ASIA PACIFIC ENERGY RESEARCH CENTRE

ENERGY EFFICIENCY INDICATORS

A STUDY OF ENERGY EFFICIENCY INDICATORS IN APEC ECONOMIES

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FOREWORD

This report, *A Study of Energy Efficiency Indicators in APEC Economies*, is part of a long-term effort to improve energy efficiency - a component of a sustainable energy system - in APEC member economies. The first phase of this project, completed in March 2000, focused on the construction of descriptive indicators in three energy-intensive industries, namely iron and steel, cement and pulp and paper. The present study goes further. Indicators for all major macroeconomic sectors are constructed and observed trends in these sectors are analysed.

Indicators of energy use and efficiency provide information to policy-makers and aid in the design of focused energy efficiency policies and measures. These indicators can also be used to monitor the progress or impact of energy efficiency initiatives.

To facilitate inter-economy comparisons, a particular effort was made to build indicators at the same level of detail for as many APEC economies as possible. Given the wide disparities in data availability across economies, devising a common indicator was sometimes very challenging. To illustrate what is possible, in selected economies where data was available, more detailed indicators at higher levels of disaggregation were constructed. APERC has worked closely with organisations such as ADEME, IEA and LBNL to ensure internationally accepted methodologies were applied in this study.

Though the foundations for this long-term project have been established, much work still needs to be done. It is our hope that APERC will continue to receive strong support from member economies for this initiative.

This report is published by APERC as an independent study and does not necessarily reflect the views or policies of the APEC Energy Working Group or of individual member economies.

Finally, I would like to express my sincere gratitude to my fellow APERC researchers involved in this project, as well as all the experts that have contributed their valuable comments and suggestions.

Keiichi Yokobori
President
Asia Pacific Energy Research Centre

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The development of APERC's energy efficiency research could not have been accomplished without the contributions of many individuals and organisations. APERC would like to thank EGEDA representatives and other energy experts who participated in APERC's workshops, conferences and APERC Advisory Board meetings for their valuable comments and suggestions. In particular, we would like to thank our colleagues from ADEME and ENERDATA, for their insightful comments and methodological recommendations. Our appreciation goes as well to APERC's administration department for their support in carrying out this study.

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List of Abbreviations

ADB	Asian Development Bank
ADEME	Agency for Environment and Energy Management (France)
APEC	Asia Pacific Economic Cooperation
APERC	Asia Pacific Energy Research Centre
ASEAN	Association of Southeast Asian Nations
AUS	Australia
BD	Brunei Darussalam
BOF	Basic oxygen furnace
CDA	Canada
CHL	Chile
CO_2	Carbon dioxide
CT	Chinese Taipei
DG	Distributed generation
DSM	Demand side management
EAF	Electric arc furnace
EC	European Commission
ECCJ	Energy Conservation Center, Japan
ECPF	EnerConservation Promotion Fund (Thailand)
EDMC	Energy Data and Modelling Center (Japan)
EEAP	Enterprise Energy Audit Programme (Australia)
EECA	Energy Efficiency and Conservation Authority (New Zealand)
EEI	Energy efficiency indicator
EIA	Energy Information Administration (USA)
EMM	APEC Energy Ministers Meeting
ESCO	Energy service company
FAO	Food and Agriculture Organization of the United Nations
FEC	Final energy consumption
GDP	Gross domestic product
GEF	Global Environmental Facility
GVA	Gross value added
HKC	Hong Kong, China
IEA	International Energy Agency
IMF	International Monetary Fund
INA	Indonesia
IPCC	Intergovernmental Panel on Climate Change
IRF	International Road Federation
IT	Information technology
JPN	Japan
KEMCO	Korea Energy Management Corporation
LBNL	Lawrence Berkeley National Laboratory (USA)
MAS	Malaysia
MEPS	Minimum Energy Performance Standards
METI	Ministry of Economy, Trade and Industry (Japan)
MEX	Mexico
MOEAEC	Ministry of Economic Affairs, Energy Commission (Chinese Taipei)
MOSTE	Ministry of Science, Technology and the Environment (Viet Nam)
NGRS	National Greenhouse Response Strategy (Australia)
NRCan	Natural Resources Canada
NZ	New Zealand
ODYSSEE	On-line Database on Yearly Assessment of Energy Efficiency
OECD	Organisation for Economic Co-operation and Development

OEE	Office of Energy Efficiency (Canada)
PDM	Parametric Divisia method
PE	Peru
PNG	Papua New Guinea
PPP	Purchasing Power Parity
PRC	People's Republic of China
R&D	Research and development
RECS	Residential Energy Consumption Survey (USA)
ROK	Republic of Korea
RP	The Republic of the Philippines
RUS	The Russian Federation
SC	Space cooling
SEC	Specific energy consumption
SGES	Steering Group on Energy Standards (APEC)
SIN	Singapore
TFC	Total final consumption
THA	Thailand
toe	tonne of oil equivalent
TPES	Total primary energy supply
UN	United Nations
US or USA	United States of America
US DOE	Department of Energy (US)
VN	Viet Nam
WB	World Bank
WEC	World Energy Council

EXECUTIVE SUMMARY

This summary presents the major findings of APERC's study on *Energy Efficiency Indicators in APEC Economies*. This report is the second phase of a long-term project on energy efficiency in the APEC region. The first phase was completed in 2000. It analysed efficiency trends in three energy intensive industrial sub-sectors, namely iron and steel, cement, and pulp and paper. The second phase is more extensive. It covers all major macroeconomic sectors and focuses on the main drivers of energy intensity trends in these areas.

OBJECTIVES AND SCOPE

The objectives of this study were four-fold:

- Establish a common methodology for constructing a basic set of energy efficiency indicators for APEC economies;
- Construct energy efficiency indicators for the whole economy, major energy consuming macroeconomic sectors (industry, residential, services and transport), and for selected industrial and transportation sub-sectors of APEC member economies;
- Identify environmental implications for energy consumption in APEC economies; and
- Develop a network of energy efficiency experts and agencies in APEC member economies.

The study examines all 21 APEC member economies during the time period 1980-1998, data permitting. Energy efficiency policies and current practices in each economy are also analysed.

METHODOLOGY

The approach implemented in this report is a top-down analysis estimating economic energy efficiency, using energy intensities as proxies. Indicators are calculated at the economy or macroeconomic level, at the sectoral level and where data was available, at the sub-sectoral level. Some supplementary indicators in industrial energy intensive sub-sectors (iron and steel, pulp and paper, cement), transportation and services were constructed.

In order to improve the quality of these indicators, several adjustments were made. Decomposition analysis was applied to separate out activity, structure, weather and pure intensity effects. Both the Divisia parametric approach and Laspeyres indices were used.

To ensure reliability and comparability, international data sources, such as IEA, WB, IMF, UN, ADB and OECD, were used. These sources were supplemented with economy sources when necessary. International comparability of value-based indicators was facilitated by the use of real international dollars at purchasing power parity.

MACROECONOMIC ENERGY EFFICIENCY INDICATORS

Energy intensities for the whole economy or total energy consumption divided by GDP, are the result of a multitude of contributing factors, both physical and economic. Energy efficiency is just one of such factors.

Aggregate intensity trends for each economy were decomposed into structure and pure intensity using the multiplicative Divisia method. The analysis shows that Asian economies, except Japan, have become more energy intensive over the study period. A shift to more energy intensive sectors such as industry has raised intensities in Malaysia (+12 percent), Viet Nam (+9 percent), Indonesia (+8 percent), Thailand (+7 percent), China (+7 percent) and Korea (+7 percent). The largest structure effect was recorded in Brunei at 170 percent over the study period. In these economies, not only did the industrial sector increase its share of GDP, but there was also a noticeable shift towards energy intensive sub-sectors such as petrochemicals and iron and steel.

The most impressive declines in pure intensity, about - 6 percent per annum were realised in China over the study period. Intensity reductions of more than 1 percent annually were observed in the United States (- 2.2 percent), Chinese Taipei (- 1.8 percent), Russia (1992-98, - 1.5 percent) and Canada (- 1.1 percent). Pure intensity levels also fell in PNG, Japan, Australia, Viet Nam, Indonesia and Mexico. Intensity increased in New Zealand, the Philippines and Thailand by more than 1 percent per year. Similar trends were observed in Korea, Malaysia and Singapore though the rates are slower. Pure intensity also grew in Brunei, Chile, HKC[1] and Peru.

Nearly 12 billion tonnes of CO_2 were emitted in 1998 in APEC economies, 39 percent more than in 1980 (bar Russia). The main contributors were the US (42 percent), China (20 percent), Russia (10 percent) and Japan (8 percent). The largest reductions in CO_2 intensity have been achieved in China where intensity in 1998 was only 35 percent of the 1980 level. Increasing CO_2 intensity trends are noted in Brunei, the Philippines and Thailand.

INDUSTRIAL ENERGY EFFICIENCY INDICATORS

The industrial sector accounts for 35 to 40 percent of total final energy consumption in the APEC region. Manufacturing was responsible for nearly 97 percent of this sector's total energy consumption. The largest industrial energy users are chemicals and petrochemicals, iron and steel, pulp and paper and non-metallic minerals such as cement.

Manufacturing energy intensities in the APEC region as a whole are decreasing, particularly in developing economies such as China and Chinese Taipei, and in developed ones such as Japan. However, this indicator has increased in Korea, New Zealand, the Philippines, Russia and Thailand during the study period.

Decomposition analysis shows that most of the intensity reductions in economies such as Australia, Canada, China, Japan, Chinese Taipei and the United States were driven by pure energy intensity rather than the structure effect. The structure effect drove down energy intensity in Korea, Mexico and the United States while a shift to more energy intensive industries increased aggregate intensities in Australia, Russia and Thailand.

China's industrial sector is the largest emitter of CO_2 in the APEC region, accounting for 33 percent of the APEC total. The USA and Russia followed, with 28 and 10 percent, respectively. APEC's average CO_2 intensity by GDP declined by 25 percent from 1980 to 1995. Sharp declines in energy intensities and fuel substitution away from coal in some of the larger energy consuming economies, most notably China, contributed to this observed decline.

TRANSPORTATION ENERGY EFFICIENCY INDICATORS

Transportation is the second most important energy-consuming sector in APEC after industry. This sector is one of the fastest growing, both in developed and developing APEC economies. Road transportation is the dominant mode, accounting for 77 percent of sectoral energy consumption in 1998.

Energy intensity with respect to GDP in this sector is generally a poor indicator, because GDP is not a good measure of transportation activity. Better activity indicators such as passenger-km and tonne-km are unavailable for the majority of APEC economies. Alternative indicators such as transport energy consumption per capita show a significant increase during the study period, particularly in developing economies. In China, energy per capita is approximately 13 percent of the APEC average. Therefore, the potential for future growth in this sector is large in China. Despite low energy consumption per capita, China is currently the third most important transport energy consumer in the region after the US and Japan.

The decomposition of aggregate intensity trends into activity, structure and pure energy efficiency give insight into the main drivers behind these trends and the reasons for the differences between economies. Structure seems to play a major role in determining intensity levels. The US, with a high transportation intensity, has a structure dominated by private transportation. Hong Kong, China, with a significantly lower intensity than the US, has a structure heavily weighted toward public road transportation. Energy efficiency improvements in road transportation have been partially offset by increases in both vehicle power and weight. The substitution of light trucks for cars in many economies has also contributed to higher energy intensity levels. Consumer preferences have had a major impact on energy efficiency levels in transportation and should be considered by policy-makers in designing energy initiatives for this sector.

The US accounted for 55 percent of the 3,287 Mt of CO_2 emitted by the APEC transport sector in 1998, followed by Japan and China with 9 percent and 8 percent, respectively. CO_2 emissions in all APEC economies except Russia increased over the study period while intensities with respect to GDP varied from economy to economy. China, with an intensity reduction of - 52 percent during the period showed the largest decline. On the other extreme, carbon intensities in Brunei grew by nearly 190 percent during the period 1980-1997. Brunei now has the highest transportation intensity with respect to GDP in the APEC region.

SERVICES ENERGY EFFICIENCY INDICATORS

Though the services sector makes up from 40 to 60 percent of total GDP in most economies (57 percent in APEC in 1997), it is often neglected as a target for energy policy and detailed data collection because it is responsible for only 3 to 17 percent of total final energy consumption (9 percent in APEC in 1997). Moreover, data collection in this heterogeneous sector is expensive.

Energy intensities were constructed using GDP, floorspace and employment as measures of activity. The trends for these three intensity indicators are similar. Trends in developed APEC economies are declining or flat, while trends in developing ones are increasing rapidly. Rising incomes, improved standards of living and better working conditions are driving this growth in industrialising economies.

To more accurately assess the impact of energy efficiency on changes in energy consumption, overall energy intensity was decomposed into activity, structure, weather and pure energy intensity. Two different factorisation methods were used. The first method, applied to 13 APEC economies, is based on services sector GDP and includes labour productivity, but not climatic corrections or changes in the composition of sub-sectors. Results show that in almost all economies, activity and energy intensity effects where the main drivers behind growth in final energy consumption, while labour productivity gains helped to offset the other two effects in all economies save the Philippines.

The second factorisation method uses floor space as the activity driver, and accounts for changes in structure and climatic differences. This more rigorous method could only be applied to Canada, Japan and the United States due to data availability. As in the first factorisation method, the activity effect was the most important driver of final energy consumption growth. On a year-to-year basis, deviations from normal weather patterns caused large swings in final energy consumption. The structure effect or changes in the composition of sub-sectors proved to be of minor significance in Canada and Japan and moderate significance in the United States. Different trends in weather-adjusted intensity were observed in these three economies.

Electricity plays a pivotal role in services energy consumption. In all APEC economies, regardless of development status, there is a strong link between services GDP per capita and services electricity consumption per capita.

Overall service sector CO_2 emissions in the APEC region have increased by two-thirds during the study period growing from 875 Mt in 1980 to 1,451 Mt in 1998. The United States is by far, the largest emitter of carbon dioxide in the APEC region, being responsible for 62 percent of this total in 1998. China was the next largest emitter at 11 percent and Japan was in third place with 9 percent of total CO_2 emissions. Carbon intensities and energy intensities show similar patterns. In developing economies, carbon intensities are increasing while in industrialised economies, carbon intensities are flat or declining. Energy mix plays an important role in service sector carbon intensities. Given the high share of electricity in total energy consumption, energy inputs for electricity generation have a significant influence on carbon intensity in the services sector.

RESIDENTIAL ENERGY EFFICIENCY INDICATORS

The residential sector accounted for approximately 20 percent of final energy consumption in the APEC region in 1997.

In this sector, residential energy consumption per capita was the indicator chosen. In most economies, this intensity has been drifting upwards. There is, however, a large gap in absolute intensity levels between developing and developed economies. There was insufficient data to further decompose energy per capita into activity, structural and pure intensity components. All measures of activity: population, number of households and rates of urbanisation are steadily increasing, particularly in Asia, not including Japan.

Data on energy consumption for end uses in the residential sector is available for only a few economies. Energy consumption for space heating was adjusted for normal weather patterns in four economies: Canada, Japan, New Zealand and the US. Space heating energy use per household declined in Canada, the United States and New Zealand and increased steadily in Japan. The intensity, electricity consumption for captive uses per capita, was calculated for 11 economies, including China, Indonesia, Malaysia, the Philippines and Viet Nam. Except in Russia, electricity per capita increased rapidly in all economies, but particularly in developing economies. Rapid penetration of electrical appliances is driving much of this growth in energy consumption.

Energy consumption per capita is closely correlated with income per capita. As standards of living increase, so does energy use per capita in the residential sector.

As with energy consumption, the United States has the highest level of carbon dioxide emissions at 48 percent in 1998, followed by China with 18 percent. Except for Canada, Korea, Peru and the United States, carbon dioxide intensities per capita are increasing in APEC economies. In Chile, HKC, Indonesia, Singapore and Chinese Taipei, CO_2 intensities were growing by 4-5 percent per year over the study period. In Thailand, intensities rose by 8 percent per year. CO_2 emissions from biomass have not been included in total emissions calculations. Since 50-90 percent of energy used in many APEC economies is from biomass sources, calculated CO_2 intensities for these economies are quite low.

ENERGY EFFICIENCY POLICIES

Government agencies, non-profit organisations and the energy sector have used a variety of instruments and programmes to reduce energy consumption, to improve energy efficiency and to mitigate carbon emissions. The goal of energy efficiency policy is to minimise market barriers and encourage the adoption of energy efficient products and services. Market barriers can include a lack of information about energy efficient products, risk aversion to trying new products and high initial purchase prices. In developing a policy strategy for encouraging energy efficiency, it is beneficial for economies to examine the experiences of other APEC members.

Mandatory energy efficiency policies are considered to be the most effective, though they can be controversial. If manufacturers or importers do not meet the requirements, standards, or policies outlined by the law, they may face legal or financial penalties. Market-based policies, though usually less effective, are much easier to implement. It is generally agreed that a combination of mandatory and market-based policies applied appropriately will achieve the best results.

Common energy efficiency policies include demonstration projects to showcase new technologies, financial incentives to encourage customers to try energy efficient products and labelling programmes to provide energy efficiency information about available products. Energy audits evaluate the energy efficiency status of facilities or buildings and provide suggestions for reducing energy consumption.

Minimum energy performance standards (MEPS) are another tool for increasing the penetration of energy efficient products. A key advantage of a MEPS programme is that once a level becomes effective, all future sales of energy consuming products such as appliances and light bulbs, must meet or exceed that level. Eventually, with the natural attrition of product replacements over a period of time, the entire stock of a particular product is replaced. Energy efficiency standards for new vehicles and building codes for renovations and new construction work in a similar way. New vehicles or buildings must satisfy prescribed performance levels, if they do not, the manufacturer or builder may face legal or financial penalties. Standards for buildings are harder to enforce than those for goods because construction occurs at different locations for only a short period of time.

Industrial standards are less common. Usually under this type of initiative, an industry is benchmarked and a plan is made outlining energy efficiency and conservation measures to be installed over a period of one year or more. Such regulations exist in the following APEC economies: Australia, Japan and Korea.

The more developed economies tend to have a broader range of energy conservation policies; however, developing economies such as Indonesia, Malaysia, Papua New Guinea, Peru and Viet Nam are planning to adopt MEPS and mandatory labelling programmes. There is still a lot of room for improvement. For example, transportation is one of the faster growing end use sectors in the APEC region, yet few economies have minimum energy efficiency regulations in place for vehicle sales. Economies considering policy actions may be able to learn valuable lessons from the policy experiences of other APEC economies. Greater cooperation within the region may reduce the cost and improve the success rate of new policies.

CONCLUSIONS AND POLICY ISSUES

Energy intensities can serve as proxies for energy efficiency levels, provided that factors not related to efficiency have been removed. Several analytical tools are available to isolate structure and pure intensity effects. Pure intensity is only a good measure of energy efficiency if the aggregate intensity from which it was derived was calculated using detailed, disaggregated data.

This study shows that data is already available in most APEC economies for at least a first order analysis of energy consumption trends in all major macroeconomic sectors and opens the door to further more detailed analysis. Sectoral analysis also provides insight into the sources of energy consumption growth in APEC economies.

In many economies, transportation accounts for a large component of final energy consumption (FEC), comparable to industry, and it is growing quickly. Moreover, there are few energy efficiency policies in place to offset future consumption growth. The services sector, with energy consumption growth rates comparable to transportation should also receive more policy attention. However, it accounts for less than 5 percent of FEC in some economies and addressing consumption growth in this sector is less urgent than for transportation. The industrial and residential sectors are also important consumers of energy; however, consumption growth in these sectors is much slower.

The policies outlined in *Chapter 8: Energy Efficiency Policies* provide programme ideas for reducing consumption growth. APEC economies have used a wide range of energy efficiency policies and measures to minimise energy consumption. Of course, any slate of policy initiatives must be tailored to the unique situation of each economy. However, governments considering policy actions may be able to learn valuable lessons from the policy experiences of other APEC economies.

CHAPTER 1

INTRODUCTION

OVERVIEW

This project is an extension of APERC's *Energy Efficiency Indicators for Industry in the APEC Region* completed in March 2000. The purpose of this study is to construct a basic set of energy efficiency indicators for APEC economies. Starting with the whole economy, indicators at different levels of disaggregation will be examined. Indicators for major macroeconomic sectors such as industry, transport, services and residential, and for sub-sectors in industry and transportation will also be analysed.

Another objective of the study is to discuss energy efficiency policies in the APEC economies. This work is taking place in conjunction with a WEC/ADEME study on energy efficiency policies.

Three types of indicators are considered to describe and characterise energy efficiency trends:

- Economic ratios, relating energy consumption to a monetary variable of economic activity are called "energy intensities."
- Technico-economic ratios, relating energy consumption to an indicator of activity measured in physical terms, are called "specific consumption."
- Energy saving indicators estimate the quantities of energy saved or which could be saved, in absolute values or relative terms.

Differences in economic, geographic and climatic conditions make it difficult to compare economies. To facilitate this work, data from different economies should be presented in common units and monetary measures. Moreover, additional indicators should normalise for various structural and climatic differences across economies. These are called "adjusted energy efficiency indicators."

Energy efficiency indicators are needed for several purposes [ADEME, 1999]:

- To describe and monitor energy efficiency trends.
- To compare end use energy efficiency across economies.
- To evaluate the impact of energy efficiency programmes.
- To forecast future levels of energy consumption.

Therefore each energy efficiency indicator should be constructed to address specific questions about sectoral energy end use.

Carbon dioxide emissions, which are closely linked to energy consumption, can also be used to build indicators. These emissions indicators provide insight into the environmental implications of energy consumption.

RATIONALE FOR THE PROJECT

This project was supported at the following APEC Energy Ministers Meetings:

- Third Meeting of APEC Energy Ministers, Okinawa, Japan, 9 - 10 October 1998

  "Ministers … agreed that energy efficiency should continue to be a priority of the Asia Pacific Energy Research Centre, encouraging the Centre to advance its work on energy efficiency indicators."

- Fourth Meeting of APEC Energy Ministers, San Diego, USA, 10 - 12 May 2000

  Encouraged APERC to advance its work on energy efficiency indicators and to continue to have energy efficiency as a priority.

- The project is also in support of Policy No. 2, 11 and 13 of the APEC 14 Non Binding Energy Policy Principles, respectively:

  -# 2: "Pursue policies for enhancing the efficient production, distribution and consumption of energy.";

  -# 11: "Encourage energy research, development and demonstration to pave the way for cost effective application of new, more efficient and environmentally sound energy technologies."; and

  -# 13: "Promote cost effective measures which improve the efficiency with which energy is used but reduce greenhouse gases as part of a suggested regional response to greenhouse gas reductions."

OBJECTIVES AND SCOPE

The objectives of this study were four-fold:

- Establish a common methodology for constructing a basic set of energy efficiency indicators for APEC economies;
- Construct energy efficiency indicators for the whole economy, major energy consuming macroeconomic sectors (industry, residential, services and transport), and for selected industrial and transportation sub-sectors of APEC member economies;
- Identify environmental implications for energy consumption in APEC economies; and
- Develop a network of energy efficiency experts and agencies in APEC member economies.

The study examines all 21 APEC member economies during the time period 1980-1998, data permitting. Energy efficiency policies and current practices in each economy are also analysed.

CHAPTER OVERVIEWS

Chapter 2 begins with a general discussion on energy intensities. Data adjustments are made in this report to improve the quality of intensities discussed. In order to isolate energy efficiency, energy consumption is decomposed into its key drivers: activity, structure, weather and pure intensity. The decomposition techniques applied to the overall economy, the industrial, transportation and services sectors are discussed in detail.

Chapter 3 is devoted to the upper level of economic activity. Gross domestic product (GDP) at purchasing power parity, as an indicator of economic activity, is compared to total energy consumption. Decomposition analysis is implemented to separate the effects of changing structure and energy efficiency improvements. Cross-economy comparisons are attempted using the indicators constructed.

Chapter 4 outlines suitable indicators for evaluating energy efficiency in the industrial sector. Intensities for the manufacturing sector are decomposed into their structural and pure intensity components. Efficiency trends are analysed with reference to physical indicators for energy intensive sub-sectors, iron and steel, pulp and paper and cement.

Chapter 5 constructs energy efficiency indicators for transportation. Since road transportation accounts for 80 percent of energy consumed in the sector, analysis is focused on this sub-sector. Where data was available, detailed energy efficiency indicators were constructed using passenger-km and tonne-km as the activity variables.

Chapter 6 focuses on energy efficiency indicators for the services sector. Energy consumption is decomposed into its activity, structure and pure intensity components. Energy efficiency trends are analysed with reference to weather and end use data wherever possible.

Chapter 7 provides specific energy efficiency indicators for residential energy consumption. Though a decomposition of energy consumption per se is not possible due to data constraints, key energy drivers in this sector are discussed.

Chapter 8 provides a general discussion of energy efficiency policies such as energy audits, demand side management, energy efficiency standards and voluntary agreements. Case studies for labelling and energy audits are also presented.

Chapter 9 provides conclusions and recommendations based on the overall findings, results and analysis of this study.

All the sectoral chapters include a discussion of carbon dioxide emissions which are directly related to energy consumption in that sector.

Appendix A summarises the preliminary results from the ADEME/APERC survey of energy efficiency policies in APEC economies.

Appendix B provides a brief overview of current status and developments in the area of energy efficiency for all 21 APEC economies.

Appendices C and D outline case studies on energy audits and financial incentives, respectively, for energy efficiency in selected APEC economies.

CHAPTER 2

METHODOLOGY

OVERVIEW

Energy intensity indicators measure the quantity of energy required to perform a particular activity, such as the production of output [Martin *et al*., 1994]. Indicators can be denominated in either physical units, where energy is directly related to the physical quantity of output, or alternatively in economic terms, where energy consumption is linked to the monetary value of production. Typically physical indicators are constructed at a more disaggregated level than monetary indicators. Energy intensity indicators perform a variety of functions, ranging from the monitoring of energy efficiency, through to policy analysis and evaluation, and the appraisal of new technologies. However the usefulness and effectiveness with which energy intensity indicators can be used is subject to a number of stipulations, particularly in relation to the availability and quality of data.

Energy intensity indicators measure "how well" energy is used in the production of output.

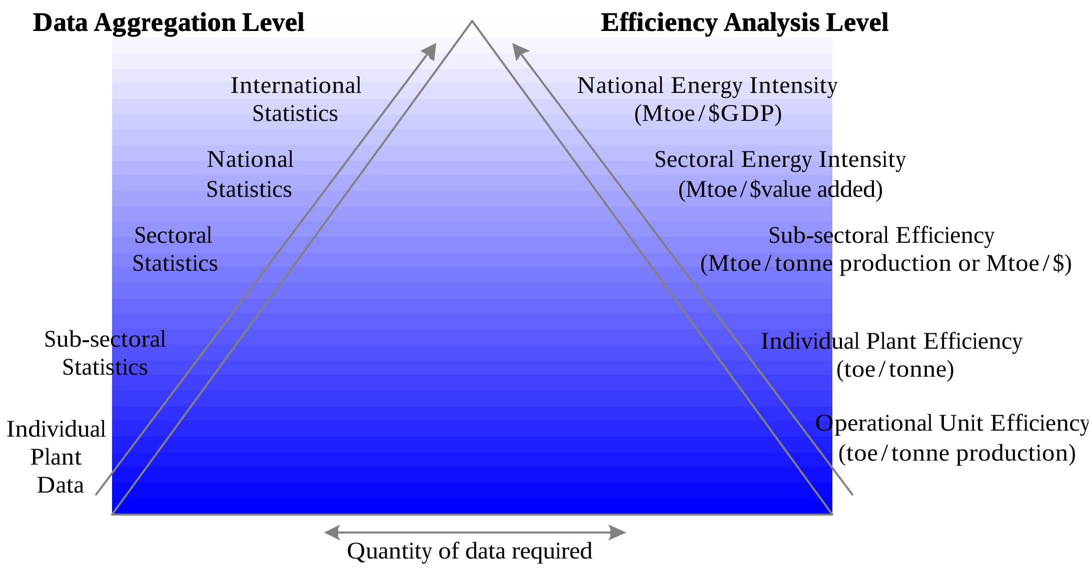
As Figure 1 shows, indicators of energy efficiency can be constructed from aggregated international or national statistics through to output data from individual operating units within a plant. At the highest levels of aggregation - the whole economy and macroeconomic sectors - few indicators of energy intensity can be constructed. Moreover, due to the large level of aggregation, these broad indicators often include many separate effects that can potentially bias the results. For example, although declines in measured national energy intensities for many APEC economies suggest improvements in energy efficiency, other factors, such as the declining importance of energy intensive sectors (structural change) and non-energy related efficiency improvements, also contribute to this result.

As the level of aggregation decreases (moving down the pyramid in Figure 1), the influence of changing structural effects and other factors also decline. Physical indicators which can only be calculated at more disaggregated levels, measure specific energy consumption relative to a physical measurement of output, such as tonnes of steel or gasoline consumption by vehicle [Phylipsen *et al*., 1998]. Physical indicators reflect a direct relationship between the indicator and technology, which could be more or less energy efficient. Physical indicators cannot be constructed at a sectoral level, because there are no macro-sectors with homogenous bulk output. Clearly, moving further down the pyramid increases the understanding of the multitude of factors that affect more aggregated measurements of energy efficiency, and ultimately affect other variables such as national energy consumption. However, as Figure 1 indicates, the quantity of data required (at the bottom of the pyramid) increases substantially, and the acquisition of data becomes increasingly difficult.

DATA SOURCES AND ENERGY EFFICIENCY INDICATORS IN THIS REPORT

An *Energy Efficiency Indicators Project Database* for APEC economies was constructed at the outset of this study. This database includes information about economic activity and energy consumption in the main end use sectors - agriculture, industry, transport, services and residential sectors. Wherever possible, data was collected for the period 1980 to 1998. In order to ensure reliability and comparability, international data sources, such as the International Energy Agency (IEA), the World Bank (WB), the

Figure 1 Energy Efficiency Indicator Pyramid



Source Phylipsen *et al*., 1998.

International Monetary Fund (IMF), the United Nations (UN), the Asian Development Bank (ADB) and the Organisation for Economic Co-operation and Development (OECD), were used. A basic set of indicators was calculated from this data set.

Energy data for most APEC economies came from the IEA's *Energy Balances from OECD and Non-OECD Countries Database*. Where IEA data was unavailable or questionable, economy or other sources were used. Energy data from Japan came from the Energy Data and Modelling Center (EDMC), Papua New Guinea data came from the EDMC's *APEC Energy Database*, Chinese Taipei data was from MOEAEC and US data was from the Energy Information Administration (EIA). Where IEA data for industrial sub-sectors looked questionable, data from economy sources was normalised to IEA totals. All of the energy data cited in the report is secondary energy demand, not primary.

All higher level macroeconomic data were taken from the World Bank's *2000 World Development Indicators CD-ROM.* Detailed industrial breakdowns for GDP were not available from the World Bank so, if available, sub-sector industrial GDP data from economy or other sources was normalised to WB totals.

Production data for pulp, paper and paperboard came from the Food and Agriculture Organization (FAO) of the UN forestry database. Steel and cement production data were taken from economy and other sources. Most of the data was updated from APERC's previous study *Energy Efficiency Indicators for Industry*.

Services employment data came from the OECD and the Asian Development Bank and if necessary, were supplemented by economy sources.

For transportation, data on vehicle stocks, fuel efficiency and kilometres travelled were compiled from the International Road Federation, ADB, WB and a variety of economy sources.

The approach implemented in this report is a top-down analysis estimating economic energy efficiency. At the top of the pyramid, data on GDP, value added in macroeconomic sectors (agriculture, industry and services) and corresponding energy consumption is available for all 21 APEC economies. Moving down to more disaggregated levels, data is not as readily available and energy intensities become more difficult to construct, particularly for developing and transitional economies. In this report, indicators are calculated at the economy or macroeconomic level, at the sectoral level and where data was available, at the sub-sectoral level. Some supplementary physical indicators in industrial energy intensive sub-sectors (iron and steel, pulp and paper, cement), transportation and services were constructed. In order to improve the quality of these indicators, decomposition analysis was applied to separate out activity, structure, weather and pure intensity effects.

DECOMPOSITION OF ENERGY CONSUMPTION

Decomposition of energy consumption aims to separate, or "decompose," sub-sectoral activity and / or explanatory variables from aggregate or sectoral data. By isolating the importance of activity and structure, it is possible to estimate the impact of pure energy intensity on changes in energy consumption. Pure energy intensity is sometimes interpreted as an indicator of energy efficiency. However, pure intensity and energy efficiency are only strongly correlated at high levels of disaggregation.

E_t is the sum of sub-sector's energy consumption E_{it}:

$$E_t = \sum_i E_{it}$$

where i is the index of sub-sector.

The total energy consumption E_t is a function of three variables:

1) LEVEL OF OUTPUT, A_t, which measures sectoral activity either in economic or physical units and consists of sub-sectoral inputs;

$$A_t = \sum_i A_{it}$$

2) ENERGY INTENSITY OF SUB-SECTORS, I_{it}, defined as a sub-sectoral energy consumption E_{it} per unit of activity A_{it};

$$I_{it} = \frac{E_{it}}{A_{it}}$$

3) STRUCTURAL PARAMETER, S_{it}, defining the share of sub-sector i in the total sectoral output in the year t;

$$S_{it} = \frac{A_{it}}{A_t}$$

The following equations decompose total energy consumption into the terms of activity, structure and energy intensity:

$$E_t = \sum_i \left(A_t \times S_{it} \times I_{it}\right)$$
$$= \sum_i \left(A_t \times \left[\frac{A_{it}}{A_t}\right] \times \left[\frac{E_{it}}{A_{it}}\right]\right)$$

For the analysis of time series in sectoral energy consumption the Laspeyres indices and Divisia parametric approaches can be applied to calculate the relative impact of each term over time. The indices are constructed by first choosing a base year, then taking the ratio of the above identity to itself, and then allowing one term in the numerator to vary over time while holding all other terms in the numerator and denominator at their base year values. The result is an index that measures the relative impact of the varying term on total energy consumption.

In the decomposition approach, changes in energy consumption between the base year and year t can be divided into activity, intensity and structure effects plus a small residual term:

$$\begin{aligned}
\Delta E_{0t} &= E_t - E_0 \\
&= \sum_i \left(\left[A_0 + \Delta A_t\right] \times \left[S_{i0} + \Delta S_{it}\right] \times \left[I_{i0} + \Delta I_{it}\right]\right) - \sum_i \left(A_0 \times S_{i0} \times I_{i0}\right) \\
&= \sum_i \left(\Delta A_t \times S_{i0} \times I_{i0}\right) && \leftarrow \text{activity effect} \\
&+ \sum_i \left(A_t \times \Delta S_{i0} \times I_{i0}\right) && \leftarrow \text{structure effect} \\
&+ \sum_i \left(A_t \times S_{i0} \times \Delta I_{i0}\right) && \leftarrow \text{energy intensity effect} \\
&+ R_{0t} && \leftarrow \text{residual term}
\end{aligned}$$

where:

E_t, E_0 = energy used by sector in year t and 0 (base year)

$I_{i0} + \Delta I_{it}$, I_{i0} = energy intensity of sub-sector i in year t and 0, respectively

$S_{i0} + \Delta S_{it}$, S_{i0} = output share of sub-sector i in year t and 0

$A_0 + \Delta A_t$, A_{t0} = level of sectoral activity in year t and 0

Once the activity effect is removed, the decomposition approach can be used to analyse trends in energy intensity. In this case, changes in aggregate energy intensity are decomposed into the pure intensity effect and structure effect.

DATA ADJUSTMENTS

Imperfections in the quality of the data set, particularly in terms of consistency and comprehensiveness, can sometimes be improved through careful adjustments. In this report, two key adjustments were made to data: a constant price adjustment and an adjustment for weather effects.

CONSTANT PRICE AND PPP ADJUSTMENTS

The value of output is commonly reported in nominal monetary terms. Both inflation, which hinders year-to-year comparisons, and different valuations of production, which hinders comparisons across economies, influence the value of nominal GDP and can therefore bias the calculation of energy intensity indicators. In this report, in order to ensure consistency and facilitate comparability, all GDP data used for calculating indicators were converted to the value of a 1995 international dollar at purchasing power parity ($95 at PPP).

To account for inflation, nominal values have been converted to 1995 real dollars using a GDP deflator for each economy. By removing the influence of market driven pricing effects and reporting the value of output in "real" terms, meaningful year-to-year comparisons of GDP levels can be made in an economy.

In the APEC region, member economies are at very different stages of economic development and rely on a variety of methods for setting prices. Therefore, using exchange rates to convert different currencies to a common currency may not provide an adequate picture of economic output, because it does not take into account the true value of production. Purchasing power parity (PPP) is calculated by looking at the number of units of local currency required to buy the same basket of goods and services in the domestic market as a US dollar would buy in the United States [WB, 2000]. Therefore, under the definition of PPP, an international dollar has the same "value" or purchasing power in each economy. To standardise the valuation of production and to facilitate comparisons across economies, GDP in local currency was converted to international dollars at purchasing power parity using a normalisation factor provided by the World Bank.

The World Bank does not calculate a PPP conversion factor for Chinese Taipei. Therefore, for this economy, GDP at its 1995 value in local currency was converted to US dollars using an official exchange rate.

WEATHER ADJUSTMENTS

In the residential and services sectors, where buildings account for the bulk of energy consumption, deviations from normal weather patterns can cause energy consumption to fluctuate. Weather-induced variations in energy consumption can bias the numerator of the indicator and appear erroneously as "improvements" or "deterioration" in energy efficiency in a given economy. Adjustments for normal weather patterns facilitate inter-temporal comparisons of intensity. Data requirements for this adjustment are quite demanding. Information on space heating and cooling energy consumption as well as heating and cooling degree-day data are required for each economy. Sufficient data to adjust for weather-induced energy variations were available in only 4 APEC economies: Canada, Japan, New Zealand and the United States.

Due to the wide range of climates, tropical to cold northern, patterns of end use vary across economies. It makes little sense to compare residential and commercial end use intensities across economies. Some economies use more energy per unit of floorspace because the climate is colder and not because they are using energy less efficiently. To facilitate cross-economy comparisons a normal or standard weather pattern should be established for the APEC region or for groups within the APEC region. If all economies were adjusted to a standard set of climatic conditions, meaningful comparisons could be made about efficiency for end uses such as space conditioning. Due to insufficient data, this adjustment to a standard regional set of climatic conditions was not attempted.

In the residential and commercial sectors, only the space heating and space cooling components of final energy consumption require adjustment. The Office of Energy Efficiency in Canada [OEE, 2001] adjusts its residential and services data for weather effects using the method outlined below:

$$SH' = \frac{SH}{SHAW}$$

where

$$SHAW = 1 - \left(1 - \left(\frac{HDD}{HDDR}\right)\right) \times HDDElasticity$$

where

SH'	=	space heating energy consumption adjusted for weather effects
SH	=	unadjusted space heating energy consumption
$SHAW$	=	space heating adjustment for weather
HDD	=	heating degree days
$HDDR$	=	normal or average heating degree days
$HDDElasticity$	=	the percentage change in energy consumption per percentage change in heating degree days

The same procedure was used to adjust space cooling (SC). For residential, the $HDDElasticity$ = $CDDElasticity$ = 1.0. For commercial, the $HDDElasticity$ = $CDDElasticity$ = 0.75 [OEE, 2001]. The final adjustment is the following:

$$E' = E - SH - SC + SH' + SC'$$

where

E'	=	adjusted sectoral energy consumption
E	=	unadjusted sectoral energy consumption

In the ODYSSEE database for European Union countries constructed by ADEME and the European Commission, a similar weather adjustment process is used. In ODYSSEE, however, only the space heating component of energy consumption is adjusted and both residential and services are assumed to have degree-day elasticities of 1.0 [ADEME/EC, 1999].

The OEE method of weather adjustments was chosen for this report because it was more comprehensive than the European method and, in the services sector, it yielded better results. In the services sector, weather is not the only determinant of heating and cooling requirements in a building. Interaction effects between space conditioning equipment and lighting and office equipment can also play a role. For example, the cooling load of a building may be increased in the summer due to heat emitted from lighting and office equipment. Conversely, for the same reason, the need for space heating may be reduced in the winter. The elasticity of 0.75 used at the OEE makes allowance for this interaction and reduces variability in the series more than the elasticity of 1.0 from the ODYSSEE database.

One problem encountered was differences in definitions of heating and cooling degree-days. In Canada and the United States, a heating degree-day is defined as deviations from the mean daily temperature below 18°C or 65°F. For example, if a weather station recorded a temperature of 5°C then the weather station would report 13 heating degree-days. A cooling degree-day was defined as deviations above 18°C or 65°F. In Japan, the definition was different. A heating degree-day was defined as deviations from the mean daily temperature below 14°C and a cooling degree-day was deviations above 22°C if the recorded temperature exceeded 24°C. Since each economy has different preferences for heating and cooling, no adjustments were made for these differences.

APPLICATION OF ENERGY DECOMPOSITION METHODS BY SECTOR

Different decomposition approaches were applied to different sectors depending on the availability of data and the appropriateness of the techniques for a given sector. A parametric Divisia approach was used for the whole economy and the industrial sector. Divisia decomposes energy intensity into structural and pure intensity components. Laspeyres techniques were used for the services and transportation sectors. Using this method, energy consumption is broken down into activity, structure and pure intensity effects. Both techniques are essentially the same; however, Laspeyres has more explanatory power since it measures the impact of activity on overall energy consumption.

MACROECONOMIC AND INDUSTRIAL SECTORS

Energy intensity at the macroeconomic level is defined as the amount of energy (in energy units) used to produce a unit of output (in monetary units). The productive sectors which make up the whole economy are agriculture, industry and services.

Two types of indicators are used in the industrial sector. These are physical and economic indicators. The first is the specific energy consumption per unit of physical output, for example tonnes of cement, iron and steel or paper and pulp. Physical indicators do not fully reflect the factors that determine energy usage, such as technological aspects or the mix of energy activities yet they are more closely tied to technology and energy efficiency than are monetary indicators [Greening, *et al.*, 1997]. The second is the specific energy consumption per unit of gross domestic product (GDP) of the manufacturing industry branches or energy intensities.

THE PARAMETRIC DIVISIA DECOMPOSITION METHOD

To examine energy consumption trends in the industrial sector and to determine the causes of these trends, the parametric Divisia decomposition method was used. This Divisia method is applied on a yearly basis and decomposes the growth rate of the intensity of industry between a base year and a past or a future year into two growth rates, one for structure and the other for pure intensity. The parametric Divisia decomposition method is derived as follows:

The aggregate energy intensity at time *t* can be expressed as the sum of the products of the energy intensities and share of each branch to the total activity of the sector [Ang, 1995], that is:

$$I_t = \sum_i S_{it} \times I_{it} \tag{1}$$

where

$$S_{it} = \frac{A_{it}}{A_t}; I_{it} = \frac{E_{it}}{A_{it}}$$

S_{it} = share of industrial branch i to total gross value added (GVA) (= A_{it}/A_t)

I_{it} = energy intensity of industrial branch i (= E_{it}/A_{it})

A_t = total gross value added (GVA)

A_{it} = GVA of industrial branch i at time t

E_t = total final energy consumption (FEC) at year t

E_{it} = FEC of industrial branch i at year t

I_t = aggregate energy intensity (= E_t/A_t)

Differentiating equation (1) with respect to t yields:

$$I_t' = \sum_i I_{it} \times S_{it}' + \sum_i S_{it} \times I_{it}' \tag{2}$$

Bhaduri (1998), conducted the following derivation:

Dividing both sides of the equation (2) by I_t and integrating on both sides from the base year 0 to year T, yields:

$$\ln\left(\frac{I_T}{I_0}\right) = \int_0^T \left(\sum_i \frac{I_{it} \times S_{it}'}{I_t}\right) dt + \int_0^T \left(\sum_i \frac{I_{it}' \times S_{it}}{I_t}\right) dt \tag{3}$$

Setting $RI_{0T} = I_T/I_0$ as the ratio between the intensities in years T and 0, and using the identities above, equation (3) can be rewritten as equations (4) and (5):

$$RI_{0T} = \exp\left[\int_0^T \left(\sum_i \frac{E_{it}}{E_t} \times \frac{S_{it}'}{S_{it}}\right) dt\right] \times \exp\left[\int_0^T \left(\sum_i \frac{E_{it}}{E_t} \times \frac{I_{it}'}{I_{it}}\right) dt\right] \tag{4}$$

$$RI_{0T} = \exp\left[\int_0^T \left(\sum_i \frac{I_{it} \times S_{it}'}{I_t}\right) dt\right] \times \exp\left[\int_0^T \left(\sum_i \frac{S_{it} \times I_{it}'}{I_t}\right) dt\right] \tag{5}$$

$$RI_{0T} = RI_{Str} \times RI_{Int} \tag{6}$$

where RI_{Str} is the estimated structural effect and RI_{Int} the estimated intensity effect.

To transform the integral path into a parametric problem, consider the integral path that satisfies the following conditions:

$$\min\left\{\frac{E_{i0}}{E_0}, \frac{E_{iT}}{E_T}\right\} \leq \frac{E_{it}}{E_t} \leq \max\left\{\frac{E_{i0}}{E_0}, \frac{E_{iT}}{E_T}\right\} \tag{7}$$

$$\min\{S_{i0}, S_{iT}\} \leq S_{iT} \leq \max\{S_{i0}, S_{iT}\} \tag{8}$$

With the conditions above, the parameter, b_i, which satisfies the following equation can be derived:

$$RI_{Str} = \exp\left\{\sum_i \left[\frac{E_{i0}}{E_0} + b_i\left(\frac{E_{iT}}{E_T} - \frac{E_{i0}}{E_0}\right)\ln\left(\frac{S_{iT}}{S_{i0}}\right)\right]\right\} \tag{9}$$

where $0 \leq b_i \leq 1$.

Applying the above procedure to every term on the right hand side of equations (4) and (5), the following two general parametric Divisia methods (PDM) can be obtained:

PDM1:

$$RI_{Str} = \exp\left\{\sum_i \left[\frac{E_{i0}}{E_0} + b_i\left(\frac{E_{iT}}{E_T} - \frac{E_{i0}}{E_0}\right)\ln\left(\frac{S_{iT}}{S_{i0}}\right)\right]\right\} \tag{10}$$

$$RI_{Int} = \exp\left\{\sum_i \left[\frac{E_{i0}}{E_0} + g_i\left(\frac{E_{iT}}{E_T} - \frac{E_{i0}}{E_0}\right)\ln\left(\frac{S_{iT}}{S_{i0}}\right)\right]\right\} \tag{11}$$

For PDM2:

$$RI_{Str} = \exp\left\{\sum_i \left[\frac{I_{i0}}{I_0} + b_i\left(\frac{I_{iT}}{I_T} - \frac{I_{i0}}{I_0}\right)(S_{iT} - S_{i0})\right]\right\} \tag{12}$$

$$RI_{Int} = \exp\left\{\sum_i \left[\frac{S_{i0}}{I_0} + g_i\left(\frac{S_{iT}}{I_T} - \frac{S_{i0}}{I_0}\right)(I_{iT} - I_{i0})\right]\right\} \tag{13}$$

where $0 \leq b_i, g_i \leq 1$. For this study, these parameters were set to 0.5 to give equal weight to both years and decomposition is performed in a symmetrical manner with respect to time [Ang, 1995].

SERVICES SECTOR

This section describes the Laspeyres decomposition methods applied to services energy consumption. Due to the uneven availability of data, two different Laspeyres factorisation methods were applied. The first method is a variation on a simple factorial approach used in a recent LBNL study on the services sector [Krackeler *et al*., 1999]. The original equation, which was designed to decompose services emissions from energy consumption, was simplified to calculate only services energy consumption. The second factorisation method is based on one used by the Office of Energy Efficiency (OEE) at Natural Resources Canada [OEE, 2000]. It requires more disaggregated end use and floorspace data and could only be applied to a few APEC economies. Both techniques apply a fixed-year Laspeyres index in order to evaluate changes over time in the components of energy consumption. Separate indexes with a base-year of 1990 have been built for final energy consumption as well as for the activity, structure and intensity effects.

FACTORISATION METHOD 1

The identity modified from LBNL to characterise service sector energy consumption for any given year is the following:

$$E = A\left(\frac{W}{A}\right)\left(\frac{E}{W}\right)$$

where

E = final energy consumption

A = activity (service sector GDP at PPP)

W = employment in the services sector

W/A = labour productivity

E/W = energy intensity

Under this simple model, services sector GDP in $95 at PPP is the activity driver. The second term is a measure of labour productivity in the services sector; that is, how many workers are required to produce a unit of services GDP. Energy intensity is measured using energy consumption per worker.

Data Problems

In factorisation method 1, commercial energy is normalised using services employment data. Employment data came from the OECD and the Asian Development Bank and if necessary, were supplemented by economy sources. There was some variation in the definition of service sector employment. In some economies it included self-employed workers and in others it did not. In ADB data in particular, services employment was employment that was not manufacturing, agriculture or mining. The lack of a standard definition of services employment has likely introduced some error into the calculation of indicators.

FACTORISATION METHOD 2

The identity used by the OEE in Canada in their more detailed factorisation method is the following:

$$E = A\sum_i\left(\frac{A_i}{A}\right)\left(\frac{E_i}{E'_i}\right)\left(\frac{E'_i}{A_i}\right)$$

where

E = final energy consumption

A = activity (floor space)

E' = weather adjusted final energy consumption

i = services sub-sector

$$\frac{A_i}{A} = \text{structure effect}$$

$$\frac{E_i}{E_i'} = \text{weather effect}$$

$$\frac{E_i'}{A_i} = \text{intensity effect}$$

In this model, floor space not GDP or employment, is the activity driver. The structure effect is measured by each sub-sector's share of total floor area. This indicator gives insight into how the composition of the sector is changing over time and what impact this may have on energy consumption. The weather effect measures the impact of deviations from normal weather patterns on overall energy consumption. The magnitude of the impact will vary from sub-sector to sub-sector depending on the proportion of total energy devoted to space conditioning. The intensity effect measures energy (adjusted for normal weather patterns) per unit of floor area for each sub-sector. The OEE treats this indicator as a measure of "energy efficiency" in an economy. However, this energy intensity measure includes not only technical energy efficiency, but also behavioural components, fuel mix effects and even changes in business practices.

CONCLUSIONS

Technical work for this report has been very demanding. The compilation of a database covering 21 APEC economies, the construction of indicators for all macroeconomic sectors and the further decomposition of these indicators using established statistical techniques has been challenging but rewarding work. This analytical approach has permitted a more rigorous treatment of energy intensity indicators and has contributed to a better understanding of the sources of energy consumption growth.

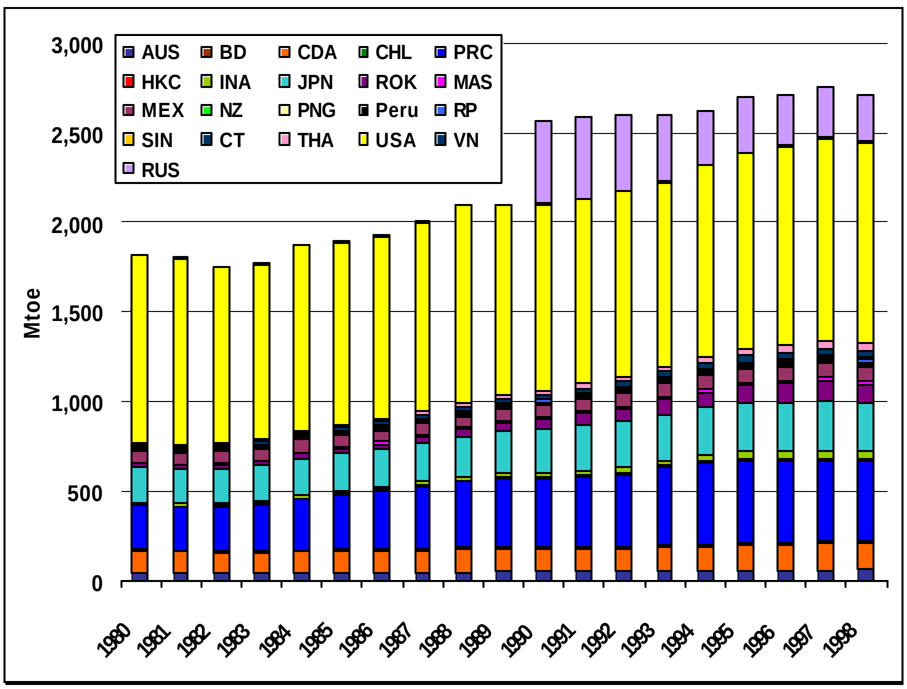
CHAPTER 3

MACROECONOMIC ENERGY EFFICIENCY INDICATORS

OVERVIEW

Energy intensity indicators for the whole economy can be constructed by comparing economic output on a macro-level with related energy input over a given time span. Gross Domestic Product (GDP) represents economic activity in each economy. The corresponding energy input is total final energy consumption (FEC) minus residential energy consumption and non-energy use.[2] The time period covered in this study is 1980 to 1998. Energy consumption for productive sectors in APEC economies is shown in Figure 2.

Figure 2 Whole Economy Energy Consumption*



Source APERC, 2000a * excludes residential and non-energy consumption

Over the 1980-1998 period, energy consumption rose 1.7 percent annually[3] while over the same period, total GDP increased at 4.0 percent per year. GDP for all economies was measured in millions of $95 at PPP.[4]

ENERGY CONSUMPTION TRENDS

The relationship between energy inputs and economic output varies depending on the APEC economy. Figure 3 and Figure 4 show the relationship over time between energy per capita in productive sectors and income per capita. APEC economies have been divided into two groups. The first group contains more developed economies. It includes APEC OECD members and high-income Brunei, HKC[5] and Singapore. The second group is made up of less developed economies. The study period covers 1980 to 1998, except for Brunei (1990-98), Russia (1990-98) and Viet Nam (1989-98).

Several different patterns are observed in Figure 3 and Figure 4. In general, due to industrial development, rising incomes have led to higher energy consumption. This trend is observed in the majority of APEC economies: Australia, Korea, Singapore, Japan (1984-90), Chinese Taipei, Chile, Malaysia (1980-97), China (1980-1996), HKC (1980-92), Thailand, Viet Nam, Peru and the Philippines (1991-98).

In the Philippines (1980-90) and Russia (1990-98) both GDP and energy consumption have been falling. This pattern is associated with economic recession.

A third trend is observed in the USA (1997-98), Canada (1998) and HKC (1995-97). In these economies, GDP has been rising but energy consumption has been declining. Improvements in labour and capital productivity have been driving economic growth in these economies (see box). Energy conservation can also achieve a similar result. In China from 1995 to 1998, GDP growth remained high yet fewer energy inputs were consumed. Fuel switching and more efficient use of energy have likely contributed to the observed trend.

THE UNITED STATES CASE

The US economy grew by 5.3 percent in 1997 and by 3.9 percent in 1998. Total primary energy supply (TPES) increased by 1.9 percent in 1997 and remained stable in 1998, resulting in a 3.2 percent drop in energy intensity in 1997 and a 3.7 percent drop in 1998. The US is undergoing a fundamental structural economic transformation driven by expansion in the information technology (IT) sector. The growing importance of less energy-intensive sectors with more value added has fundamentally changed the structure of the economy. Rapidly rising labour productivity has been the key to strong expansion in the US economy in the late 1990s. Mild weather in 1998 also contributed to the observed energy intensity decline. Energy efficiency programmes (such as ENERGY STAR® and Green Light) launched in the early 1990s, which have helped to reduce energy consumption in buildings, have contributed to the ongoing decline in energy intensity [IEA, 2000b].

Figure 3 Total GDP per capita and Energy per capita, Group 1

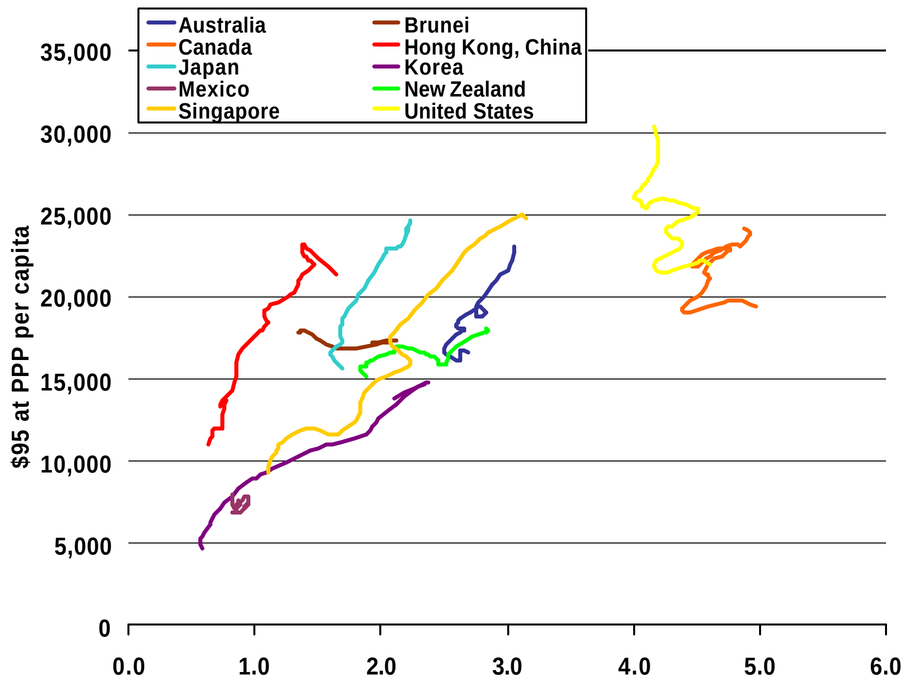
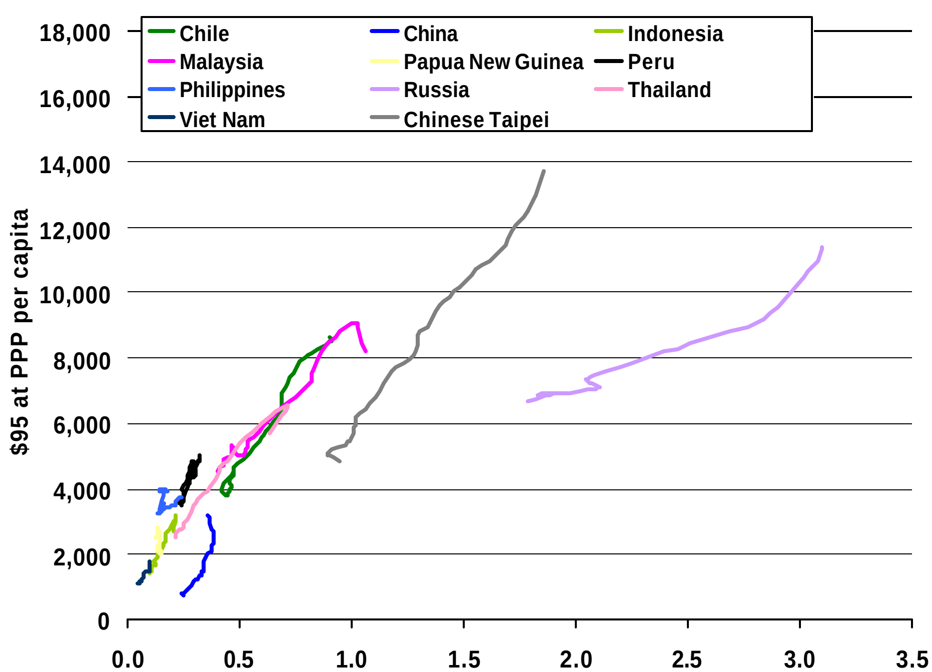


Figure 4 Total GDP per capita and Energy per capita, Group 2



Source APERC, 2000a

In the US and Canada, after the second oil-price shock, there was a deep recession from 1980 to 1983. Energy consumption by productive sectors (industrial, services, transportation and agriculture) declined approximately 2.5 percent per year during these years while GDP (measured in $95 per capita at PPP values) stayed at approximately the same level. In order to reduce energy costs and improve productivity, firms substituted away from energy or found ways to use energy more efficiently. The US used a similar strategy during the next major recession in 1989-92.

An opposite result, increase in energy consumption with a virtually flat GDP, is observed in New Zealand (1983-90) and Brunei (1990-98). This pattern could be the result of a shift to more energy intensive industries and/or a deterioration in energy efficiency levels.

The economies of Indonesia, Malaysia, HKC and Thailand were adversely affected by the Asian Financial Crisis in 1997. In 1998, GDP figures in these economies fell but energy consumption levels stayed at pre-1997 levels resulting in sharp increases in energy intensity.

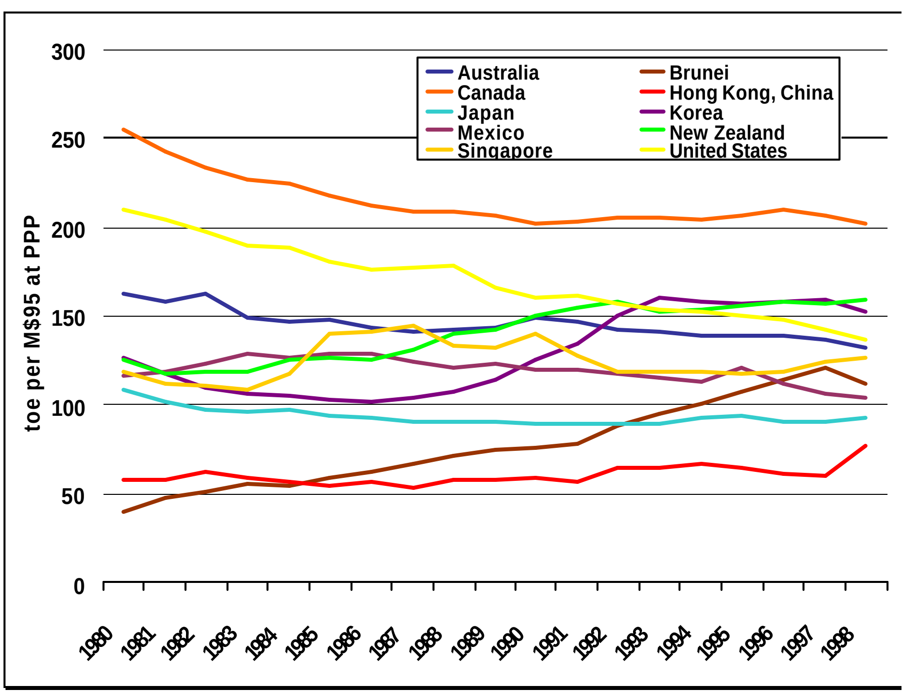
ENERGY INTENSITIES

The first step towards identifying energy efficiency trends is to calculate overall energy intensity, a general indicator of energy end use. Energy intensity is defined as the amount of energy (in energy units) used to produce a unit of output (in monetary units). Actual energy intensity values in APEC economies over the study period are shown in Figure 5 and Figure 6.

GDP energy intensity can be used to analyse issues related to total energy consumption, energy conservation, pollutant emissions, and energy demand forecasting. However, this indicator is influenced by a plethora of factors including economic structure, climate, population density, income levels, resource endowment and prices.

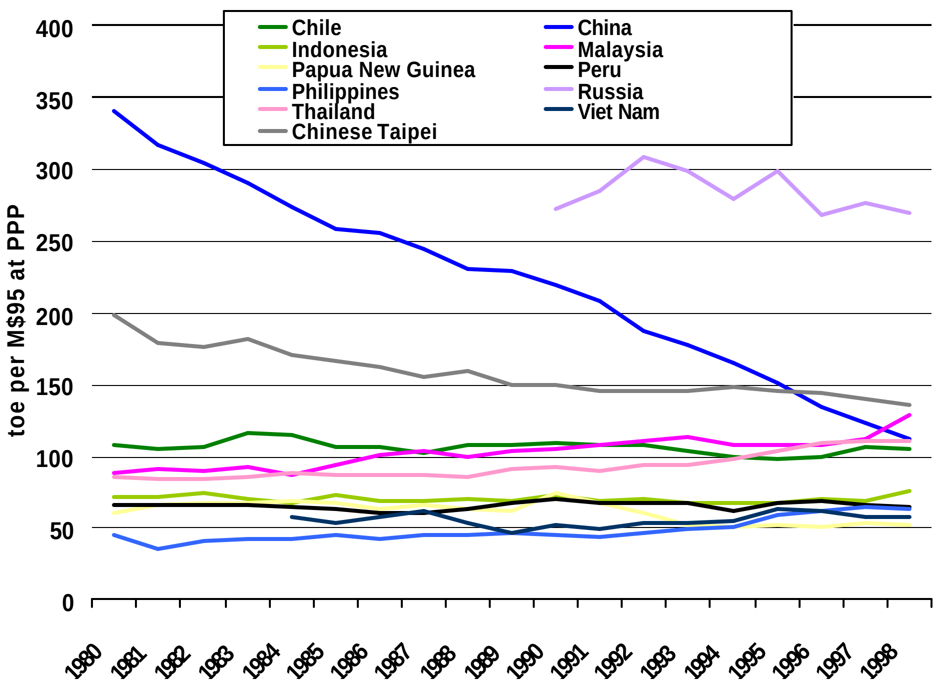
The most energy intensive economies in APEC in 1998 were Russia (269 toe per M$95 at PPP) and Canada (202 toe per M$95 at PPP), two resource-producing economies with harsh climates. The least

Figure 5 Whole Economy Energy Intensities by Total GDP*, Group 1



Source APERC, 2000a * energy for residential and non-energy consumption is excluded.

Figure 6 Whole Economy Energy Intensities by Total GDP*, Group 2



Source APERC, 2000a * energy for residential and non-energy consumption is excluded.

energy intensive economies were Papua New Guinea (52 toe per M$95 at PPP), Viet Nam (57 toe per M$95 at PPP) and HKC (77 toe per M$95 at PPP). Energy intensity in other economies fell in the range 70 to 160 toe per M$95 at PPP. A downward trend is apparent in Australia, Canada (1980-90), China, Japan (1980-93), Chinese Taipei and the United States. Clear upward trends were exhibited by Brunei (1990-97), Korea (1986-93), Malaysia, New Zealand (1980-92), the Philippines and Thailand. GDP energy intensity has been virtually flat in Canada (1990-98), Chile, HKC (1980-97), Indonesia, Mexico, New Zealand (1992-98), Peru and PNG. Energy intensity in Russia (1990-98) and Singapore has been quite volatile.

Higher energy intensity does not always imply less efficient use of energy. Some economies have a larger proportion of energy-intensive industries and by virtue of their economic structure are more energy-intensive. Energy intensity trends are also driven by energy efficiency changes. The impact of structure and pure intensity effects should be isolated in order to determine their contribution to overall energy intensity changes. There are several decomposition methods that can be used to identify these two effects.

DECOMPOSITION ANALYSIS

In this section, the multiplicative Divisia decomposition method is used to decompose energy intensity for the whole economy into two components, structure and pure intensity changes.[6] For this decomposition, structure refers to the GDP share of the three major productive sectors, agriculture, industry and services.[7] By separating out the structure effect from overall energy intensity, a better measure of energy efficiency for the economy is obtained.

Table 1 presents results of 3-sector decomposition analysis of GDP energy intensity trends. The percentages shown are growth rate for the entire period. To obtain overall energy intensity, the structure and pure intensity effects are multiplied.

Table 1 Decomposition Results for GDP Energy Intensity

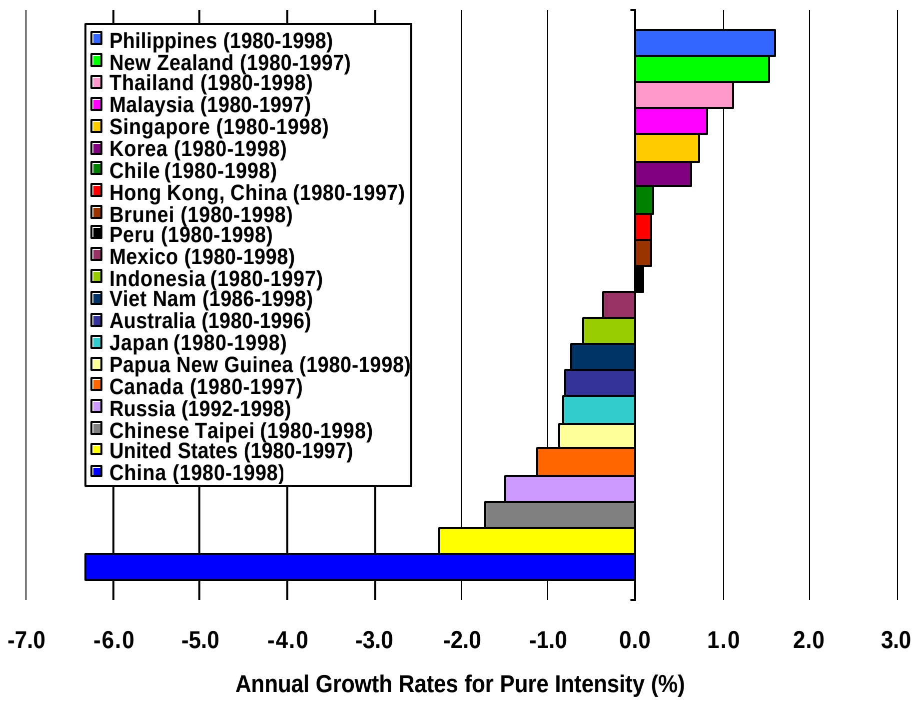
Economy	Period	Structure Effect	Pure Intensity Effect
		percent	
Australia	1980-96	-2.7	-12.1
Brunei	1980-98	170.7	3.0
Canada	1980-97	-4.3	-17.5
Chile	1980-98	-5.9	3.6
China	1980-98	6.7	-69.1
Hong Kong, China	1980-97	1.4	2.9
Indonesia	1980-97	8.1	-9.8
Japan	1980-98	-1.4	-13.8
Korea	1980-98	7.0	12.2
Malaysia	1980-97	12.0	14.7
Mexico	1980-98	-3.4	-6.3
New Zealand	1980-97	-1.6	29.2
PNG	1980-98	1.2	-14.6
Peru	1980-98	-4.3	1.6
Philippines	1980-98	3.1	33.2
Russia	1992-98	-4.7	-8.6
Singapore	1980-98	2.2	14.1
Chinese Taipei	1980-98	-6.2	-26.8
Thailand	1980-98	6.8	22.1
United States	1980-97	0.2	-32.3
Viet Nam	1986-98	9.1	-26.8

Note Derived from APERC, 2000a

Asian economies, except Japan, have become more energy intensive over the study period. A shift to more energy intensive sectors such as industry have raised intensities in Malaysia (+12 percent), Viet Nam (+9 percent), Indonesia (+8 percent), Thailand (+7 percent), China (+7 percent), Korea (+7 percent) and less in the Philippines (+3 percent) and Singapore (+2 percent). The largest structure effect was recorded in Brunei at 170 percent over the study period. The industrial sectors in all of these economies expanded rapidly and made significant progress during the study period. Not only did the industrial sector increase its share of GDP, but there was also a noticeable shift towards energy intensive sub-sectors such as petrochemicals and iron and steel.

Figure 7 shows annualised trends in pure energy intensity at the macroeconomic level. In Figure 7, APEC economies are ranked by the value of the pure intensity effect. The most impressive declines, about - 6 percent per annum were realised in China over the study period. Intensity reductions of more than 1 percent annually were observed in the United States (- 2.2 percent), Chinese Taipei (- 1.8 percent), Russia (1992-98, - 1.5 percent) and Canada (- 1.1 percent). Pure intensity levels also fell in Papua New Guinea, Japan, Australia, Viet Nam, Indonesia and Mexico.

Figure 7 Pure Intensity Trends at the Macroeconomic Level



Note Derived from APERC, 2000a

Pure intensity increased in New Zealand, the Philippines and Thailand at a pace of more than 1 percent annually. Korea, Malaysia and Singapore show similar trends though the rates are slower. Pure intensity in the three major producing sectors also grew in Brunei, Chile, HKC and Peru.

The three-sector structure of GDP is highly aggregated and the indicators obtained provide only a rough estimate of pure energy intensity on a macroeconomic level. The strength of decomposition at this aggregated level is that data availability is good and all 21 APEC economies can be compared consistently.

DRIVERS, EXPLANATORY VARIABLES

Energy efficiency can be better understood in the broader context of economic efficiency. Economic decisions are driven by total cost minimisation. Labour, capital and energy are inputs into the production process. Energy costs typically make up only a small percentage of the total cost of production. In the industrial sector, energy accounts for only 3-8 percent of total cost. In energy intensive sub-sectors the figure is higher at 10-14 percent.

The relative prices of productive factors determine the mix of inputs used in the production process. Average wages are good proxies for the prices of labour, interest rates reflect capital costs and energy prices directly value energy inputs. When energy prices were low as in the late 1990s, there was little incentive to adopt energy efficiency processes and to purchase energy efficient equipment. Since energy is relatively cheap compared to other factors of production, firms tend to use more of it.

The Asian Financial Crisis in 1997 had a significant impact on energy intensity in Asia. Currency devaluations pushed down the value of output and led to jumps in energy intensity in Indonesia, Malaysia and Thailand. (Figure 6)

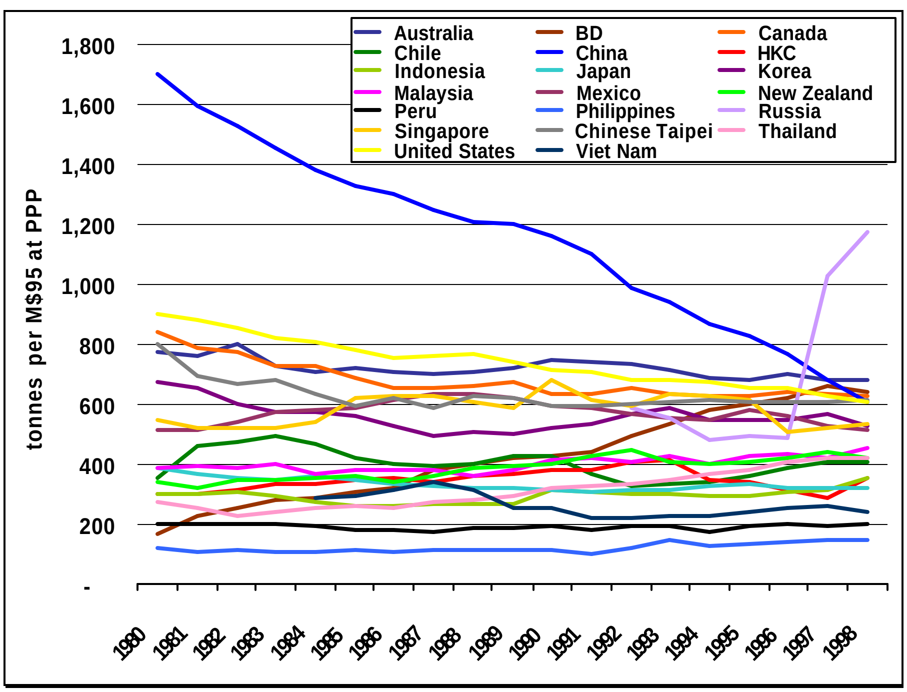
MACROECONOMY CARBON DIOXIDE EMISSIONS

Energy consumption in economic sectors is directly linked with CO_2 emissions. In this study, CO_2 emissions were calculated for full-cycle energy use in all end use sectors. Therefore, emissions have been calculated for all fuels consumed in end use sectors as well as for emissions produced during the electricity generation process. The conversion factors for fossil fuel are those recommended by IEA [IEA, 1998], namely:

- for coal: 3.97 tonnes CO_2 per toe;
- for petroleum products: 3.08 tonnes CO_2 per toe;
- for natural gas: 2.36 tonnes CO_2 per toe.

Energy related CO_2 emissions vary significantly across APEC economies. About 12 billion tonnes of carbon dioxide were emitted in 1998 in APEC, 38.7 percent more than in 1980 (bar Russia). The main contributors were the US (42.0 percent), China (20.2 percent), Russia (9.7 percent) and Japan (8.2

Figure 8 Whole Economy Carbon Dioxide Intensities by Total GDP



Source APERC, 2000a; IEA, 1998

percent).

The evolution of CO_2 intensities over the study period is illustrated in Figure 8. Increasing trends are noted in Brunei (four-fold growth in 1980-98), the Philippines (in 1991-98) and Thailand. The largest reductions in CO_2 intensity have been achieved in China. Intensity fell from 1,700 tonnes per M$95 at PPP to 602 tonnes per M$95 at PPP in 1998. Declining trends were observed in Australia, Canada, Russia (1992-96) and the US. This indicator has been virtually flat in Japan (1988-98), Korea (1990-98), New Zealand (in 1985-98), Peru, Chinese Taipei (1985-98) and Viet Nam (1989-98). Intensities have been variable in Chile, HKC, Malaysia and Singapore.

Since energy consumption is responsible for roughly 90 percent of CO_2 emissions, energy intensity indicators can also be used for environmental monitoring. Energy efficiency improvements are an important tool for mitigating greenhouse gases emissions.

CONCLUSIONS

Energy intensity calculated at the macroeconomic level is a broad indicator of energy use by an economy. Even when decomposed into structure and pure intensity effects, this indicator only provides general information on energy consumption trends and provides little insight into energy efficiency.

This top-level analysis, however, highlights some interesting trends. The developed OECD economies are responsible for most of the energy consumption in the APEC region, but Asian economies are the leaders in energy demand growth. The industrial sector in developing Asian economies has made significant progress over the study period and has increased its overall GDP share. Except for China and Chinese Taipei, pure intensities in these developing Asian economies have been steadily increasing at 1 percent or less per year. Therefore, energy use is growing moderately faster than GDP in Asian economies, not including Japan. This increased consumption of energy is taking place in tandem with rapid economic development, particularly in the industrial sector. Carbon dioxide intensities exhibit similar trends as pure intensity.

The sectoral chapters that follow will discuss in detail energy use trends in the individual sectors that make up the macroeconomy. These chapters will provide insight into the overall picture sketched in this chapter.