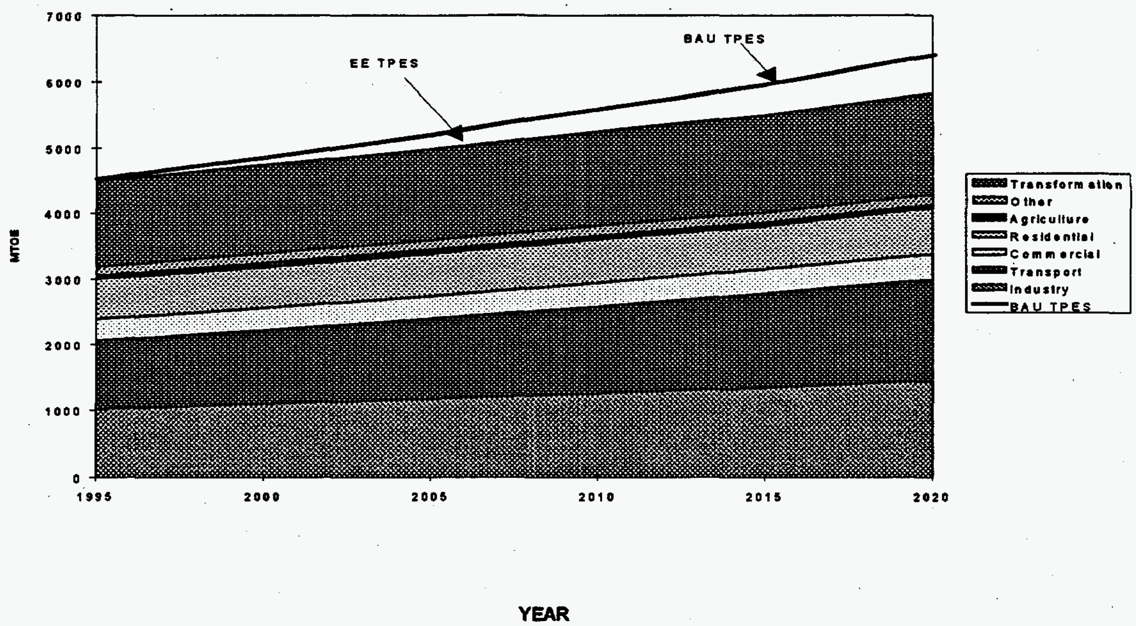

Figure 6.2. Projected Fuel Requirements for OECD by Sector Under the EE Scenario and by Total Under the BAU Scenario

6.2 REST OF WORLD (ROW)

The ROW region consists of those areas of the world not included in the previous regional definitions. For the purpose of this study, ROW includes all of Africa, and the Middle East.[3] Total population of the ROW region was 694 million in 1993, representing approximately 13% of the world's total population. Africa accounted for just under 80% of the population in ROW in 1993. The population growth rate of the region is projected at slightly over 3% annually through the end of the century, and gradually declining to 2.5% annual growth by 2015.

The ROW region exhibits great economic diversity. The region comprises 66 countries, including countries that have among the highest and the lowest per capita GDP in the world. Biomass energy consumption is prevalent in many areas of sub-Saharan Africa, while much of the Middle East relies solely on its extensive oil resource base for energy. South Africa, Morocco, and Zimbabwe are the only countries in the region that rely on coal for a significant part of the total energy consumption.

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[3] Middle East countries include Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, the Syrian Arab Republic, the United Arab Emirates, and the Republic of Yemen. Turkey is included as an OECD member.

Key Findings - Slow Growth Expected

While ROW does exhibit economic diversity, the region overall can be characterized by slower projected economic growth than the other regions of the world. Much of Africa is experiencing economic stagnation or decline. GDP per capita increased at 0.2% from 1970 to 1989.[4] Economic stagnation has occurred because of a variety of factors, including restrictive trade barriers, poorly developed infrastructure, excessive tax rates, and political instability. The overall GDP growth rate for African nations is projected to be about 1% annually through 2015. As a result of economic stagnation and relatively rapid population growth, Africa is expected to experience a decrease in per capita income during the next 20 years.

The GDPs of most Middle East countries grew rapidly during the 1970s because of increasing revenues generated by higher world oil prices.[5] Stable or declining oil prices during the 1980s and 1990s has in large part stopped Middle East GDP growth. The projected rate of GDP growth for the area through 2015 is slightly under 1% annually. As with Africa, relatively rapid population growth combined with slow GDP growth implies declining per capita incomes. The ROW population and GDP trends are shown in Figure 6.3.

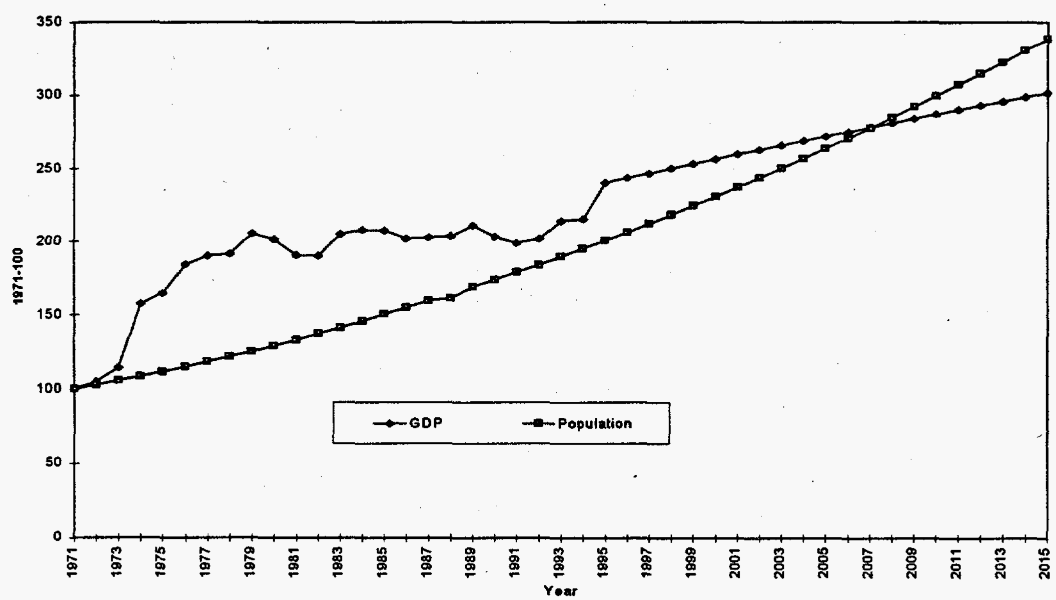

Figure 6.3. ROW GDP and Population Growth, Projected to 2015

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[4] Sachs, Jeffrey 1996. Growth in Africa, The Economist.

[5] The major exception to this growth trend was Israel, which experienced slow economic growth during the 1970s.

ROW energy consumption is expected to grow less rapidly than the world as a whole because of the slow regional economic growth rate. ROW's TER under both the BAU and the EE scenarios is expected to increase at about 1% per year until 2015, indicating a decreasing per capita TER. Given a declining per capita energy requirement, the energy efficiency scenario has little impact on ROW energy demand. The estimated regional TER under BAU and EE conditions differs by less than 1% in 2015. The slow growth in TER results in a decline from 5% of world energy consumption in 1990 to 3% in 2015 for the region. ROW's impact on world energy conditions will likely be on energy supply. The region supplied over one third of the world oil and natural gas liquids in 1990. The region will continue to play a major, and perhaps dominant, role in world energy supply in the next century. Figure 6.4 shows the BAU (and EE, which is the same) forecast for ROW.

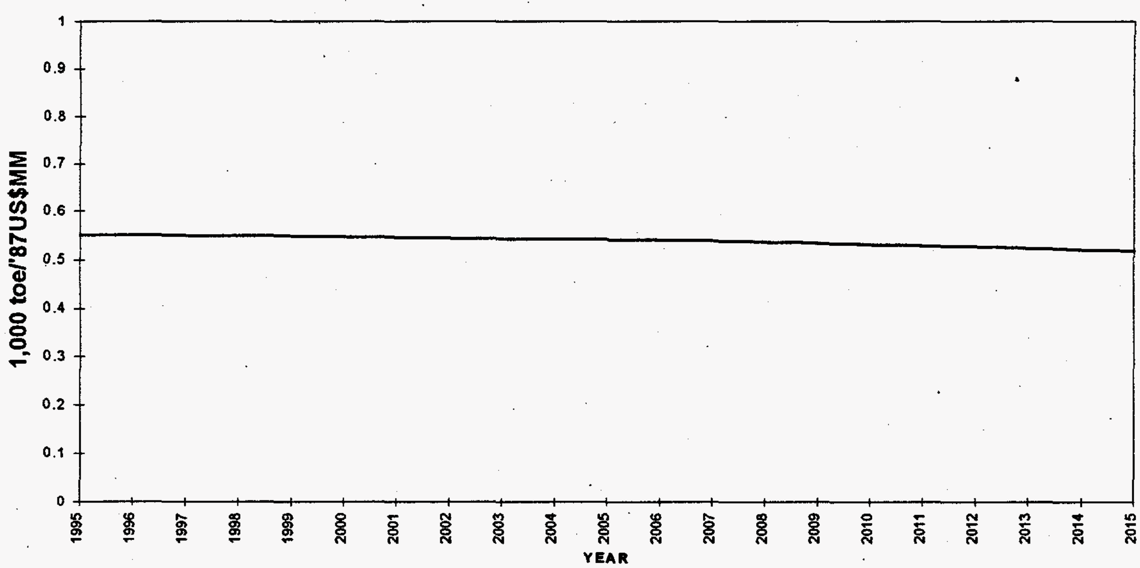

Figure 6.4. ROW Energy Intensity Projection

A Different Scenario?

The projected slow economic growth in ROW hides the real growth potential of the region. For example, a study of Africa's economic growth potential if the institutional and political barriers are overcome suggests that African real GDP could grow at 4.8% annually.[6] Similarly, if the Middle East countries could diversify their economies from oil-dependent revenues and/or if world oil prices began to increase again, the rate of

[6] Jeffery Sachs and Andrew Warner. 1996. Sources of Slow Growth in the African Economies, Harvard Institute for International Development.

economic growth for the area would increase. ROW may well play a larger role in world energy needs than current projections suggest.

7.0 EQUILIBRIUM MODEL RESULTS

An equilibrium model of energy supply and demand can assure that projections of energy supply and energy demand are in balance at an equilibrium world price, after adjusting for differences in regional taxes and tariffs. This chapter reports on the use of such a model to modify the demand projections of the earlier chapters to assure that they are in equilibrium with supply.

The construction of estimates of energy requirements, as shown in the previous five chapters, provides a sense of what energy will be needed under the projected growth rates. But these projections ignore the interaction of supply and demand that will affect price, and through price changes, what quantity of energy will be the equilibrium value for both supply and demand, at the world level. To assure the interaction of supply and demand, an energy model of the world (the ERB model) has been integrated with the previous chapters to provide the equilibrium supply and demand for world energy.

The basic reference for the Edmonds/Reilly model, the precursor to the ERB, is Edmonds and Reilly (1985). ERB is a nine sector model of world energy supply and demand. The nine sectors include three OECD regions (Europe, North America, and OECD Asia), China, the rest of Asia, South America, Africa, Russia and Eastern Europe, and the Middle East.

Energy demand in the OECD regions is built up from three end-use sectors (residential/commercial, industrial, and transportation) similar to those shown in the projections of Chapters 2.0 through 5.0. The major drivers for this demand are regional population projections, participation rates, and productivity growth, which yield regional GDP. The population distribution, GDP, and technical change are the factors that give rise to energy demand, which is conditioned by energy prices, which in turn are affected by world prices and regional taxes and tariffs. Energy efficiency improvements are allowed to vary through an autonomous energy efficiency improvement (AEEI) factor, which defines a growth rate for energy efficiency changes over time. The AEEI can alter both the use of energy by consumers and the production of secondary energy by producers.

Energy supply, including the transformation sector, is modeled for each of the regions, and trade allows markets to equilibrate at a world price. There are four types of fuels modeled at the secondary level: solids, liquids, gaseous fossil fuels, and electricity, with electricity produced by the combustion of fossil fuels or the use of renewables (hydroelectric and nuclear being the most significant). Primary energy consists of coal, gas, oil, biomass, nuclear, hydroelectric, and solar, with secondary fuel conversions that transform these primary fuels to other secondary fuels and electricity.

Regional energy supplies are derived from global supplies and regional resources subject to regional resource constraints and world energy prices. Regional supply and demand are reconciled to determine regional prices which are world prices modified by regional taxes and tariffs. Regional supplies and demands aggregate to global supply and demand to determine world prices, and through world prices, regional supplies and demands equilibrate.

The Edmonds-Reilly model, has been widely used in global climate changes studies including EPA (1989). The structure of the model is explained in Chapter 16 of Edmonds and Reilly (1985), the title of which is "Energy Consumption and Carbon Dioxide: A Model." The major difference between the referenced model and the ERB is the treatment of greenhouse gases other than carbon dioxide and the way tax regimes are structures. Otherwise they are essentially the same model.

Procedurally, for this study, the productivity index for each region was modified to allow the GDP growth rates to track those projected in the earlier chapters. Then the AEEI factor was modified to track the BAU scenario and the model was solved for world energy balances and equilibrium prices. The EE scenario was then replicated in the model context by adjusting the AEEI to reflect each of the region's expectations about energy efficiency improvements.

Results for the ERB model runs are shown in Table 7.1. The left-hand column shows the region with the second column being the initial and forecast years, 1990, 2005, and 2020. The third column, labeled "New BAU" is the BAU scenario, as indicated in each of the regional chapters earlier. The fourth column is the EE scenario, shown here as the model results would normally appear, with price feedbacks to indicated how energy use might be modified due to lower prices that result from lower than BAU demand for energy. The final column shows how demand and supply would be reconciled without those price feedbacks.

This final column is, of course, not possible, but illustrates the difference in demand levels had the prices not been lower. For the world in total, in 2020, 11 EJ more energy is consumed because of the lower prices that result from decreased demand.

Table 7.1. ERB Model Estimates

OECD	Year	New BAU	New EE	W/O PF
	1990	177.12	177.12	177.12
	2005	184.29	176.96	176.59
	2020	221.8	203.98	202.09
China	1990	27.87	27.87	27.87
	2005	108.28	102.15	105.15
	2020	277.98	246.55	243.21
FSU-CEE	1990	89.74	89.74	89.74
	2005	68.78	57.44	56.7
	2020	118.51	86.14	81.26
S. Asia	1990	20.92	20.92	20.92
	2005	51.99	44.64	44.97
	2020	126.05	92.95	91.88
Latin America	1990	18.19	18.19	18.19
	2005	32.51	28.97	28.58
	2020	36.65	29.03	28.77
ROW	1990	18.22	18.22	18.22
	2005	21.90	22.01	21.90
	2020	23.50	23.57	23.50
TOTAL	1990	352.06	352.06	352.06
	2005	467.75	432.17	433.89
	2020	804.49	682.22	670.71

7.1 Edmonds-Reilly-Barns Model

The ERB is a well-documented (Edmonds and Reilly 1985; Edmonds et al. 1986), frequently used, long-term model of global energy and fossil fuel greenhouse gas emissions. The model can be thought of as consisting of four parts: supply, demand, energy balance, and greenhouse gas emissions. The first two modules determine the supply of and demand for each of six major primary energy categories in each of nine global regions. The energy balance module ensures model equilibrium in each global fuel market.[1] The greenhouse gas emissions module is a set of three post-processors which calculate the energy-related emissions of carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). The original version of the model is documented in Edmonds and Reilly (1985), while major revisions are discussed in Edmonds et al. (1986). The model is currently configured to develop scenarios for benchmark years: 1990, 2005, 2020, 2035, 2050, 2065, 2080, and 2095.

Energy demand for each of the six major fuel types is developed for each of the nine regions. Five major exogenous inputs determine energy demand: population; labor productivity; exogenous energy end-use intensity; energy prices; and energy taxes, subsidies, and tariffs.

The model calculates base GNP directly as a product of labor force and labor productivity. An estimate of base GNP for each region is used both as a proxy for the overall level of economic activity and as an index of income. The base GNP is, in turn, modified within the model to be consistent with energy-economy interactions. The GNP feedback elasticity is regional, allowing the model to distinguish energy supply dominant regions, such as the Mideast, where energy prices and GNP are positively related, from the rest of the world where the relationship is inverse.

The exogenous end-use energy-intensity improvement parameter is a time-dependent index of energy productivity. It measures the annual rate of growth of energy productivity that would continue independent of such other factors as energy prices and real income changes. In the past, technological progress and other non-price factors have had an important influence on energy use in the manufacturing sector of advanced economies. Including an exogenous end-use energy-intensity improvement parameter allows scenarios to be developed that incorporate either continued improvements or technological stagnation assumptions as an integral part of these scenarios.

The final major energy factor influencing demand is energy prices. Each region has a unique set of energy prices derived from world prices (determined in the energy balance component of the model) and region-specific taxes and tariffs. The model can be modified to accommodate non-trading regions for any fuel or set of fuels. The model assumes that regions do not trade solar, nuclear, or hydroelectric power, but all regions trade fossil fuels.

The energy-demand module performs two functions: it establishes the demand of energy, and its services; and it maintains a set of energy flow accounts for each region. Oil and gas are transformed into secondary liquids and gases that are used either directly in end-use sectors or indirectly as electricity. Hydroelectric, nuclear, and solar electric or fusion are accounted for directly as electricity. Nonelectric solar energy is

[1] Primary electricity is assumed to be non-traded; thus supply and demand balance in each region.

included with conservation technologies as a reduction in the demand for marketed fuels.

The four secondary fuels are consumed to produce energy services. In each region of the model, energy is consumed by three end-use sectors: residential/commercial, industrial, and transportation.

The demand for energy services in each region's end-use sectors is determined by the cost of providing these services and by the levels of income and population. The mix of secondary fuels used to provide these services is determined by the relative costs of providing these services using each alternative fuel. The demand of fuels to provide electric power is then determined by the relative costs of production, as is the share of oil and gas transformed from coal and biomass.

Energy supply is disaggregated into two categories, renewable and non-renewable. Energy supply from all fossil fuels is related directly to the resource base by grade, the cost of production (both technical and environmental) and to the historical production capacity. The introduction of a graded resource base for fossil fuel (and nuclear) supply allows the model to explicitly test the importance of fossil fuel resource constraints as well as to represent fuels such as shale oil, in which only small amounts are likely available at low costs but for which large amounts are potentially available at high cost.

Note here that nuclear power is treated in the same category as fossil fuels. Nuclear power is constrained by a resource base as long as light-water reactors are the dominant producers of power. Breeder reactors, by producing more fuel than they consume, are modeled as an essentially unlimited source of fuel that is available at higher cost.

A rate of technological change is also introduced on the supply side. This rate varies by fuel and is expected to be both higher and less certain for emerging technologies.

The supply and demand modules each generate energy supply and demand estimates based on exogenous input assumptions and energy prices. If energy supply and demand match when summed across all trading regions in each group for each fuel, then the global energy system balances. Such a result is unlikely at an arbitrary set of energy prices. The energy balance component of the model is a set of rules for choosing energy prices which, on successive attempts, bring supply and demand nearer a system-wide balance. Successive energy price vectors are chosen until energy markets balance within a prespecified bound.

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