ASIA PACIFIC ENERGY RESEARCH CENTRE

ENERGY EFFICIENCY INDICATORS

A STUDY OF ENERGY EFFICIENCY INDICATORS FOR INDUSTRY IN APEC ECONOMIES

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FOREWORD

Over the course of the last two decades, government policy-makers and industry leaders alike have come to recognise the important role energy efficiency plays in supporting economic growth and international competitiveness. Within APEC, the deliberations of the APEC Energy Working Group (EWG) and APEC Energy Ministers meetings, have expressed a desire to promote the importance of energy efficiency policies and measures, and to develop ways of assisting individual economies to increase economic efficiency through the wiser use of energy.

Developing a complete understanding of energy end-use, and ways in which energy can be used more efficiently, requires an appreciation of the many complexities which make up economic and social activity, and the ways in which these interact.

Before an assessment of energy efficiency can be made, it is necessary to thoroughly analyse particular sectors of each economy to appreciate the factors that may be important. In particular, it needs to be recognised that individuals and firms must carefully weigh the costs of efficiency improvements against the period of time over which a return on the investment can be achieved.

The purpose of APERC's energy efficiency study has been to examine three important sectors, namely iron and steel, cement, and pulp and paper. These sectors were chosen, and approved by the APEC Expert Group on Energy Data and Analysis, because they are energy intensive and their production flows through all other parts of the economy.

A particular aim of the research has been to develop a wider and more complete appreciation of the subject with respect to productive sectors in APEC member economies. Through the interaction of a network of energy efficiency experts, assembled by APERC as part of this research, and through this report, I am confident this objective has been successfully accomplished.

I would like to express my sincere gratitude to my fellow APERC researchers who have been involved in this research, and also to the many experts who have contributed valuable comments as APERC's research progressed. APERC is particularly indebted to the help and support offered by Lawrence Berkeley National Laboratory in the United States and Utrecht University in the Netherlands.

Keiichi Yokobori
President
Asia Pacific Energy Research Centre

March 2000

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ABARE	Australian Bureau of Agricultural and Resource Economics
ADEME	Agency for Environment and Energy Management (France)
AIT	Asian Institute of Technology
ANZSIC	Australian and New Zealand Standard Industrial Classification
APEC	Asia Pacific Economic Cooperation
APERC	Asia Pacific Energy Research Centre
AVE-PDM	Average parametric Divisia method
BOF	Basic oxygen furnace
BP	Best practice
$CaCO_3$	Limestone
CDQ	Coke dry quenching
CEMBUREAU	European Cement Association
CHP	Combined heat and power
CIEDAC	Canadian Industrial Energy End-Use Data and Analysis Centre
CO_2	Carbon dioxide
DRI	Direct reduced iron
EAF	Electric arc furnace
ECCJ	Energy Conservation Center, Japan
EDMC	Energy Data and Modelling Center (Japan)
EECA	Energy Efficiency and Conservation Authority (New Zealand)
EGAT	Electricity Generation Authority of Thailand
EGEDA	Expert Group on Energy Data and Analysis
EGEEC	Expert Group on Energy Efficiency and Conservation
EIA	Energy Information Agency (US)
E^nR	European Network of Energy Efficiency Agencies
ERI	Energy Research Institute (China)
EWG	Energy Working Group
FILP	Fiscal Investment and Loan Program (Japan)
GDP	Gross Domestic Product
GHG	Greenhouse gases
GJ	Giga joules
IEA	International Energy Agency
IEEJ	Institute of Energy Economics, Japan
IISI	International Iron and Steel Institute
INEDIS	International Network on Energy Demand Analysis in the Industrial Sector
I-O	Input-Output
ISI	Fraunhofer Institute for Systems and Innovation Research
ISIC	International Standard Industrial Classification of All Economic Activities

JDB	Japan Development Bank
JSIC	Japanese Standard Industrial Classification
KEEI	Korea Energy Economics Institute
ktoe	kilo tonne of oil equivalent
kWh	kilowatt-hour
LBNL	Lawrence Berkeley National Laboratory (US)
LOE	litres of oil equivalent
MITI	Ministry of International Trade and Industry (Japan)
Mtoe	Million tonnes of oil equivalent
NA	Not available
NAICS	North American Industry Classification System
NEDO	New Energy and Industrial Technology Development Organisation (Japan)
NRCanada	Natural Resources Canada
NSP	Suspension preheater kiln with calciner
ODYSEE	On-line Database on Yearly Assessment of Energy Efficiency
OHF	Open hearth furnace
R&D	Research and Development
SEC	Specific energy consumption
SP	Suspension preheater kiln
TPES	Total primary energy supply
TRT	Top pressure recovery turbine
US SIC	US Standard Industrial Classification
WEC	World Energy Council

EXECUTIVE SUMMARY

ENERGY EFFICIENCY INDICATORS

OVERVIEW

The Asia Pacific region has experienced rapid economic growth over the last two decades, with much of this concentrated on the rapidly emerging economies in Southeast and Northeast Asia. APEC, which comprises 21 member economies on the Pacific Rim, includes the world's wealthiest, and some of the globe's poorer economies, struggling to overcome the entrenched problems of poverty, lack of infrastructure, and undeveloped legal and financial institutions.

What is most interesting about the Asia Pacific region is the structural change occurring in the emerging economies as they move through the industrial age and towards the post-industrial, service and information oriented structures now clearly evident in the most developed of economies.

Economic growth is generated either by increased inputs of capital and labour, or by the more efficient use of those inputs. This can come about as a result of new technology, or through better management. Energy is one of the critical inputs in the energy intensive industrial sector, and as growth based on increasing inputs of capital begins to reap diminishing returns, the efficiency with which energy is managed becomes increasingly important.

The advantage emerging economies in the Asia Pacific region have, in the modern world with its relatively open market economies, is a very good opportunity to adopt innovations developed by more advanced nations, and to use such technology and know-how to greatly assist their own economic development. Because adopters of technology do not have to bear the full costs of capital intensive innovation, they can use sparse capital more effectively to develop essential infrastructure, and for social policy imperatives.

However, to make use of the technologies the developed world has to offer, in terms of modern, efficient processes and equipment, emerging economies require information. Firms in the productive sectors require information - to avail themselves of more efficient technologies and management methodologies - and so do policy-makers, so that the macro-economy functions efficiently. This leads to the importance of basic, consistent and homogenous statistics, and the dissemination of information from the analysis of those statistics, to provide a tool for others to allocate capital most effectively.

Broad scale energy efficiency indicators contribute to an understanding of what is happening at a macro-economic level. GDP growth in the most rapidly emerging economies has been high over the last two decades, in particular up until the financial crisis in 1997. Total Primary Energy Supply (TPES) has grown substantial in line with this economic expansion. However, what is most interesting is the fact that the growth in TPES has been less than GDP growth in many APEC economies.

This implies that less energy is being used to produce each unit of economic output. The further implication is that where this is happening, economies are: (1) rapidly adopting the newest, most efficient technologies and processes; and (2) moving through the industrial age and into the post-industrial era. To test these assumptions, it is necessary to have energy information at a more detailed level than the broad, macro-economic level.

APERC'S ENERGY EFFICIENCY INDICATORS RESEARCH

APEC member economies, through the deliberations of the APEC Energy Working Group (EWG) and APEC Energy Ministers' meetings, have expressed a desire to promote the importance of energy efficiency policies and measures, and to develop ways to assist individual economies to increase economic efficiency through the wiser use of energy.

APERC undertook this project to facilitate a broader understanding of energy use in the APEC region through an analysis of three important energy-intensive industrial sectors, namely iron and steel, cement, and pulp and paper. Macro-economic indicators have also been assessed to determine their usefulness in providing information on the overall structure of individual economies. Another facet of APERC's research has been to draw together experts from APEC member economies and facilitate an exchange of information by creating a network of energy efficiency experts.

This last activity has been the most successful, and most important outcome of this research. It has become obvious in the course of this study that good historical energy end-use information is patchy, even for the most developed economies. To address this problem, a network of energy data experts is required, each tasked with the job of convincing policy-makers in their own economy that certain key energy end-use statistics should be gathered, and basic reliable, consistent and homogenous databases be developed and maintained.

Because of the cost of gathering energy statistics and maintaining databases, a focus has been put on discerning which basic set of statistical information is essential, and which desirable, to provide useful information on the structural changes occurring within the economy. Further to this, the importance of this information needs to be promoted within the productive sectors of each economy.

THE METHODOLOGY FOR THIS STUDY

INDICATORS

Energy intensity indicators measure the quantity of energy required to perform an activity. The measurement of indicators, either in physical or monetary units, and the type of indicator to use, vary according to the nature of the analysis to be undertaken. Generally, indicators measured in monetary units are applied to the analysis of energy efficiency at a macro economic level, while physical units are applied to sub-sectoral level indicators.

Indicators of energy efficiency can be constructed from aggregated national statistics through to output data from individual operating units within a plant. At the highest level, there are only a few indicators that can be constructed. These broad indicators contain many structural effects that can bias the indicators developed. 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. The same is true at a sub-sectoral level, where differences in technologies, product mix, and other factors may limit the comparative analysis of indicators, especially between economies. Several techniques exist to decompose an aggregate energy intensity trend into its underlying factors. However, they are usually limited by the availability of disaggregated data.

In this study, the "Best Practice" approach was used to assess the energy efficiency potentials that exist in the three sectors studied.

DATA

A key message arising from early collaboration with international organisations was the importance of reliable data that was preferably official. The data used in most of this report is derived either from the APEC Energy Database, APEC member economy statistics, INEDIS Database and from respected international organisations such as the International Energy Agency, World Bank and the Asian Development Bank. Sources include both publications and special tabulation of data generated by energy and non-energy authorities in member economies. Non-energy authorities included those ministries and statistical sources reporting on industrial data.

As has been the case with most energy efficiency studies, one of the major obstacles encountered has been the availability of comprehensive, reliable, homogenous and detailed data. This has limited the study mainly in terms of the economies covered, the period considered, and the depth of the analysis performed.

ENERGY EFFICIENCY INDICATORS

Energy intensities in both physical and economic terms were calculated, as well as energy saving potentials and CO_2 intensities. However, given the limited data availability, in most cases only descriptive trends could be derived.

IRON AND STEEL SECTOR

In response to the growing production of iron and steel in the Asia Pacific region, energy consumption has increased steadily over the study period (1980-1996).

Although a general trend of declining energy intensity in the industry (amount of energy required to produce one tonne of iron and steel) for most APEC member economies can be discerned, the decline for most developed economies is relatively flat, suggesting that major structural changes have not been occurring. The most interesting trends are those for China and the Philippines. They suggest significant changes have occurred in the sector over time, as old inefficient processes (often small scale) have given way to more efficient, modern processes that have captured substantial economies of scale as the industry has consolidated and matured. Russia constitutes an interesting study case, where its rising energy intensity trend was decomposed into its explanatory variables (activity, structure and pure intensity effect).

Indicators of energy saving potentials suggest that the adoption of best practice could significantly reduce energy consumption in most of the economies studied.

CEMENT SECTOR

Cement production in the APEC region has been increasing at a faster pace than the world average, accounting in 1995 for almost 63 per cent of world production. In terms of energy consumption, world cement production accounts for nearly 2 per cent of the total primary energy demand.

Sectoral energy intensity indicators of almost all the economies with available data, show a declining trend for most of the period studied (1980-1995). This has been the result, among other measures, of the introduction of the dry process and of various energy-efficient technologies, especially cement kilns with precalciners and suspended preheaters (NSP kilns).

The analysis of energy saving potentials shows that Japan has reached a stage where further substantial energy efficiency improvements will require major technological breakthroughs. Other economies would seem to have considerable room for lowering their energy intensities.

PULP AND PAPER SECTOR

The majority of APEC economies show a general trend of declining pulp and paper sector energy intensities, although the extent and consistency of the trend varies significantly between economies. Electricity intensities in the pulp and paper sector have declined steadily over the 1980s for almost all economies, although some economies had rising intensities in the latter part of the decade. Overall, the data suggests that energy intensities for fuels other than electricity have remained fairly constant or declined moderately in the more developed economies. Declining intensity over time is more marked for developing economies (especially China, Thailand, and Chinese Taipei).

The above, together with the analysis of indicators of energy saving potentials suggest that substantial improvements in efficiency levels are occurring in the sector in the developing economies with time.

CONCLUSIONS AND POLICY ISSUES

There is a wide recognition among APEC member economies that energy efficiency improvements have a positive effect on economic development, energy security and environmental protection.

Energy efficiency indicators can be very useful tools to evaluate energy efficiency, monitor changes, develop and assess policies, facilitate comparisons and construct demand projections.

However, a fundamental requirement for all these analyses is the availability of data, which proved to be the biggest obstacle in this study.

Concerted efforts should be focussed on developing a database with a consistent industry classification system and methodology to establish and institutionalise comparable energy efficiency indicators in APEC member economies. The role of policy-makers in this task is crucial.

CHAPTER 1

APERC'S ENERGY EFFICIENCY RESEARCH

OVERVIEW

APERC's Energy Efficiency Indicators for Industry research was initiated by a desire among APEC member economies to improve efficiency generally. The focus of the study on energy intensive industries reflects the greater potential for energy savings in these industries. As energy is utilised throughout all sectors of an economy, the potential gains from enhancing energy efficiency are significant and, in aggregate, can amount to billions of dollars.

APERC's research aims to facilitate a broader understanding of energy efficiency in the APEC region through the analysis of three important industrial sectors, namely, iron and steel, cement and pulp and paper. APERC has also reviewed macro-economic indicators and assessed their usefulness. Another facet of APERC's research has been to draw together experts from APEC member economies and facilitate an exchange of information by creating a network of energy efficiency experts.

PROJECT BACKGROUND

Over the course of the last two decades, government policy-makers and industry leaders alike have come to recognise the important role energy efficiency plays in supporting economic growth, international competitiveness and environmental protection.

Within APEC, the deliberations of the APEC Energy Working Group (EWG) and APEC Energy Ministers meetings, have expressed a desire to promote the importance of energy efficiency policies and measures, and to develop ways of assisting individual economies to increase economic efficiency through the wiser use of energy.

Improving energy efficiency is embodied in several of the 14 APEC Non-Binding Energy Principles, and is also fundamental to many new bilateral and multi-lateral agreements, including the Kyoto Protocol.

APEC 14 NON-BINDING ENERGY POLICY PRINCIPLES

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

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

Article 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."

Most recently, APEC Energy Ministers underlined the importance of enhancing energy efficiency in the APEC region during their third meeting in Okinawa, Japan, during October 1998. Ministers and officials recognised the importance of energy to all sectors of the economy, and to regional economic growth and development.

THIRD APEC ENERGY MINISTERS DECLARATION, Okinawa, Japan.

Paragraph 22: "Ministers instructed the Energy Working Group to develop a program to exchange information on policies, technologies and practices to improve the efficient production, transportation and consumption of energy. 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."

In Okinawa, Energy Ministers also underscored the importance of fostering further sharing of information and experience in achieving improved energy efficiency, and developing indicators and databases that will enable the measurement of performance over time. On this premise, Ministers agreed that APERC's Energy Efficiency Indicators in Industry research should be prioritised.

RESEARCH OBJECTIVES

APERC's research into APEC Energy Efficiency Indicators has been conducted with the following objectives:

- To compile an adequate set of information on energy use in the industry sector;
- To develop a common methodology to measure energy efficiency throughout the APEC region;
- To identify potentials and key factors that facilitate improvements in energy efficiency; and,
- To establish a network of industry sector energy experts within APEC member economies.

RESEARCH PRIORITIES AND SCOPE

During the early stages of the study, APERC decided, in collaboration with other institutions, to focus on energy intensive industries as well as provide general macroeconomic indicators for as many APEC economies as possible.

The selection of the energy intensive industries took into account the relative economic significance, the relative dependence of energy in production and the utilisation of output throughout the economy and region. Taking these factors into account, three sectors were selected:

- Iron and Steel
- Cement
- Pulp and Paper

The attractiveness in selecting these sectors also extended to the documentation and data available at the sectoral level. However it was recognised that sub-sectoral data availability could potentially limit the scope of the research. As an international research organisation, APERC has not pursued the collection of primary data, instead relying on the collection of data from energy organisations in individual economies.

In the iron and steel industry, energy indicators were generated for the following economies:

- Australia
- Canada
- Chile
- People's Republic of China
- Japan
- Korea
- Philippines
- Russia
- Singapore
- Chinese Taipei
- United States

In the cement industry, energy indicators were generated for the following economies:

- Australia
- Canada
- Chile
- Japan
- Korea
- Mexico
- Philippines
- Thailand
- United States

In the pulp and paper industry, energy indicators were generated for the following economies:

- Australia
- Canada
- Chile
- People's Republic of China
- Japan
- Mexico
- New Zealand
- Philippines
- Chinese Taipei
- Thailand
- United States

PROJECT METHODOLOGY

The overall project approach adopted by APERC to address the project objectives was divided into four categories, representing the fundamental objectives of the project.

INDUSTRY SECTOR ENERGY EFFICIENCY EXPERTS

The creation of a network of energy efficiency experts, focusing on the industrial sector, was a key feature of the project, and was successfully achieved through a four-part approach.

CONSULTATION

In developing the network, APERC consulted with the APEC Expert Groups on Energy Data and Analysis (EGEDA) and Energy Efficiency and Conservation (EGEEC), as well as a number of established international and national research groups.

BACKGROUND RESEARCH

APERC's consultation process was supplemented by efforts to compile industrial sector data and establish common methodologies for the construction and analysis of industrial energy efficiency indicators. This process identified further experts and organisations working in the fields related to energy efficiency across the globe.

ATTENDANCE AT INTERNATIONALLY RECOGNISED CONFERENCES AND WORKSHOPS

As part of the desire to increase the skills and expertise, APERC assigned researchers to attend a number of internationally recognised conferences and workshops. Researchers also participated in a number of APEC fora meetings, such as those held by the APEC EGEEC. Researchers' attendance at these various meetings, conferences and workshops is consistent with APERC's 'Know-How Transfer' programme.

APERC WORKSHOPS

Two energy efficiency workshops were conducted in Tokyo, during September 1998 and October 1999. The workshops provided an important opportunity for the invited expert participants to meet and discuss various topics relating to energy efficiency and the calculation of energy efficiency indicators. APERC's 1999 Annual Conference also included an afternoon session addressing energy efficiency indicators which provided a further opportunity for the invited efficiency experts to collaborate and discuss APERC's research.

The operation and interaction of the network of energy efficiency experts that has been established as a result of APERC's research programme has proved a major success. As the energy efficiency research will continue at APERC through 2000, a forum for energy efficiency experts will be available during forthcoming APERC workshops and conferences.

COMPILATION OF INDUSTRIAL SECTOR ENERGY DATA

In the early part of the project, a survey was developed and delivered to APEC member economies. The survey solicited general economy energy data as well as sectoral production and energy use data for the period 1980-96. Although relatively simple, the survey provided important information for APERC's research, and was discussed during APERC's Energy Efficiency Indicators for Industry Workshop held in September 1998.

In many instances the survey data returned to APERC was insufficient to meet the objectives of the project. Where possible this data was augmented by gathering further information directly from officials at national energy agencies of the member economies. This process provided an opportunity to partially validate data, as well as providing details of the current energy situation and industrial reforms taking place in particular economies.

In conjunction with the survey, APERC researchers reviewed existing APERC databases, established as part of the APEC Energy Demand and Supply Outlook work, as well as databases held by foreign governments and international organisations. A key message from early collaboration with international organisations was the scarcity of reliable official data. Developing energy data though concise and consistent methodologies is a fundamental prerequisite for any authoritative analysis of energy efficiency.

The data used in most of this report is derived either from APEC member economy statistics, the APEC Energy database (compiled by EDMC, the coordinating agency of EGEDA) or from respected international organisations' databases, such as the International Energy Agency, World Bank and the Asian Development Bank. Sources include both publications and specific databases generated by energy and non-energy authorities in member economies. Non-energy authorities included those ministries and statistical sources reporting on industrial data.

Data was further supplemented by additional information requested through EGEDA and industry experts representing various organisations. In some instances non-APEC member economy information was obtained to take advantage of the important energy efficiency work taking place outside the APEC region.

COMMON ENERGY EFFICIENCY INDICATOR METHODOLOGIES

Determining methodologies for calculating energy efficiency indicators was facilitated through research and cooperation with energy experts. A number of methodologies have been developed to calculate and analyse energy efficiency indicators at various levels of aggregation.

The project's methodologies are reviewed in Chapter 3.

ENERGY EFFICIENCY IMPROVEMENT POTENTIALS

Ultimately potential energy efficiency improvements occur as the summation of the potential operational efficiency improvements measured at a plant level or lower.

ANALYSIS OF ENERGY EFFICIENCY INDICATORS

By constructing energy efficiency indicators that compare similar energy consuming processes and eliminate external influences, comparative static analysis can be applied to identify a relative improvement potential. Subject to the influence of external factors, a difference in energy efficiency indicators implies potential for an improvement in energy efficiency.

The challenge with this approach is excluding external influences that reflect differences in the economic structure, economic and technological development, energy consumption and other variables. As indicators of energy efficiency are calculated at more aggregate levels, the influence of external factors increases and it becomes increasingly difficult to account for these differences.

In developing approaches to identify energy efficiency improvement potentials, APERC sought to review and compare the application of existing indicator methodologies, and thereby establish a framework for analysis.

EXPERT RECOMMENDATIONS

A constructive outcome from the network of energy efficiency experts was the important feedback on methodologies to calculate and analyse energy efficiency indicators. In some instances, experts were also able to advise on technical improvement potentials available as a result of new technologies.

APERC ENERGY EFFICIENCY WORKSHOPS

An important part of APERC's energy efficiency programme has been the organisation of three international meetings in Tokyo to discuss energy efficiency indicators. The first and third of these meetings were organised as workshops, and the other took place as part of APERC's Annual Conference. These workshops aimed to provide a discussion forum for energy efficiency experts. Experts were invited from throughout the APEC region, and also from selected sources outside the region.

Not including the attendance of representatives from the APEC Expert Group on Energy Data and Analysis (EGEDA), energy efficiency experts invited to participate in APERC's workshops represented the following organisations (in alphabetical order) corresponding to 15 of the 21 APEC economies:

- APEC Energy Working Group - Expert Group on Energy Efficiency and Conservation (EGEEC)
- Asian Institute of Technology (AIT), Thailand
- Agency for Environment and Energy Management (ADEME), France
- Australian Bureau of Agricultural and Resource Economics (ABARE), Australia
- Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC), Canada
- Department of Energy, Philippines
- Department of Petrochemicals and Energy, Papua New Guinea
- Electricity Generation Authority of Thailand (EGAT), Thailand
- Energy Conservation Centre, Japan (ECCJ), Japan
- Energy Efficiency and Conservation Authority (EECA), New Zealand
- Energy Information Administration (EIA), United States Department of Energy, USA
- Energy Research Institute (ERI), China
- Environment and Energy Technology Centre, Malaysia
- Fraunhofer Institute for Systems and Innovation Research (ISI), Germany

- Inha University, Korea
- International Energy Agency (IEA), France
- Industrial Technology Research Institute, Chinese Taipei
- Institute of Energy Economics (IEEJ), Japan
- Korea Energy Economics Institute (KEEI), Korea
- Lawrence Berkeley National Laboratories (LBNL), USA
- Ministry of Commerce, New Zealand
- Ministry of International Trade and Industry (MITI), Japan
- Ministry of Mines and Energy, Indonesia
- National Cheng Kung University, Chinese Taipei
- National University of Singapore, Singapore
- Natural Resources Canada (NRCanada), Canada
- New Energy and Industrial Technology Development Organisation (NEDO), Japan
- TECH Support Services, USA
- Universidad Austral de Chile, Chile
- University of Utrecht, Netherlands

The first of APERC's Energy Efficiency Workshops, conducted in September 1998, focused on broadening the participants' understanding of energy efficiency and addressed approaches for calculating energy efficiency indicators in seven APEC economies: Australia, Canada, China, Korea, Japan, Chinese Taipei and the United States. The workshop considered the studies on energy efficiency taking place within the APEC region, and reviewed the effectiveness of alternative energy efficiency indicators. Another key part of the workshop was a review of current energy efficiency initiatives in the APEC region, including the observations of EGEDA representatives.

APERC's second workshop on Energy Efficiency Indicators was conducted as part of APERC's Annual Conference, held in Tokyo during February 1999. Just prior to the conference APERC released its Interim Report on Energy Efficiency Indicators for Industry, which was used to provide the basis for discussion throughout the conference. The Energy Efficiency Indicator sessions at APERC's Annual Conference also permitted energy efficiency experts to comment on the direction and progress of APERC's research.

The final Energy Efficiency Indicator workshop was held in Tokyo during October 1999. The workshop provided participants with an update of APERC's research, and also considered similar studies taking place in other organisations. Importantly, the workshop also considered the effective application of energy efficiency indicators to the policy decision-making process.

Proceedings of APERC's first and third energy efficiency workshops are available from APERC.

LITERATURE SURVEY

Several authors agree that one of the major issues of an energy efficiency policy has always been evaluation: evaluation of results achieved, evaluation of targets, and evaluation of relative situations among countries (Bosseboeuf *et al*, 1997).

One of the major findings of past studies is that straightforward comparison of energy intensities and efficiency indicators will not give a meaningful insight into whether one economy is more energy efficient than another. This is due to structural differences between economies, resource endowments, and other lifestyle and behavioural factors.

Bosseboeuf *et al* identified the following difficulties in comparing energy intensities between different economies:

- Data used are not homogenous in definition and measurement;
- Ratios and indicators calculated for assessing energy efficiency are different from one country to another;
- Interpretation of similar ratios diverges considerably; and,
- Even concepts of efficiency, conservation, savings, and rational use have different definitions among countries.

Another problem with respect to energy efficiency indicators is the separation of energy efficiency effects from structural effects (Phylipsen *et al*, 1998). Authors agree that this problem could be addressed by disaggregating production data to increase the number of indicators.

To reach a consensus on the methodologies for computing energy efficiency, Bosseboeuf *et al* suggested the following:

- Progressive harmonisation of data;
- Definition of a common methodology for energy efficiency assessment; and
- Establishment of an appropriate mechanism to confront on a regular basis the experiences of various countries in the field of energy efficiency policies and to harmonise interpretations.

The French Agency for Environment and Energy Management (ADEME) spearheaded a project on energy efficiency indicators in collaboration first with 12 agencies within the European Network of Energy Efficiency Agencies (E^nR) network and then with 16 agencies or governments (ADEME-SAVE-ENR, 1995, 1996) (Bosseboeuf *et al*, 1997). The ODYSSEE database was developed for the determination and international comparison of energy efficiency indicators.

The project has the following characteristics: a decentralised setting for data collection and expertise, as well as for the interpretation of ratios and energy efficiency indicators; the organisation, storage and processing of data to a common computer database; and double coordination, on a technical level and on an institutional level for supporting common goals (Bosseboeuf *et al*, 1997).

The study discovered comparability problems, such as:

- Primary energy intensities are more adequate for comparing overall energy requirements against GDP, since they account for both the final consumption of energy and the self consumption and losses of the energy transformation system; but the comparison is likely to be biased by the accounting rules adopted for primary electricity (hydro, geothermal) when differences in amount and nature of primary electricity exist among economies; and,

- Final energy intensities are more suitable for comparing the actual energy use pattern against GDP, since they directly refer to the final end-uses of energy; but this comparison can also be misleading if the electricity share in the final consumption differs significantly among economies, because of the high end-use efficiency of electricity and the low transformation efficiency in thermal plants.

The study resulted in the publication: *Energy Efficiency Indicators – The European Experience*, published jointly by ADEME in France, the Association of Energy Efficiency in Europe (the E^nR Club) and the SAVE Programme of the European Commission (ADEME, 1999).

Nagata (1997) conducted a comparison of energy intensities between the USA and Japan. He divided primary energy consumption into energy conversion efficiency, energy mix, actual intensity in each sub-sector and structural effects. He concluded that non-technological effects have considerable impacts on the difference in energy consumption, and the greater US land area had the biggest effect. He also found that even with the exclusion of the non-technological factors in the comparison, the US still consumes more energy than Japan. He was also able to show that using a total energy/GDP ratio for comparison is not appropriate and suggested that the residential and private transportation sectors be excluded in the accounting.

Phylipsen *et al* (1997) identified structural differences in energy intensive industries and described ways of incorporating these differences into international comparisons of energy efficiency. The authors claimed that structural indicators arise from product mix and import/export streams. They also identified non-structural explanatory indicators such as penetration of energy efficient equipment and Combined Heat and Power (CHP) generation technologies. They identified data aggregation as one of the problems. They also cited crossing sector boundaries, absence of data on non-productive sectors and non-commercial/unconventional fuels and feedstock energy requirements as factors that distort energy consumption data.

The authors developed a methodology that shows structural differences can be taken into account in cross-country comparisons of energy efficiency if appropriate physical energy efficiency indicators are used. The specific energy consumption was measured in such a way that all of the energy used in each industrial process is disaggregated into primary energy input, purchased energy (purchased by other users, such as excess electricity from CHP), net available energy, and final energy.

Freeman *et al* (1997) suggested that careful examination of value-based indicators is necessary before they can be used for policy decision-making. The authors presented the results of their analysis of the value of production, of shipment and value-added, which are commonly used as measures of energy intensities. They found that trends in energy intensity based on value of output can diverge sharply from trends in intensity based on the volume of output and these discrepancies are due to the way by which industrial output statistics are constructed under the US Standard Industrial Classification System.

For the pulp and paper industry, Farla *et al* (1997) proposed a method for cross-country, cross-time comparison of energy efficiency developments where it is possible to follow energy efficiency trends, separately for fuel and electricity consumption. The method is based on the use of physical production data as a measure of activity growth for the manufacturing industry and was applied to the pulp and paper industry of eight member economies of the Organisation for Economic Cooperation and Development (OECD). They concluded that their methodology could be used to compare not only the efficiency development between countries but also the energy efficiency levels over a period of time.

Worrel *et al* (1997) followed the simple average parametric Divisia decomposition methodology proposed by Farla *et al* (1997) to understand the factors that contribute to the specific energy consumption (SEC) over time in the iron and steel industry in seven economies. They found varying trends. Efficiency improvement played a key role in the observed energy savings in Brazil, China, Germany and the US, while structural changes were the main driver for energy savings in France and Japan. The decrease in energy efficiency noted in Poland was due to the economic restructuring process. They suggested that economic indicators were generally not meaningful for developing economies. They found that physical indicators provide a basis for a more robust analysis, and recommended their use in analysis and comparison of industrial intensity and efficiency trends.

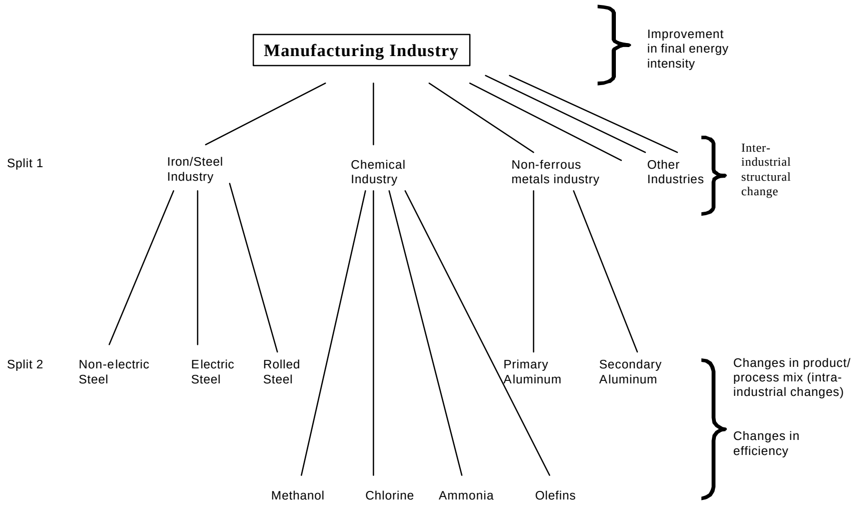
Eichhammer and Mannsbart (1997) in their study *Indicators for a Cross-Country Comparison of Energy Efficiency in the Manufacturing Industry* illustrated suggested disaggregation levels for the analysis of the inter-industrial structural changes and for changes in energy consumption (see Figure 1).

They also used the Divisia method of decomposition and applied it to calculate the energy intensities of the manufacturing industries at constant structure. They concluded that a great deal of analytical work is still needed, as many factors have been neglected, like the integration of foreign trade in energy-intensive intermediate and final products. They also concluded that the simplicity of indicators and the progress in understanding the link between technological changes and influential factors, such as changes in energy price levels, or energy and environment policies, are key factors in the future success of indicator analyses (Phylipsen *et al*, 1998).

OTHER SIGNIFICANT WORK

The *Handbook on International Comparisons of Energy Efficiency in the Manufacturing Industry*, recently published by the Department of Science, Technology and Society of the Utrecht University, The Netherlands was the outcome of two workshops on "International Comparisons of Energy Efficiency" held in 1994 and 1996. This is a methodology handbook that aims to establish a conceptual framework for developing indicators to measure energy efficiency in the manufacturing industry, and to propose indicators for the most important sectors of that industry. It contains energy efficiency indicators for energy-intensive industries. It also identifies the required data and their sources and the methodological and data pitfalls. For each of the sectors, some examples of the suggested indicators are presented, with a checklist of data required for international comparison.

Figure 1 Levels of Manufacturing Industry Disaggregation for Structural Analyses



Source: Eichhammer and Mannsbart, 1997

WEC STUDY ON ENERGY EFFICIENCY POLICIES AND INDICATORS

During the Tokyo Conference of the World Energy Council (WEC), ADEME was tasked to coordinate a study entitled "Energy Efficiency Policies and Indicators". The study conducted by Moisan *et al* (1998), was aimed at describing and evaluating energy efficiency policies and their effect on energy efficiency trends through various indicators, to identify policy measures that were proven most effective in industrialised countries so as to make recommendations for developing ones. A total of 30 countries, 15 OECD and 15 non-OECD, were included in the study.

For energy efficiency indicator analysis, the ODYSSEE and ENERDATA databases as well as data from national correspondents in some countries were used. Energy intensities were based on purchasing power parities as the usual conversion at exchange rates does not give a true comparison of the actual differences in economic activity.

The major findings in the study include:

- In almost all industrialised countries, the primary energy intensity (energy consumed to produce one unit of GDP) has regularly decreased until 1990. The decrease was faster in all countries under study during the period 1980-1986.
- Most of the decrease in total energy intensity can be attributed to the industry sector.
- With the drop in the oil prices in the 1986, less priority is given to public energy efficiency policies, which was attributed to budgetary constraints and a liberalisation trend.
- Energy efficiency programs have been pursued by national governments at national, local and Union levels in several European countries. In non-OECD

countries, energy efficiency policies were mainly focused on electricity through Demand-Side Management (DSM) and Integrated Resource Planning (IRP).

- In most countries, energy efficiency measures were implemented with the private sector playing a major role. The main measures include: energy pricing, information dissemination, energy labelling and impositions of efficiency standards for new buildings and appliances.

- Despite the steady decline in energy prices, energy intensities of industries also declined which were attributed to specific instruments such as: voluntary agreements, mandatory audits, energy management and energy saving plans.

- In the residential and service sectors, the involvement of government remained quite important through imposition of standards and market-oriented measures.

- In transport, only a few countries have implemented energy efficiency policies after 1986.

In conclusion, the drop in oil prices led to disengagement of governments in energy efficiency policies. However, government regulatory measures are still effective where market fails to give the right signals for energy efficiency improvements.

IEA STUDY ON ENERGY INDICATORS FOR MANUFACTURING

Manufacturing energy use in 13 OECD countries was examined in this study in order to find the causes of observed changes in energy intensity. Six sub-sectors: food and kindred products, paper and pulp, chemicals, non-metallic minerals, iron and steel and non-ferrous metals were included in the study.

For each sub-sector, the structure of output and the energy intensity were analysed. The former is measured as shares of value added in each sub-sector, while the latter is measured as delivered energy per unit of value added. To evaluate changes in each country's manufacturing energy use, and to compare changes over time by country, the changes in total energy use were decomposed into impacts from changes in manufacturing output, structure, and sub-sectoral energy intensity using a rolling Adaptive Weighting Divisia index method (Unander *et al*, 1999). Development in the periods after the oil price hikes and the period of relatively stable energy prices were given distinct analysis.

Findings show that changes in the structure of output drove up energy use between 1973 and 1994 in some countries and down in others. Changes in energy intensity were observed to be on a downtrend in all countries examined ranging from 20 per cent to 57 per cent between 1973 and 1994, or 0.7 per cent to 3.5 per cent reductions per year. It was also noted that the decline in energy intensities during the period of energy price stability slowed down but did not reverse with falling prices, indicating that energy efficiency improvements seem to take place even when the energy price is low.

INTERNATIONAL WORKSHOPS ON ENERGY EFFICIENCY

WORKSHOP ON INTERNATIONAL COMPARISON OF ENERGY EFFICIENCY (MARCH, 1994)

In March 1994, the International Comparison of Energy Efficiency Workshop was held, organised by the Lawrence Berkeley National Laboratory of California, USA and Utrecht University, The Netherlands. The aim of the workshop was to identify particular issues in the development of efficiency indicators, to promote better cooperation and information sharing in the analysis of such indicators, and eventually to promote the incorporation of indicators into the policy area in the hope that a standard set of indicators provides a stronger impetus for action through the comparison of response strategies on a common basis (Martin *et al*, 1994). Energy experts from North America, Europe, Japan and developing countries participated.

Discussions were oriented to the development of indicators with particular emphasis at the sectoral level, such as residential, commercial, transportation, industry, and energy transformation. Through these indicators, changes in energy use that account for structural changes and other lifestyle and behavioural effects are identified (Martin *et al*, 1994). It was also found that there is no apparent basis for comparison of energy efficiency among countries. Thus, there is a need for a common methodology for developing indicators and continued need for strong cooperation between countries and international organisations.

It was recommended that countries develop an informal network of research analysts involved in the development and use of indicators, pursue follow-up workshops covering individual sectors and develop a handbook on the measurement and comparison of energy efficiency and on the analysis of potentials to improve energy efficiency (Martin *et al*, 1994).

It was also agreed that there is a need for a common use of and methodology for developing indicators. The continued strong cooperation and involvement of policy makers and research analysts in individual countries and international organisations, can help to bring more consensus on the best choice and use of indicators.

WORKSHOP ON METHODOLOGIES FOR INTERNATIONAL COMPARISONS OF INDUSTRIAL ENERGY EFFICIENCY (APRIL, 1996)

As a follow-up to the March 1994 workshop, the Workshop on Methodologies for International Comparisons of Industrial Energy Efficiency was held in April 1996. The aim of the workshop was to elaborate on the "Handbook on Energy Efficiency Indicators for the Manufacturing Industry" written by Utrecht University and to discuss various energy efficiency indicators and energy data collection methods adopted by countries represented at the workshop (Phylipsen *et al*, 1998). The publication of the Handbook on Energy Efficiency Indicators for the Manufacturing Industry was an offshoot of the workshop.

The methodologies proposed in the handbook were extensively discussed. Discussion ranged from measurement of energy use, sectoral classification of energy end-use processes, adoption of the most appropriate heating value for energy accounting, structural versus explanatory indicators, economic versus physical indicators, conversion of fuels and electricity to final energy and references for energy efficiency improvement.

The issues and agreements that arose during the workshop were as follows:

- Different types of fuels and electricity should be reported separately to satisfy differing needs.
- Higher Heating Value (HHV) is a better measure than Lower Heating Value (LHV). Therefore, HHV should be used in addition to LHV if the latter is the local custom of efficiency analysis but these should be explicitly reported.
- CHP should be included within the industry utilising it instead of the transformation sector. Total input, output, heat and energy sold should however be totally accounted for.

- Feedstock energy should be explicitly accounted for, and included as a component of efficiency indicators in the case where feedstock resource has the potential of being an energy resource.

- Economic indicators give some indication of economic efficiency while physical indicators are needed for energy efficiency. The former can be used as a proxy for the latter. It might be useful to compare physical indicators with different economic indicators to see which one is most closely related to the former.

- No agreement on the best reference point (Best Plant vs Best Practice) was arrived at. Therefore, it is very important to report the exact figure of the reference level.

- No agreement was reached on conversion of fuels and electricity to primary energy. It was therefore agreed that separate reporting be recommended in the Handbook, to allow for various approaches.

SEOUL CONFERENCE ON ENERGY USE IN MANUFACTURING: ENERGY SAVINGS AND CO_2 MITIGATION POLICY ANALYSIS (MAY, 1998)

The objectives of the conference were:

- To discuss methodologies and tools designed for estimating energy savings or CO_2 mitigation potentials;

- To discuss results of studies carried out by applying such methodologies and tools with a special focus on the industry and transformation sectors; and

- To discuss energy saving technology options in studies on Asian developing countries.

The papers presented at the conference show that energy efficiency studies are not only for the purpose of reducing energy use for economic reasons but also for environmental protection, through reduction of CO_2 emissions.

CHAPTER 2

ENERGY EFFICIENCY INDICATORS

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). Energy efficiency is effectively the inverse of this ratio, but aims to measure 'how well' the energy is used to produce output. The calculation of indicators, either in physical or monetary units, varies according to the nature of the analysis to be undertaken. Generally, indicators calculated in monetary units are applied to the analysis of energy efficiency at a macro economic level, while energy efficiency indicators denominated in physical units are more suited to detailed sub-sectoral analysis.

Energy efficiency 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 efficiency indicators can be used is subject to a number of stipulations, particularly in relation to the availability and quality of data.

ENERGY EFFICIENCY INDICATORS

Energy efficiency indicators can be generated according to many different formulations, each of which can be used to answer specific or general questions related to energy efficiency. Figure 2 illustrates the broad variety of energy efficiency indicators that can be utilised.

> *Energy efficiency indicators measure 'how well' energy is used in the production of output.*

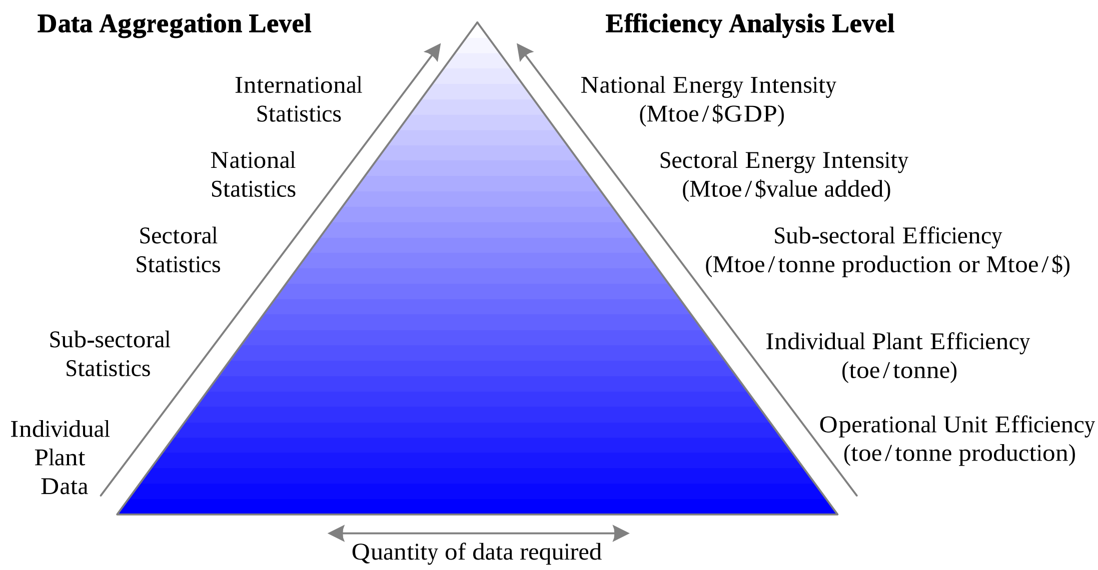
As Figure 2 shows, indicators of energy efficiency can be constructed from aggregated international or national statistics through to output data from individual operating units within a plant. At the highest level, there are only a few indicators of energy efficiency that can be constructed. However, 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 2), then the influence of changing structural effects and other factors also decline.

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 2 indicates, the quantity of data required (at the bottom of the pyramid) increases substantially, and the acquisition of data becomes increasingly laborious.

Determining the appropriate level of detail for the construction of energy efficiency indicators needs to reflect the goals of the specific analysis.

Figure 2 Energy Efficiency Indicator Pyramid



Source: Phylipsen *et al*, 1998.

CALCULATING ENERGY EFFICIENCY INDICATORS

The purpose of this section is to review procedures for calculating energy efficiency indicators, including explanations of the units that indicators are measured in, fundamental data requirements and procedures to enhance the value of energy efficiency indicators through adjustments. The actual methodology for calculating energy efficiency indicators is discussed in the following chapter, and this section is limited to a relatively theoretical discussion.

UNITS OF MEASUREMENT

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.

PHYSICAL INDICATORS

Physical indicators calculate specific energy consumption relative to a physical measurement of production, such as tonnes of product (Phylipsen *et al*, 1998). The advantage of physical indicators is that there is a direct relationship between the indicator and the energy efficiency technology. For example, improvements in technologies will be indicated as savings in the specific energy consumption, and result in an indicator that assesses a lower specific energy requirement per tonne of output.

Since physical energy efficiency indicators are necessarily applied to the analysis of energy efficiency at less aggregated levels, problems associated with the structural effects lessen.

However, to the extent that the product mix and energy source vary, some structural inconsistencies may still exist.

Problems associated with physical indicators include:

- Difficulties associated with aggregating physical energy efficiency indicator data. Since the denominator is defined as a physical unit it is not possible to compare physical indicators defined in differing units unless conversions be made;

- Limitations on the comparability of physical indicators that are measured in different forms. The comparability of physical indicators is limited primarily to different units of denomination, but significant data limitations also exist (which will be discussed in the following section);

- The data requirement associated with the construction of physical energy efficiency indicators is generally more laborious, and is not necessarily easily interpreted.

VALUE BASED INDICATORS

Value based indicators measure the quantity of energy consumed relative to the economic/monetary value of the activity generated, denominated in a currency related unit, for example the quantity of energy consumed relative to the value added of steel sector production. Rather than expressing the output as a measured quantity, such as tonnes of steel, the value associated with production is measured generally in a monetary unit.

The key advantage of using economic value based energy efficiency indicators is that indicators can be compared across industries since the denominator (monetary value) is similar even though dissimilar products are produced. As energy efficiency indicators are constructed at more aggregated levels, economic energy efficiency indicators become increasingly common. At the top of the pyramid represented in Figure 2, the construction of value based energy efficiency indicators is the only alternative.

Although appealing, economic based energy efficiency indicators suffer from a number of limitations, including:

- No inclusion of structural changes either between economies, or within an economy. Decomposition analysis (discussed in Adjustments below) can, to an extent, remedy this deficiency;

- Economic indicators incorporate a range of non-energy efficiency related influences, such as pricing effects;

- Not all sectors of the economy are represented adequately in economic variables, such as the household and personal transportation sectors;

- Differences in aggregation and measurement techniques between economies can also limit the analysis. Analysis of energy efficiency at or below a sectoral level tends to lessen these problems, however the problem is acute where multi-sector aggregated analysis is conducted. Measurement problems are also prevalent in many developing and centrally planned economies where some activities, such as barter, are significant and not included in GDP measures of value added.

DATA REQUIREMENTS

The data requirements for the construction of energy efficiency indicators vary according to the depth of analysis (Figure 2). As more detailed and comprehensive analysis is conducted, the data requirements also increase.

Energy efficiency indicator data covers a broad spectrum from energy consumption related data, through to production level data and value added data. Regardless of the exact specifications of the required data, three fundamental requirements exist: comprehensiveness, consistency and validation. Divergence in the quality of the data from these requirements will limit the construction of energy efficiency indicators, as well as lowering the depth and validity of the energy efficiency analysis.

COMPREHENSIVENESS

The availability of comprehensive data increases the depth of the analysis, and can result in the construction of more robust energy efficiency indicators. Conversely, limited data lowers the certainty of the analysis, and limits the capacity of energy efficiency indicators to study energy efficiency.

Ideally, energy efficiency indicator data should be comprehensive with respect to:

- scope of analysis (sub-sectoral, sectoral, national and international);
- time span of data;
- energy commodities.

CONSISTENCY

Data consistency relates to the way in which the data is measured, and is required to ensure that energy efficiency indicators are comparable. Features of consistent data include:

- use of similar methodologies in the measurement and construction of the data, including assumptions, base years and similar factors;
- similar aggregation classifications;
- continuation of methodologies and classifications when data is collected as a series (over a period of time).

Except in instances where the data has been collected by the same institution, data is generally not consistent. In most instances, these inconsistencies can be accounted for and appropriate adjustments incorporated into the data.

VALIDATION

A final requirement of the energy efficiency indicator data is that it be validated. Data validation is particularly important to ensure the accuracy of the energy efficiency indicators, and also serves as a useful error checking mechanism.

DATA AND INDICATOR ADJUSTMENTS

Imperfections in the quality of the data set, particularly in terms of the consistency and comprehensiveness, can sometimes be improved through careful adjustments. Most often these adjustments aim to account for external influences that result in biased data, and remove these effects either from the data set, or the calculation of the energy efficiency indicator. This section highlights some common adjustments that, when implemented, enhance the analytical capabilities associated with the analysis of the energy efficiency indicators.

AGGREGATION OF ALTERNATIVE ENERGY SOURCES

In cases where the development of energy efficiency indicators requires the aggregation of two or more energy commodities, it is necessary to aggregate the energy sources into a common unit for comparability. This is done by applying conversion factors to a common energy unit, for example, into tonne of oil equivalent (toe).

CONSTANT PRICING ADJUSTMENT

Adjustments for pricing variations are needed for the calculation of value based energy efficiency indicators. The value of output is most commonly denominated in nominal monetary terms, which is susceptible to changes in the value of the monetary unit, and changes in the value of production. Both of these effects influence the denominator and can therefore bias the calculation of energy efficiency.

Changes in the value of the monetary unit arise as a result of inflation or variations in exchange rate. Other factors being equal, inflation increases the monetary value that is associated with a unit of output. In instances where international comparisons are being made and an exchange rate is used to convert the value of output to a common monetary unit, variations in the rate of exchange can also increase or decrease the nominal monetary value of output. In both instances, the comparability of energy efficiency indicators can only be facilitated when adjustments are introduced to remove the effects of external pricing fluctuations.

At a sectoral level, the value of output is subject to variations in the supply and demand conditions through the pricing mechanism. For example an increase in the value of output following an increase in market prices, would erroneously imply a decrease in the energy requirement to produce a unit of output. Although some theoretical models recognise the potential for pricing changes to influence improvements in efficiency, it is difficult to incorporate this effect into the calculation of value based energy efficiency indicators.

Removing the influences of market driven pricing effects, the value of output can be calculated in so-called 'real' terms, and comparisons can be established both internationally and over a period of time.

OTHER ADJUSTMENTS

A number of other data adjustments may be applied to the data to enhance the level of consistency and/or comprehensiveness. Examples include climatic corrections, applying appropriately derived energy conversion factors and other adjustments designed to account for external influences on energy efficiency, such as the adoption of an energy policy that imposes emission controls.

ANALYSING ENERGY EFFICIENCY INDICATORS

The calculation of energy efficiency indicators represents the first step in the ultimate goal of understanding and evaluating energy efficiency. The analysis of energy efficiency indicators is fundamental to developing a thorough understanding of energy efficiency, and can be achieved through a variety of complementary techniques.

EXPLANATORY ANALYSIS

Explanatory analysis relies on the calculation of energy efficiency indicators at a level below the desired level of analysis to provide an indication of changes in aggregated energy efficiency. For example, the analysis of trends in sectoral energy efficiency would be based on the energy efficiency indicators at the sub-sectoral level. In aggregate the sub-sectoral indicators provide an indication of the underlying trends affecting sectoral energy efficiency.

Explanatory analysis is generally supplemented through a comprehensive study of the sectoral and sub-sectoral structure.

TECHNO- ECONOMIC (ADEME, 1999)

The methodology for examining techno-economic effects focuses on an assessment of the technical and behavioural energy savings achieved, and their contribution to the changes in energy consumption. These energy savings are aggregated from individual energy savings calculated at a detailed (disaggregated) level. Energy savings are calculated on the basis of variations in energy performances compared to a base year, with the level of activity and structures of the current year. For a given sector, energy intensities can be combined with unit consumption or specific consumption expressed in different units (for example, litres/100 km with toe/seat-km and toe/pass-km) to characterise energy performances.

ADEME (1999) suggests three complementary alternatives for comprehensively reviewing trends in energy efficiency at a sectoral or sub-sectoral level:

- ENERGY INTENSITY – Energy intensities consider whether energy, as an input to production, is used efficiently. Energy intensities analysis is generally based on relative comparisons with established benchmarks, historical trends, or other comparable energy intensities.

- TECHNO-ECONOMIC RATIOS – These ratios calculate, from an engineering perspective, the economic production associated with the unit or specific consumption of energy.

- ENERGY SAVINGS INDICATORS – These indicators endeavour to measure energy savings achieved by consumers over a period. These ‘techno-economic effects’ essentially analyse changes in the techno-economic ratios.

DECOMPOSITION ANALYSIS

Decomposition analysis is applied to the analysis of energy efficiency indicators to determine the separate influences affecting energy consumption, including changes in the level of activity, structural change, and energy efficiency. Decomposition analysis is most commonly applied to economic indicators, which potentially incorporate many separate influences into the calculation.

For example decomposition analysis applied to the iron and steel sector, could be used to decompose a measure of sectoral energy intensity (toe/value added) into the effect attributable to improvements in technology, structural change within the sector, and changes in economic activity.

There are a number of methods that have been developed to facilitate these calculations.

ROLE OF ENERGY EFFICIENCY INDICATORS

Properly constructed energy efficiency indicators have an important role in the evaluation of energy efficiency, monitoring changes in energy efficiency, developing energy policies, facilitating energy efficiency comparisons and enhancing energy projections (ADEME, 1999).

EVALUATION OF ENERGY EFFICIENCY

The central aim of energy efficiency indicators is to provide an insight into levels of energy efficiency, and in so doing evaluate levels of energy efficiency in comparison to other measures or benchmarks. In cases where policy initiatives to improve energy efficiency are linked to specified energy efficiency indicator improvements, the indicator evaluates the effectiveness of the policy.

Energy agencies or organisations in charge of the implementation of energy efficiency programmes are also directly concerned with such evaluations to justify their actions (ADEME, 1999).

MONITORING

The application of energy efficiency indicators for the purpose of monitoring energy efficiency is generally in relation to specified objectives contained in an energy efficiency programme. The objective may be expressed in numerous ways, but will usually include the definition of specified targets to be achieved over a period of time.

POLICY PLANNING

Emphasis on energy efficiency as a component of energy policy increased substantially following the oil crises in 1973-74 and 1979-80. At the same time, the use of energy efficiency indicators by policy-makers for the analysis of energy efficiency also increased. Energy efficiency indicators allow policy-makers to:

- define and monitor energy efficiency targets;
- evaluate the effectiveness of programmes designed to enhance energy efficiency;
- develop energy policies that respond effectively to changes in energy efficiency;
- supplement energy demand and supply forecasts with energy efficiency information;
- develop intra and inter economy comparisons.

Changes in energy efficiency indicators can also be attributed to improvements in energy technologies. By monitoring energy efficiency indicators, policy-makers can determine the overall influence of the new production technologies on levels of energy consumption.

Appendix A supplements this discussion by briefly examining barriers to enhance energy efficiency, and policies that can be implemented to overcome these barriers.

INTRA AND INTER ECONOMY COMPARISONS

As the emphasis on energy efficiency has increased, the desire to compare indicators of energy efficiency within and between economies has also increased. Comparisons of energy efficiency indicators can be used as a basis for evaluating the relative strengths and weaknesses of respective energy efficiency policies, identifying improvement potentials, and developing reasonable policy objectives.

Although such comparisons are desirable and justified, in practice the difficulty of constructing truly comparable indicators will, in most cases, limit the analysis. These difficulties arise from inconsistencies in a range of factors that influence the measurement of the energy efficiency indicators. For example, differences in the economic structure, resource base, prevalent technologies, data measurement techniques, as well as geographical and climatic considerations. Various data and indicator adjustments can be used to overcome these difficulties, such as the denomination of a common currency unit or standardisation of annual heating days.

ENERGY DEMAND ANALYSIS

The evaluation of energy efficiency, through the use of indicators, is an important tool in developing energy demand and supply projections. Understanding the trends in energy efficiency indicators can be useful for improving the quality of energy forecasts and accounting for future changes in energy efficiency.

Since energy efficiency indicators can be defined at highly aggregated or disaggregated levels, different indicators can be applied to so-called ‘top-down’ and ‘bottom-up’ energy models.

CHAPTER 3

METHODOLOGY AND DATA AVAILABILITY

OVERVIEW

Indicators of energy efficiency can be considered as derivatives of initial data on energy consumption and industrial production. The quality of available data is crucial for robust energy efficiency estimates. This chapter describes the basic methodology for construction of energy efficiency indicators at different levels of aggregation and data constraints.

METHODOLOGY

Two categories of energy efficiency indicators have been identified according to their purposes. Descriptive indicators describe the energy efficiency situation and evolution, while explanatory indicators explain the driving forces behind the energy efficiency level and evolution. Both of these indicators can be expressed in monetary or physical terms or what can be referred to as economic and physical indicators defined as follows:

ECONOMIC INDICATORS

$$EI_i = E_i / PE_i$$

where, EI_i is an energy intensity for industrial activity i; E_i is energy consumption required for industrial activity i; PE_i is the measure of industrial activity i in monetary units.

PHYSICAL INDICATORS

$$SEC_i = E_i / P_i$$

where, SEC_i is specific energy consumption for industrial activity i; E_i is energy consumption required for industrial activity i; P_i is a measure of physical production generated by industrial activity i.

Energy efficiency indicators can be constructed at different levels of aggregation, reflecting analytical objectives. Table 1 highlights the different levels of analysis for monetary and physical indicators.

Table 1 Definitions of Aggregate Energy Efficiency Indicators

Level of aggregation	Energy Efficiency Indicators
National Economy	Economic. Energy Intensity of Gross Domestic Product (GDP): energy consumption per unit of GDP Physical. Non-available
Macroeconomic Sectors. Industry	Economic. Energy Intensity in Industry: energy consumption per unit of value added in industry Physical. Non-available
Industrial Sectors	Economic. Energy Intensity in Industrial Sectors: energy consumption per unit of value added in industrial sector Physical. Specific Energy Consumption: energy consumption per unit of physical production in industrial sector
Industrial Sub-Sectors	Economic. Sub-Sectoral Energy Intensity: energy consumption per unit of value added in industrial sub-sector Physical. Specific Energy Consumption: energy consumption per unit of physical production in industrial sub-sector
Individual Plant	Economic. Plant Energy Intensity: energy consumption per unit of economic output Physical. Specific Energy Intensity: energy consumption per unit of physical output
Technological Process	Economic. Non-available Physical. Specific Energy Consumption: energy consumption per unit of physical output

Descriptive indicators can reflect the combined effects of energy efficiency variations, but they cannot yield a proper interpretation to the relative contributions of the plausible effects. Explanatory indicators serve that purpose. Methods used for formulating explanatory indicators can be grouped into two approaches: the decomposition approach and the general equilibrium approach. The former is widely adopted to decompose the change in energy consumption and energy intensity (Ang and Lee, 1994; Farla *et al*, 1997; Sun, 1998). On the contrary, the latter is relatively less utilised.[1]

DECOMPOSITION OF ENERGY CONSUMPTION

Decomposition of energy consumption aims to separate, or 'decompose', subsectoral activity and/or explanatory variables from aggregate or sectoral data. This is particularly important if the energy intensity of each subsector differs, since relative strong growth in one subsector can then affect aggregate energy intensity.

By isolating the importance of activity and structure, it is possible to estimate the impact of the energy intensity effect on changes in energy consumption. This energy intensity effect is a better measure of efficiency than aggregate energy intensity (energy divided by activity) because it separates out the influence of structure and activity. The change in energy intensity effect can be interpreted as an "indicator" of the change in energy efficiency, the latter of which is only directly measurable at the greatest level of disaggregation.

[1] Appendix B provides an example of decomposition analysis for Chinese Taipei, while Appendix C presents an overview of the methodology used in input-output analysis.

The manufacturing sector's energy consumption in the year t, E_t is the sum of subsector'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, Y_t, which measures sectoral activity either in economic or physical units and consists of sub-sectoral inputs;

$$Y_t = \sum_i Y_{it}$$

2) ENERGY INTENSITY OF SUBSECTORS, EI_{it}, defined as a sub-sectoral energy consumption E_{it} per unit of activity Y_{it};

$$EI_{it} = E_{it} / Y_{it}$$

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

$$S_{it} = Y_{it} / Y_t$$

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

$$\begin{aligned} E_t &= \sum_i \left(Y_{it} \times EI_{it} \times S_{it}\right) \\ &= \sum_i \left(Y_{it} \times [E_{it} / Y_{it}] \times [Y_{it} / Y_t]\right) \end{aligned}$$

For the analysis of time series in sectoral energy consumption the Laspeyres indices approach 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:

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

where:

E_t, E_0	energy used by manufacturing sector in year *t* and 0 (base year);
EI_{i0} + EI_{it}, EI_{i0}	energy intensity of subsector *i* in year *t* and 0, respectively;
S_{i0} + S_{it}, S_{i0}	output share of subsector *i* in year *t* and 0;
Y_{i0} + Y_{it}, Y_{i0}	level of sectoral activity in year *t* and 0.

The decomposition approach can be used to analyse trends in energy intensity, after eliminating an obvious activity effect. In this case the changes in energy intensity are decomposed into the pure intensity effect and structure effect.

Descriptive indicators, based on the decomposition technique can be determined only if the sufficient sub-sectoral data is available. Case studies on iron and steel, pulp and paper and cement industries in Chinese Taipei and iron and steel industry in Russia, which contain the results of the decomposition approach, are presented in Appendix A and Chapter 5 respectively.

ASSESSMENT OF ENERGY SAVING POTENTIALS

Energy Saving Potentials measure the possible energy consumption gains that could be obtained from energy efficiency improvements resulting from the introduction of "Best Practice" performance. In this project "Best Practice" levels in Iron and Steel, Cement and Pulp and Paper industries were obtained from comparative international studies by Worrell *et al* (1995, 1999) and Park *et al* (1998). Actual Best Practice levels are provided in tables below.

The Best Practice performance concept is only relevant for physical energy efficiency indicators, and permits international comparability. Monetary based indicators do not allow the formulation of such benchmarks.

Energy Saving Potentials are identified by comparing actual trends in Specific Energy Consumption (SEC) with trends in the estimated "Best Practice" Specific Energy Consumption (SEC_{BP}). The difference between the actual SEC and estimated SEC_{BP} for a given year represents an estimate of the energy savings potential (relative to SEC_{BP}) for each period, and hence measurement of the energy efficiency improvement potentials (Worrell *et al*, 1997). As the following equation shows, Energy Saving Potentials measure the portion of actual energy consumption that could be saved if energy efficiency was improved to match the best practice potential.

$$EnergySavingPotential = \frac{\left(SEC_{actual} - SEC_{bestpractice}\right)}{SEC_{actual}} \times 100$$

Clearly, an improvement in energy efficiency would be synonymous with a movement in actual SEC towards SEC_{BP}. Therefore, from the above equation, a lower percentage would imply a higher level of energy efficiency and lower improvement potential.

The successful development of Energy Saving Potentials is contingent on being able to breakdown energy consumption and product production to the level of individual process technologies which have an identified SEC_{BP}. This breakdown is needed to ensure comparability between SEC and SEC_{BP}. However in many APEC economies, data availability restricts the level of disaggregation and thereby limits the analysis. In cases where the sub-sectoral share of each technology, or an alternative proxy sub-sectoral structure variable, is known, then a weighted average aggregate of SEC_{BP} can be applied to facilitate the equal comparability between SEC and SEC_{BP}. While the share weighted aggregation of SEC_{BP} is not necessarily ideal, it does permit analysis of actual energy intensity trends relative to the structurally adjusted SEC_{BP} trends.

Table 2, Table 3 and Table 4 provide "Best Practice" potentials for Iron and Steel, Cement and Pulp and Paper industries according to a number of internationally recognised studies. While there is no time dynamics included in these numbers, it is also accepted that specific sectoral technologies have not improved significantly over the decade from the late 1980s.

Table 2 'Best Practice' Weighting Factors for Selected Steel Products

Product	**Fuel**		**Electricity**	
	GJ/t	toe/t	GJ/t	toe/t
Basic Oxygen Furnace, slab	14.24	0.3400	0.36	0.0086
Electric Arc Furnace, slab	0.79	0.0189	1.52	0.0363
Hot Rolling	1.82	0.0435	0.37	0.0088
Cold Rolling	1.10	0.0263	0.53	0.0127

Source: Worrell *et al*, 1999

Table 3 'Best Practice' Weighting Factors for the Cement Industry

Process	**Fuel**		**Electricity**	
	GJ/t	toe/t	GJ/t	toe/t
Clinker Making	2.92	0.0697	0.36	0.0086
Cement Grinding			0.24	0.0057

Note: The denominator in clinker making is tonne of clinker, while in cement it is tonne of cement.
Source: Worrell *et al*, 1995

Table 4 'Best Practice' Weighting Factors for the Pulp and Paper Industry

	Fuel		Electricity	
	GJ/t	toe/t	GJ/t	toe/t
Mechanical Pulping	-2.1	-0.0500	5.3	0.1266
Chemical Pulp	10.0	0.2388	2.5	0.0597
Other Wood Pulp	-3.0	-0.0716	6.0	0.1433
Wastepaper Cleaning and Pulping	0.4	0.0096	1.4	0.0334
Newsprint Papermaking	2.5	0.0597	1.4	0.0334
Printing/Writing Papermaking	7.0	0.1670	2.0	0.0480
Sanitary Papermaking	5.0	0.1194	2.4	0.0573
Packaging Papermaking	5.0	0.1194	1.5	0.0358
Other Papermaking	6.0	0.1433	1.8	0.0430

Note: The pulping energy figures are based on using wood as feedstock. Straw pulping is common in China for instance, but no "Best Practice" figures are available.

Sources: Worrell *et al*, 1994 and Farla *et al*, 1997

DATA ISSUES AND SOURCES

DATA ISSUES

As has been the case of most energy efficiency studies, one of the major obstacles encountered refers to the availability of comprehensive, reliable and detailed data. This has limited the study mainly in terms of the economies covered, the period considered and the depth of the analysis performed.

Data availability varies widely among APEC member economies (see Table 5 for a summary of available data), especially when disaggregated figures are considered. This responds to various reasons, ranging from differing degrees of statistics development to different industry classifications –the latter being especially relevant in the case of the cement industry, classified as non-metallic minerals together with other products in many databases.

Table 5 Basic Data Availability
Years with available data

Economy	Iron and steel		Cement		Pulp and paper	
	Production	Energy consumption	Production	Energy consumption	Production	Energy consumption
Australia	1980-1997	1980-1996	1980-1995	1980-1996	1980-1992	1980-1996
Brunei Darussalam	na	na	na	na	na	na
Canada	1980-1997	1980-1996	1980-1995	1980-1995	1980-1996	1980-1996
Chile	1980-1997	1980-1996	1980-1995	1980-1996	1980-1993	1980-1996
China	1980-1997	1980-1990 1993-1996	1980-1997	1980-1995**a**	1980-1996	1980-1996
Hong Kong, China	1980-1996	1980-1992	1980-1995	na	1980-1992	na
Indonesia	1980-1997	1980-1996	1980-1995	na	1980-1993	na
Japan	1980-1997	1980-1996	1980-1997	1981-1996	1980-1997	1980-1996
Korea	1985-1997	1980-1996	1980-1996	1981-1996	1980-1996	1980-1996
Malaysia	1980-1997	1980-1996	1980-1995	na	1980-1993 **b**	na
Mexico	1980-1997	1980-1996	1980-1995	1980-1995	1980-1993	1985-1996
New Zealand	1980-1997	1980-1996	1980-1995		1980-1993	1980-1988, 1991-1996
Papua New Guinea	na	na	na	na	na	na
Peru	1988-1997	1980-1996	1980-1995	na	na	na
Philippines	1980-1997	1980-1996	1980-1995	1980-1996	1980-1993	1980-1996
Russian Federation	1987-1997	1980-1996	1980, 1985, 1988-1995	na	na	1990-1996
Singapore	1980-1997	1980-1996	1980-1995	na	1980-1993 **c**	na
Chinese Taipei	1980-1997	1980-1996	1980-1995	na	1980-1994	1980-1996
Thailand	1980-1997	1980-1996	1980-1995	1981-1996	1980-1994	1980-1996
United States	1980-1997	1980-1996	1980-1995	1980-1990, 1992-1995	1980-1996	1980-1996 **d**
Viet Nam	1988-1997	1980-1996	1980-1995	na	na	na

Note: **a** – electricity only; **b** - pulp production unavailable for 1980 and 1988; **c** – paper only; **d** - no petroleum products data for 1983-1994; na – data is not available.

In the previous table, data availability corresponds to the years included in the main information sources used (see Table 6 below). Except for justified cases, time periods were not extended with information from additional sources, so as to maintain consistent data sets.

As can be seen in the table, some data series present gaps, most notably petroleum products consumption in the US pulp and paper industry for the period 1983-1994.

However, the mere availability of data is not sufficient for its blindfolded utilisation, especially in a study of energy efficiency indicators where, as seen previously, numerous factors can affect the final result. In fact, the comparison of data from different sources, even at the most basic aggregation level, reveals that there are numerous figures for the same variables.

This consistency problem can respond to various causes, among which the following can be cited (Karbuz, 1998):

- Definition of energy use: primary, final;

- Calorific values: not only the issue of whether net or gross values are used is relevant, but also the change across time and economies must be considered;

- Boundary of the industry: consumption activities considered;

- Consideration of non-energy use: by definition, in an energy efficiency study the use of energy as feedstock should be excluded;

- Different industry classifications: the International Energy Agency (IEA) uses the International Standard Industry Classification (ISIC), Australia and New Zealand use the Australian and New Zealand Standard Industrial Classification (ANZSIC) 1983, Canada uses the North American Industry Classification System (NAICS), Japan uses the Japanese Standard Industrial Classification (JSIC), while USA uses the US Standard Industrial Classification (US SIC 1987); as noted previously, the inclusion of cement production under non-metallic minerals in the statistics of some economies and major databases (namely the IEA database, where ISIC Division 26 is considered, which includes cement, glass, ceramics, etc.), posed a serious hindrance to the inclusion of many relevant economies in the analysis made for this sector;

- Fuel classification: there is no unified fuel classification system in use globally; for example, in Australia, coke oven gas and blast furnace gas are classified as coal by-products and are included in coal, while other economies such as Austria and Germany group them under gas; in Japan and New Zealand, petroleum coke is included in coal, whereas in the US it is included in oil;

- Consideration of renewable energy sources: biomass, solar and other renewable energy sources are not always considered in energy balance tables; for example, Australia and Mexico identify them, but Canada neither identifies nor includes them;

- Data collection type and survey quality: significant discrepancies can be found between supply-side and demand-side statistics; also, the periodicity with which data is collected can make estimations for intermediate years deviate from actual data collected by other sources.

The above factors can affect data consistency and quality for two of the most basic data inputs required, namely production and energy consumption. A new set of difficulties arises when the denominator is value of output in monetary terms to derive economic indicators. In this case, some issues that have to be dealt with include (Karbuz, 1998):

- Use of value added, value of shipments or value of production;

- Current and real monetary units: inflation, deflators, price indices (choice of index, breaks in series, composition of index, etc.);

- Existence of multiple prices: shipment price, order price, list price, actual transaction price, a gross price or a price net of transportation costs, etc.;

- Existence of multiple goods: for example, in the paper industry, products include newsprint, coated and uncoated groundwood paper, coated freesheet, bond and writing paper, each one with a different price.

Conclusions based on the analysis of energy efficiency indicators derived from non-comparable databases, can be highly misleading.

DATA SOURCES

In the early stages of this study, a survey questionnaire was sent to each member economy, in order to gather basic economic, production and energy consumption data for the three sectors considered. The degree of response was varied – both in terms of the number of economies that responded the questionnaire and its completeness – requiring a significant effort of data collection from other sources.

However, the issues discussed above – especially the consistency issue– recommended the use of comprehensive databases maintained by recognised international organisations, in lieu of scattered data coming from different sources. Nevertheless, the latter was used for comparison purposes in the iron and steel and pulp and paper sectors.

As for energy consumption data in the cement sector, however, the reduced number of economies (3) covered from the only consistent source that was available for this study, namely the INEDIS database provided by Lawrence Berkeley National Laboratory, made the inclusion of other data sources necessary. The main sources used were the surveys submitted by each economy and the energy statistics published by the Ministry of International Trade and Industry (MITI) of Japan. As highlighted in the respective chapter, this makes inter-economy comparisons lead to possibly erroneous conclusions. Nevertheless, the data for each economy is internally consistent, so individual trends can be validly derived, reason why this approach was adopted.

The following table summarises the main data sources used in this study.

Table 6 Main Data Sources Used in the Study

Sector	Production	Energy consumption
Iron and steel	1980-1994 from APEC database, 1995-1997 from Steel Statistical Yearbook (1998). Data for Peru, Russian Federation and Viet Nam is taken from Steel Statistical Yearbook (1998).	IEA database. Data for the Russian Federation between the years 1980-1989 comes from the Russian Statistics Agency.
Cement	APEC database and Cembureau (1998, 1999)	INEDIS database (Canada, Mexico, US), surveys (Australia, Chile, Korea, Philippines, Thailand), and MITI (Japan)
Pulp and paper	APEC database	IEA database

CHAPTER 4

MACRO-ECONOMIC ENERGY EFFICIENCY INDICATORS

OVERVIEW

Energy is one of the very few commodities that is utilised by all sectors of the economy, meaning that energy efficiency improvements can be pursued in every sector and sub-sector. In this chapter, aggregate macro-economic indicators of energy efficiency are constructed at a national and sector level for APEC economies. Analysis allows aggregate measures of energy intensity to be derived and used to provide a glimpse of industrial sector energy trends since 1980.

The aim of this chapter is to provide a background to more detailed industrial energy efficiency analysis in subsequent chapters of the iron and steel, cement, and pulp and paper industries. Since the structure of APEC economies varies widely, measures of aggregate levels of energy efficiency, such as energy intensity, do not provide an effective measure of energy efficiency. However, comparisons of aggregate indicators supported by more detailed sectoral and sub-sectoral analysis offer interesting and important insights into APEC economies, including the economic structure, changes occurring through economic development, as well as a qualified assessment of the relative level of energy efficiency.

APEC REGIONAL SYNOPSIS

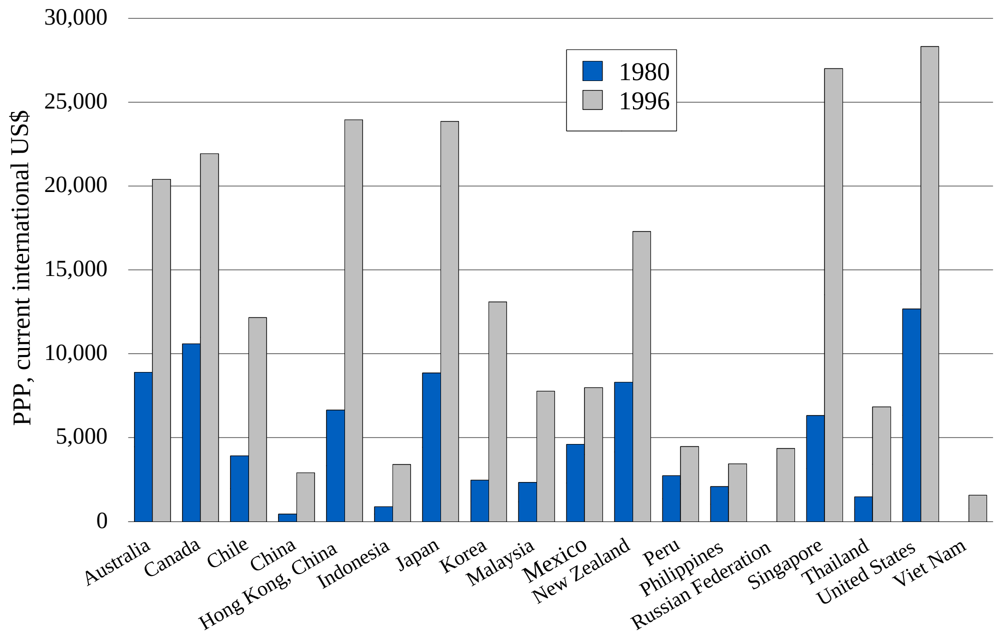
The Asia Pacific Economic Cooperation (APEC) forum consists of 21 economies in the Asia-Pacific region. In aggregate, these economies account for over half the global population, 55 per cent of the global aggregate output (GDP) and contribute to more than 40 per cent of international trade. From an energy perspective the APEC region includes both energy surplus (exporting) economies, such as the United States, Mexico and Australia, as well as net energy deficit (importing) economies, including Japan and Korea.

It is not only the combined magnitude of APEC economies that is impressive. The APEC forum is also highly diversified, in terms of the economic structures and levels of development through to cultural and political differences. In particular, differences in the level of development within APEC economies have implications for a range of energy indicators. For example, higher environmental standards and competitive markets, which are more prevalent in developed APEC economies, tend to increase the incentive to invest in a more efficient use of energy.

Economic development can be proxied by measuring per capita income on a purchasing power parity basis. The adjustment for purchasing power parity is applied for comparability so that each dollar is capable of purchasing a uniform basket of goods in each economy. Figure 3 below highlights the disparity between developed and developing APEC economies in 1980 and 1996. Interestingly, the variance of per capita incomes in the APEC region has increased over this period, indicating an increased regional income inequality. The currency devaluations and subsequent economic downturn in several Asian APEC economies that emerged from late 1997 is not accounted for in this data, however it would be expected that per capita incomes in these economies would have decreased slightly since 1996 on a purchasing power parity basis.

Nevertheless, comparing GDP per capita in 1980 with 1996 highlights the rapid economic growth that has taken place in the APEC region, particularly among developing economies.

Figure 3 APEC Economies GDP Per Capita
Selected APEC Economies; Purchasing Power Parities; 1980 and 1996.

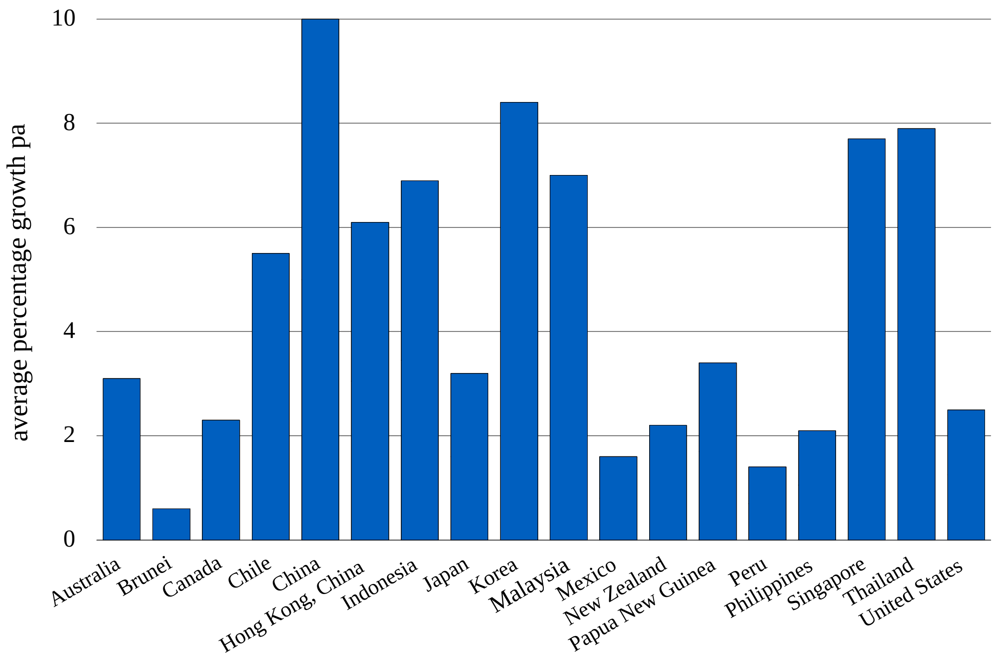


Source: World Bank, 1999.

The rapid development of the APEC region, over the period 1980 to 1996, is reflected in the high GDP growth (Figure 4), which across the region averaged an impressive 3 per cent a year. Growth was especially strong among Asian APEC economies including: China, Korea, Thailand, Singapore, Malaysia and Indonesia. Economic growth in these economies was dominated by exceptionally strong industrial sector expansion, while the more moderate growth occurring in developed APEC economies was led by the services sector.

Figure 4 APEC Average GDP Growth Rates

Selected APEC Economies; average percentage growth pa; 1980-96.



Source: World Bank, 1999.

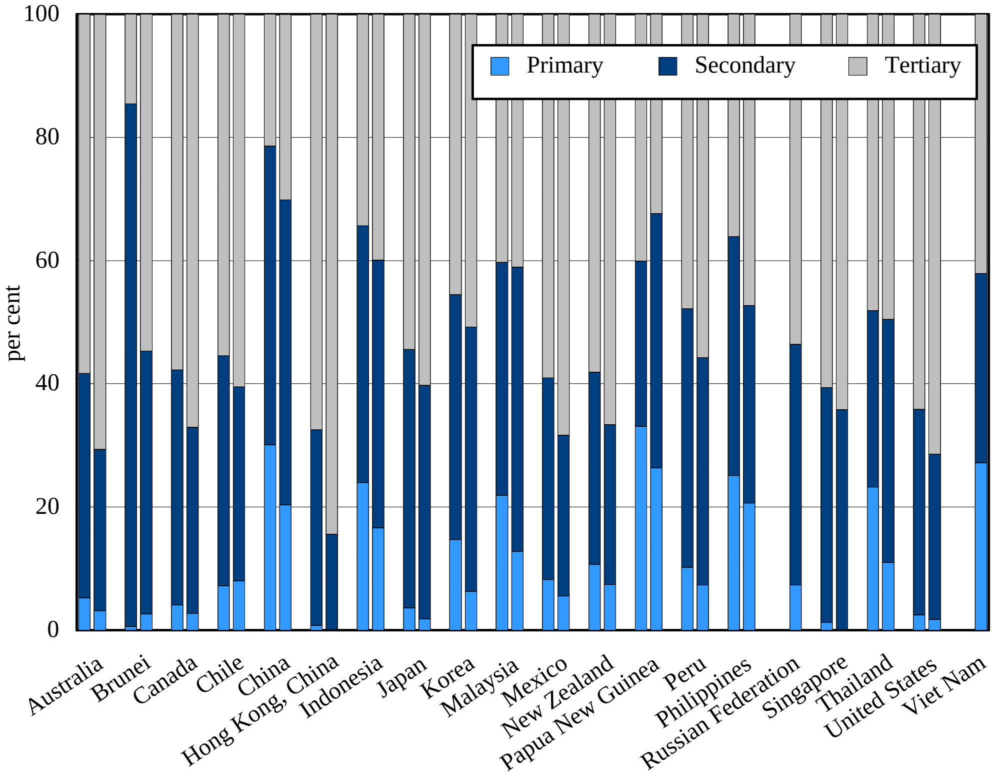
It needs to be recognised that the reported economic growth rates in an economy actually represent an average value for all sectors in the economy. Over a period of time, if some sectors grow faster than others, the fundamental structure of an economy will change. In Figure 5, below, APEC economies, excluding Chinese Taipei, are disaggregated into three fundamental sectors: primary (agricultural etc), secondary (industry, manufacturing etc) and tertiary (services, transportation etc). A comparison is provided between 1980 (left column) and 1996 (right column). It is important to note that in Figure 5 the changes are *relative* and do not necessarily show the absolute contribution of the sector to GDP.

Key points to note in Figure 5 include:

- The increased contribution of the tertiary sector in all APEC economies (except Papua New Guinea).
- The increased contribution of the secondary sector to GDP among the rapidly growing economies of China, Indonesia, Korea, Malaysia, and Thailand.
- The declining relative contribution of the primary sector in all APEC economies, excluding Brunei Darussalam and Chile.

Figure 5 Sectoral Share of GDP

Selected APEC Economies; percentage share; Comparison of 1980 and 1996.

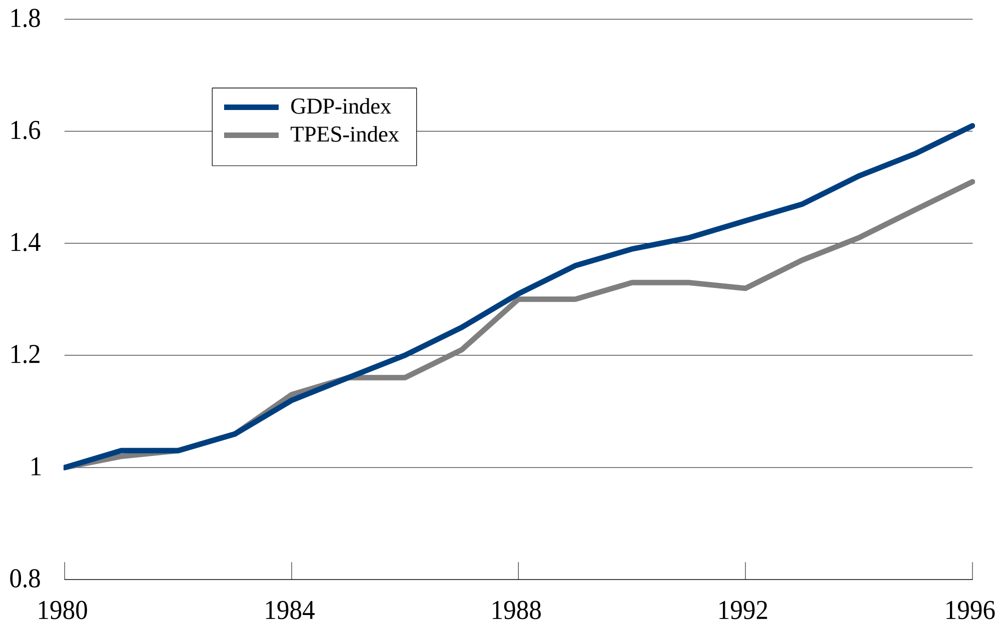


Source: World Bank, 1999

Economic growth, economic development and the changing economic structure each affect overall energy demand and therefore total energy consumption. As an input commodity, energy has the distinction, along with labour and capital, of being utilised in every sector of the economy. Consequently, energy products will always respond to external economic variables, and facilitate changes in the economy. Figure 6 highlights the positive correlation that exists between economic growth, represented as an index of APEC GDP between 1980 and 1996, and energy consumption, represented as an index of Total Primary Energy Supply (TPES) in the APEC region.

However, while all sectors of the economy utilise energy commodities, their intensity of utilisation differs. Generally speaking, the services sector is a less intensive consumer of energy than, say, the industrial sector. Accordingly, as the sectoral structure of an economy changes the intensity of energy utilisation will also change. The decreased average energy intensity of the APEC region, primarily resulting from the relative increase in the services sector is revealed in Figure 6 as the deviation between GDP and TPES in the APEC region. Other factors, such as technological innovations and changes in the energy mix, also contribute to the growing divergence.

Figure 6 APEC GDP and Total Primary Energy Supply Index
APEC Region; Index (1980=1); 1980-95.



Source: APERC, 1998.

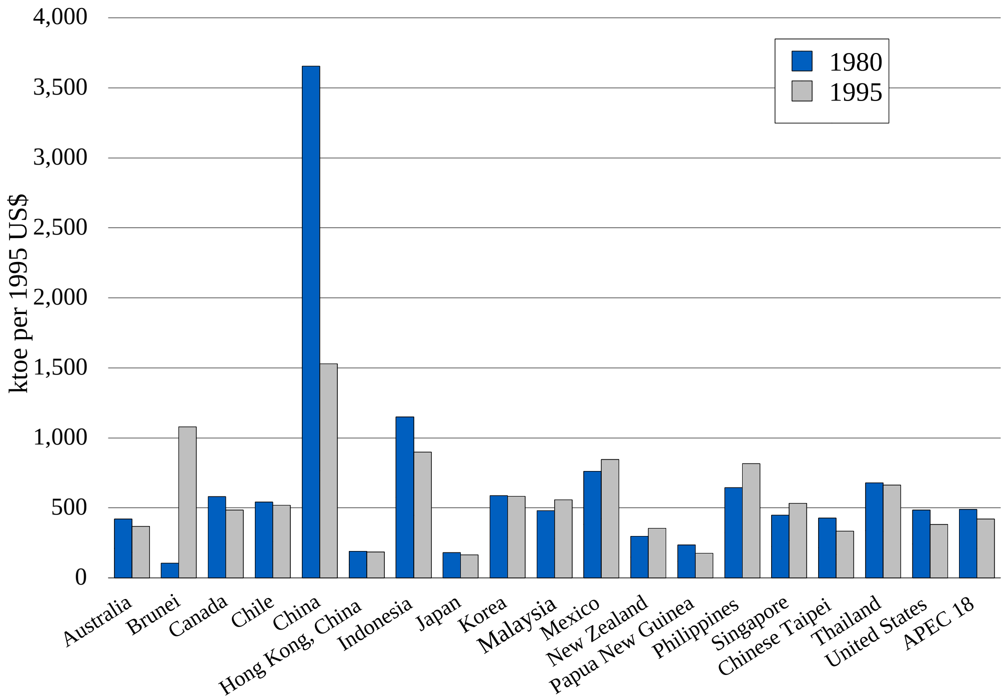
In the APEC region, energy consumption grew by 35 per cent, averaging 2.2 per cent a year, between 1980 and 1995, while the APEC economy grew by 62 per cent, averaging 3.3 per cent a year, over the same period (Figure 6). Energy growth was primarily located in economies with high economic growth, including Thailand, Chinese Taipei, Malaysia, China, Korea and Indonesia (APERC, 1998).

Against the background of strong economic and energy growth throughout the APEC region, it is important to understand the key concept of energy intensity relative to GDP in each APEC economy. At the simplest level, energy intensity represents the amount of energy consumed per unit of output.

Energy Intensity: *The quantity of energy consumed per unit of output produced.*

Figure 7 represents the information presented previously in Figure 6 for the original 18 APEC economies for 1980 and 1995. There is a strong interrelationship between the data presented in Figure 7 and the data presented earlier in Figure 5. Generally, in economies where the lower energy intensive tertiary sector has increased relative to the more energy intensive industrial secondary sector, then GDP will increase for each unit of energy consumed. This is apparent in most economies across the APEC region. Conversely, in economies where the (generally) more energy intensive secondary sector has increased as a proportion of GDP, then the energy intensity of the economy will have also increased – requiring more energy consumption per unit of GDP generated.

Figure 7 APEC Energy Intensities
Selected APEC Economies; ktoe per 1995 US$; 1980 and 1995.



Source: World Bank, 1999.

However, as Figure 7 illustrates, there are a number of exceptions to this generalisation, requiring more detailed analysis of the energy-economic linkages. For example, in New Zealand despite an increased contribution to GDP by the tertiary sector, and decreased contribution by the secondary sector, overall energy intensity increased between 1980 and 1995. Closer examination of the secondary sector between 1980 and 1995 reveals an important change in the industrial structure of New Zealand where strong growth in highly energy intensive sub-sectors, particularly iron and steel, increased the energy intensity of the secondary sector. Despite the falling contribution of the energy intensive secondary sector relative to the less energy intensive tertiary sector, the increased energy intensity within the secondary sector was sufficient to increase overall energy intensity of the New Zealand economy.

The example of New Zealand highlights the difficulty of utilising macro-economic data as a measure for energy intensity and efficiency. Unless a detailed analysis of the sectoral and sub-sectoral structure is undertaken, the conclusions that would otherwise be generated are potentially misleading.

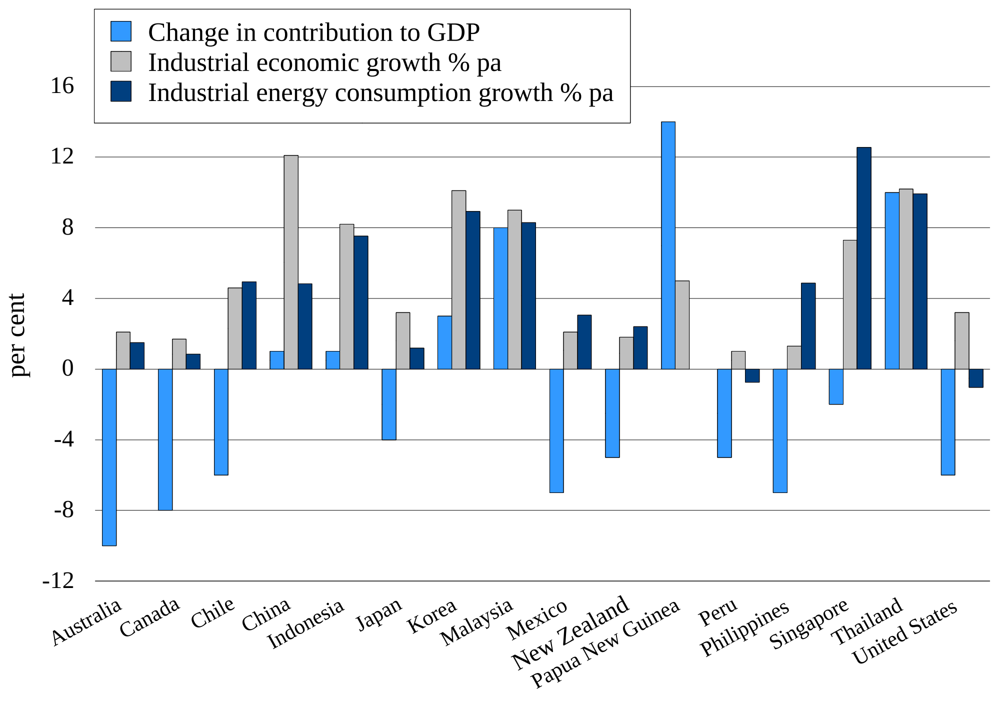
The remainder of this chapter is devoted to the industrial (secondary) sector, and begins to examine the sub-sectoral structure of the industrial sector in APEC economies. Further detail of the iron and steel, cement and pulp and paper sectors is provided in subsequent chapters.

THE INDUSTRIAL SECTOR IN APEC ECONOMIES

The industrial sector in this report includes mining, manufacturing, construction and electricity, gas and water supply, in accordance with the International Standard Industrial Classification of All Economic Activities (ISIC, 3rd revision, United Nations). This section presents an economic overview of the industrial sector in APEC economies, including energy consumption and intensities. Analytical emphasis is directed at the manufacturing sector, which incorporates the three sectors identified for detailed analysis in subsequent chapters – the iron and steel sector (ISIC #2710), the cement sector (ISIC # 2994) and the pulp and paper sector (ISIC # 2101).

Industrial sector growth has been robust throughout the APEC region. Generally, growth has been higher in rapidly developing economies; particularly China, Thailand, Korea, Malaysia and Indonesia; and more moderate in developed economies; Australia, Canada, Japan, New Zealand and the United States (Figure 8). Overall Russian industrial growth is difficult to meaningfully evaluate due to the break up of the USSR and the subsequent economic and financial turmoil, and therefore has not been included. The more moderate growth among developed APEC economies resulted in a decline in the percentage share of the industrial sector in GDP as other sectors of these economies grew strongly, particularly the services sector. In contrast, the industrial sector tended to lead economic growth in developing APEC economies and therefore increased as a proportion of GDP (Figure 8).

Figure 8 Industrial Sector Growth and Change in Contribution to GDP
Selected APEC Economies; per cent; 1980-96.



Source: APERC, 1998; World Bank, 1999.

Also illustrated in Figure 8 is industrial energy consumption growth. Generally, increasing economic growth is the primary driver for increases in energy consumption, since energy is required to facilitate the expansions in production. Comparing industrial economic growth with energy consumption growth provides a very basic indication of energy intensity trends. In most of the economies represented in Figure 8, the growth in industrial energy consumption has been less than the growth in industrial economic output, suggesting a decrease in the industrial energy intensity of the economies. Conversely, where industrial energy consumption has grown more rapidly than industrial economic output, then overall industrial energy intensity has increased.

The differential between industrial economic and energy growth shown in Figure 8 can arise through a number of factors, some of which are summarised in Table 7. At the aggregate industrial sector level, a complete analysis of these factors cannot be achieved without detailed analysis at the sub-sectoral level. Prior to the development of any policy conclusions, it is imperative that these factors are thoroughly examined.

Table 7 Factors Affecting Energy Intensity

INCREASES IN ENERGY INTENSITY	DECREASES IN ENERGY INTENSITY
▪ Increased share of relatively more energy intensive industries (Structural effect);	▪ Increased share of relatively less energy intensive industries (Structural effect);
▪ Adverse changes in the fuel mix.	▪ Increases in energy efficiency, such as the introduction of new technologies, or more efficient utilisation of existing technologies (Technical effect);
	▪ Beneficial changes in the fuel mix.

Although all sectors of APEC's economies rely on energy, the intensity of energy use differs substantially between each sector. The industrial sector classification, shown in Figure 8, includes a number of highly energy intensive industries such as iron and steel, non-ferrous metals, cement, and pulp and paper. Other sectors in the economy, such as the services sector, also include some energy intensive industries but overall they have a much lower level of energy use per unit of value added GDP generated.

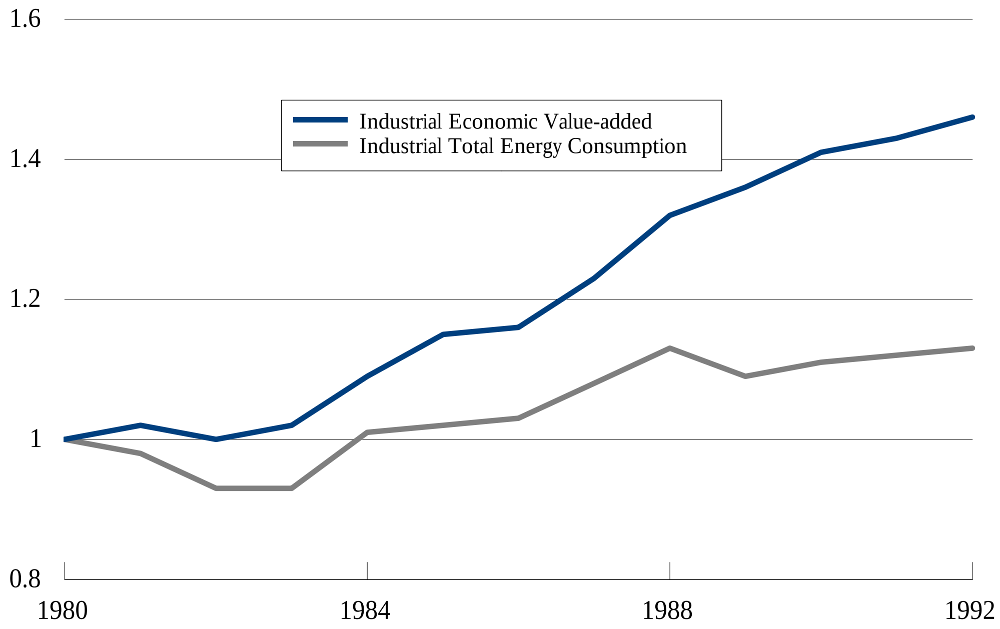
Further analysis is needed to decompose the industrial sector into energy intensive and non-energy intensive industries. In economies where energy intensive industry growth has outpaced non-energy intensive industries, it would be expected that the energy intensity has increased, that is, the amount of energy needed to generate one unit of economic output. This analysis would establish whether a decrease in industrial sector energy intensity was simply due to the introduction of less energy intensive industries, or alternatively improvements in energy efficiency.

APEC INDUSTRIAL SECTOR ENERGY DEMAND

As Figure 6 showed, increases in total APEC primary energy supply (TPES) of around 51 per cent over the period from 1980 to 1996 facilitated GDP growth in the APEC region which grew by around 61 per cent. Figure 9 below represents a similar graph, except that it only considers the industrial sector. Over the period 1980-92, industrial output in the APEC region grew by 46 per cent, but at the same time, the energy requirement of the industrial sector grew by only 13 per cent.

An important observation can be made by comparing equivalent data in 1992 (shown in Figure 6 and Figure 9) for the overall economy and industrial component. Although economic growth was approximately equal, the energy requirement of the whole economy grew by 32 per cent compared to an increase in the industrial sector of only 13 per cent. Clearly the percentage decrease in industrial energy intensity has greatly outweighed the decrease in the overall economy.

Figure 9 Industrial Value Added and Industrial Primary Energy Use Index
APEC Region; Index (1980=1); 1980-92.



Source: IEA, 1998a; World Bank, 1998.

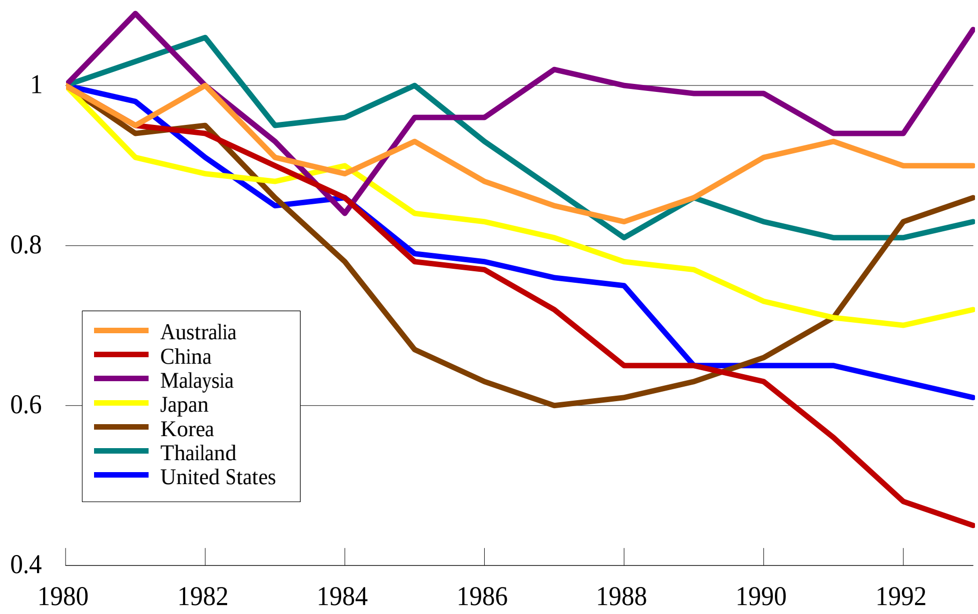
The actual decrease in industrial sector energy intensities varies considerably between individual APEC economies. As Figure 10 illustrates for selected APEC economies, large reductions are evident in China, the United States and Canada. However, for most other economies, energy intensity levels declined gradually over the 12 year period. In fact, the improvements in China (of over 50 per cent) constitute a significant component of the improvement of aggregate APEC energy intensities (also evident in Figure 8).

There are many factors underlying the trends that are apparent in Figure 7. These include:

- improvements in energy efficiencies;
- improvements in labour and capital productivity;
- fuels mix changes;
- technological developments; and,
- changing structural composition of the industrial sector, and particularly the relative size of energy intensive and non-energy intensive industries.

Consequently, before energy intensities can be properly analysed, it is necessary to consider these underlying causes. While some of these effects can be picked up at the sectoral level of analysis, a complete understanding requires sub-sectoral analysis.

Figure 10 Industrial Energy Intensities
Selected APEC Economies; Index (1980=1); 1980-92.



Source: IEA, 1998a; World Bank, 1998.

CONCLUSIONS

By examining energy intensities at a macroeconomic level, it is possible to conduct some useful, but incomplete, analyses of overall trends in the energy sector. However, aggregated data restricts the usefulness of this analysis since the causality of the changes in energy intensity cannot be identified. A complete analysis of the underlying trends in energy efficiency requires sectoral and sub-sectoral analysis. This analysis allows the factors underlying changes in energy intensity to be identified, such as improvements in energy efficiency, labour productivity, changing industrial mix and technological improvements.

There are a number of other limitations in this analysis. These include discrepancies in the measurement of aggregate monetary data, particularly in centrally planned economies where the measurement is usually only based on productive capacity. Further, the price and quantity component of monetary data means that as prices fluctuate, monetary measures of energy intensity and energy efficiency will vary. To a lesser degree these data problems are common to sectoral and sub-sectoral analysis, but highlight the need for more consistent and comprehensive data collection to facilitate the analysis of energy efficiency trends.

CHAPTER 5

ENERGY EFFICIENCY IN THE APEC IRON AND STEEL SECTOR

OVERVIEW

The iron and steel industry is present in 19 of the 21 APEC member economies – except Brunei and Papua New Guinea. Technological level and energy efficiency vary significantly among the economies. The sectoral output – iron, crude steel and steel products – is rather homogenous and can be measured in physical units, tonnes. This chapter analyses iron and steel production and energy consumption during the period 1980 to 1996, comparing energy efficiency levels among APEC economies.

PRODUCTION TRENDS AND PROCESSES

GENERAL DESCRIPTION OF RELEVANT PROCESSES

The main technological process in the Iron and Steel Industry is reduction of iron ore by coke or some combination of reducing gases (hydrogen, carbon monoxide) (see Figure 11). Iron ore is mixed with coke and limestone in a blast furnace and melted at a temperature of about 1,200°C. The blast furnace output is pig iron – mainly an intermediate product, mostly used in further crude steel production. This is a first step in a Primary Steel Route.

Another feedstock for crude steel production is scrap, used as an additive input in a Primary Steel Route and as a main input in a Secondary Steel Route.

Coke production is a highly energy-intensive process, requiring approximately 0.12 toe/tonne of coke, but in the majority of APEC national energy balances it is included in the energy transformation sector, not in industrial end-use. Therefore coke energy expenditure is excluded from Iron and Steel energy consumption.

The pig iron, scrap, manganese and fluxes additives are inputs for the Basic Oxygen Furnaces (BOF) where oxygen is injected for melting and refining of crude steel. The BOF process is predominant in the world and APEC economies, both with a share of about 60 per cent. Oxygen production is not included in the energy use estimates as an energy transformation process.

The Open Hearth Furnace (OHF), or Siemens-Martin route, is an obsolete and energy intensive old technology, steadily being eliminated in the Iron and Steel Industry with a share of about 5 per cent of the world total crude steel production in 1997 (see Figure 12). In the APEC region, this technology is relevant only in China and Russia. OHF route can use varying amounts of iron ore, pig iron and scrap as a feedstock.

The Secondary Steel Route is based on Electric Arc Furnace (EAF) technology, using scrap and directly reduced iron as a feedstock. Input materials are melted and refined using electricity in electric arc furnaces. Typical energy requirements are about 0.13 toe/tonne of crude steel. The quality of EAF steel is highly dependent on the scrap quality and could be lower than that of BOF and OHF steel. Direct reduced iron is a high quality alternative for scrap in secondary steel making. Direct Reduction is a modern, rather energy-intensive process, consuming about 0.5 – 0.7 toe/tonne of reduced iron. The combined route DRI – EAF is slightly more energy intensive than the Blast Furnace – BOF route.

However, some APEC member economies develop direct reduction process in order to diversify feedstock for EAF steel production. The share of directly reduced iron is significant in Indonesia, Canada, Malaysia and especially in Mexico (29 per cent of the crude steel production), see Table 8.

Table 8 Direct Reduced Iron Production
Selected APEC economies; million metric tonnes; 1993 – 1996.

	1993	1994	1995	1996
Canada	0.76	0.77	1.00	1.42
Indonesia	1.50	1.62	1.71	1.72
Malaysia	0.71	0.99	1.18	1.17
Mexico	2.74	3.22	3.70	3.79
Peru	0.00	0.02	0.00	0.02
Russia	1.54	1.71	1.68	1.51
United States	0.44	0.48	0.42	0.45
World	23.74	27.53	31.15	32.86

Source: IISI Statistical Yearbook, 1999.

Crude steel is converted into finished products by casting and rolling. Casting can be done in batches (ingots) or in continuous casting (slabs, blooms, billets). Ingot casting is the classical process and is rapidly being replaced by continuous casting machines which are more energy-efficient. The share of continuously casted steel increased from 60 per cent in 1990 to 78.7 per cent in 1996 in the total World production. It was more than 90 per cent in most of APEC member economies except China (53.3 per cent) and Russia (40.7 per cent).

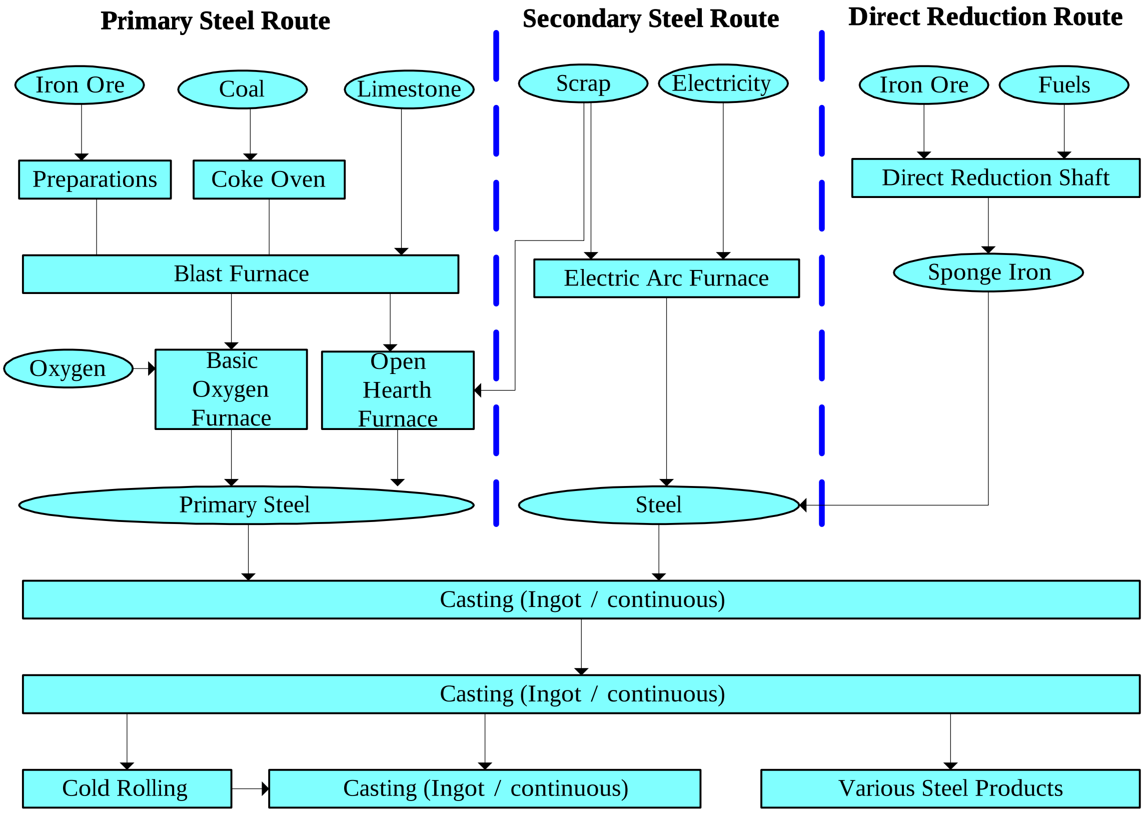
Economies with an increasing share of Direct Reduction processing would normally be expected to report increasing overall energy intensities for the production of steel. However, this report has not identified the change in trends associated with the introduction of DRI (in Mexico, Canada).

Cast steel is first rolled in hot rolling mills, producing profiles, sheets or wire with primary energy expenditure around 0.06 toe/tonne of hot rolled products. After hot rolling the steel can subsequently be rolled into thinner products in the cold rolling mill with an average specific energy consumption of 0.05 toe/tonne.

The technological chain ends in finishing, which could include annealing, pickling and surface treatment.

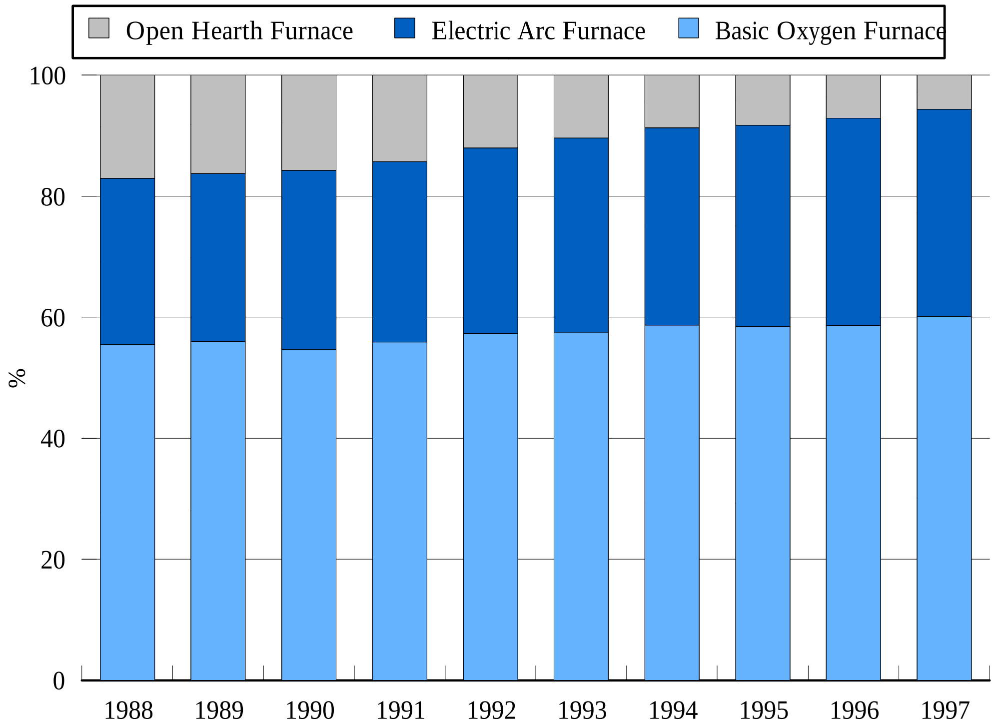
A schematic representation of potential production routes with main feedstocks and products is shown in the following diagram (Figure 11).

Figure 11 Process Routes in the Iron and Steel Industry



Source: Worrell *et al*, 1997.

Figure 12 Share of Crude Steel Production in the APEC Region
By process; 1988-97.



Source: Steel Statistical Yearbook, 1998.

PRODUCTION TRENDS

APEC economies recorded stable growth in production volumes of 4.54 per cent per annum (excluding Peru, Viet Nam, Russia) in the period 1980-1988. Between 1988 and 1996, growth slowed to an average 1.11 per cent per annum for all 21 member economies – influenced by the negative overall growth in Russia. In absolute values crude steel output in APEC economies reached 446.3 million tonnes in 1996 (Table 9), accounting for 59 per cent of the world output.

The major producers in the region are China with a share of 22.7 per cent of total APEC output in 1996 with 101.2 million tonnes, Japan with a share of 22.1 per cent or 98.8 million tonnes and the United States with a share of 21.4 per cent or 95.5 million tonnes.

Table 9 Crude Steel Production
Selected APEC Economies

	Production '000 tonnes			Average Annual Growth %		
	1980	1988	1996	1980-1988	1988-1996	1980-1996
Australia	7,594	6,387	8,415	-2.14	3.51	0.64
Canada	15,901	14,971	14,735	-0.75	-0.20	-0.47
Chile	704	909	1,178	3.25	3.29	3.27
China	37,120	59,460	101,237	6.07	6.88	6.47
Hong Kong, China	120	120	100	0.00	-2.25	-1.13
Indonesia	360	2,054	4,109	24.32	9.05	16.44
Japan	111,395	105,681	98,801	-0.66	-0.84	-0.75
Korea	na	19,117	38,903	-	9.29	-
Malaysia	210	925	3,216	20.36	16.85	18.60
Mexico	7,156	7,779	13,172	1.05	6.80	3.89
New Zealand	230	560	808	11.77	4.69	8.17
Peru	na	430	578	-	3.77	-
Philippines	350	300	920	-1.91	15.04	6.23
Russia	na	90,000	49,253	-	-7.26	-
Singapore	340	432	531	3.04	2.61	2.83
Chinese Taipei	3,417	8,313	12,350	11.75	5.07	8.36
Thailand	150	552	2,143	17.69	18.48	18.08
United States	101,457	90,650	95,535	-1.40	0.66	-0.38
Viet Nam	na	74	311	-	19.66	-
APEC total	286,504	408,714	446,295	4.54	1.11	2.81

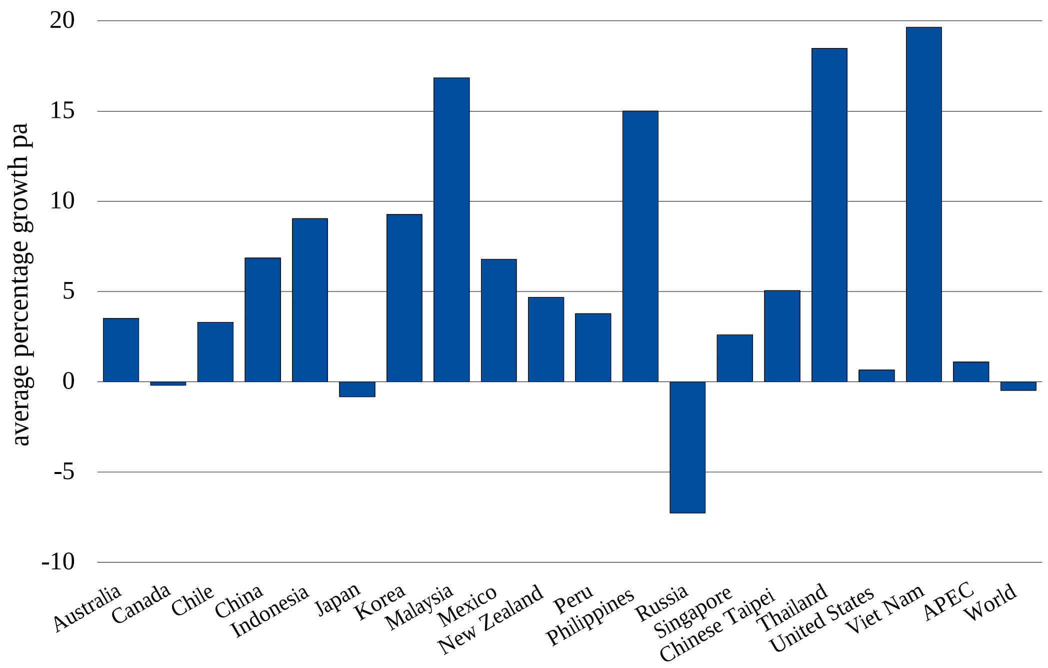
Notes: na: no data available
Source: APEC Database, Steel Statistical Yearbook 1998.

However, the average modest growth in APEC iron and steel industry in 1988 – 1996 is the result of a 0.84 per cent annual decrease in Japan, 0.20 per cent decrease in Canada and sharp output reduction of 7.26 per cent per annum in Russia on one hand and two-digit rapid growth in developing economies such as Viet Nam (19.7 per cent), Thailand (18.5 per cent), Malaysia (16.9 per cent) and Philippines (15 per cent).

Korea, Indonesia, China and Mexico also had high annual growth rates of 9.3, 9.1, 6.9 and 6.8 per cent correspondingly. The United States' crude steel production gave no signs of expansion and was mainly stable. Firm growth, between 3 – 5 per cent, was posted in Australia, Chile, New Zealand, Peru and Chinese Taipei (Figure 13).

Figure 13 Growth Rate of Steel Production

Selected APEC Economies; average percentage growth pa; 1988-96.

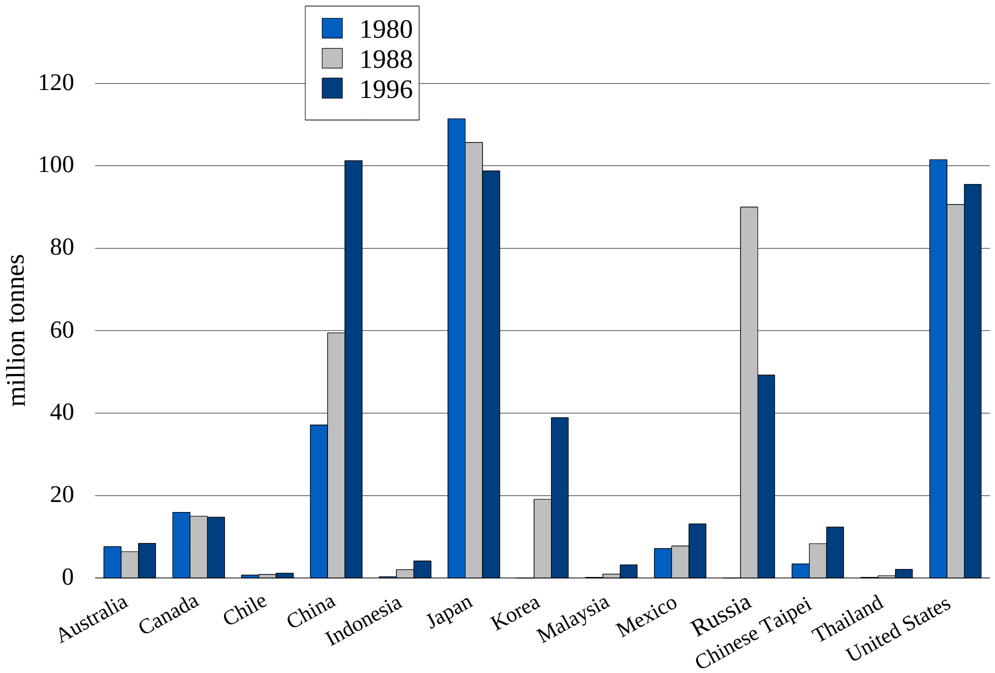


CO_2 emissions from the production of crude steel in Annex I economies, represented in APEC by Australia, Canada, Japan, New Zealand, Russia and the United States, are shown in Figure 14. This group showed a decreasing trend in iron and steel production in the 1988-96 period, and in 1996 accounted for 60 per cent of total APEC production (267.6 million tonnes). This decreasing trend was the result of the crisis in Russian industry combined with stable production levels in the United States and Japan.

Non-Annex I member economies in APEC, namely China; Chile; Hong Kong, China; Indonesia, Korea, Malaysia, Mexico, Peru, Philippines, Singapore, Chinese Taipei, Thailand, and Viet Nam increased crude steel output over the period 1980-96 reaching 178.4 million tonnes or 40 per cent of total APEC production (Figure 14). As Figure 14 shows, the largest contributor to this growth in absolute terms is China.

Figure 14 Crude Steel Production

APEC Economies with production exceeding 1 million tonnes; 1980,1988 and 1996.



ENERGY CONSUMPTION PROFILE

TOTAL ENERGY CONSUMPTION

Total energy consumption of the iron and steel industry of the 21 APEC economies in 1996 reached 210,851 ktoe from a level of 178,493 ktoe and 194,744 ktoe in 1980 and 1988, respectively. This represents an average growth of 1.1 per cent over the 16-year period. Five large economies posted negative average growths for the same years. These include Australia (-1.3 per cent), Canada (-1.8 per cent), Japan (-1.1 per cent), Russia (-2.1 per cent) and the United States (-0.4 per cent).

The latter half of the period posted a growth rate of 1.0 per cent compared with a growth rate of 1.1 per cent in the first eight years. Four member economies in Southeast Asia recorded two digit growth rates with Malaysia posting an average growth of 34.1 per cent, Indonesia with 18.3 per cent, Thailand with 14.2 per cent and Singapore with 11.8 per cent.

In terms of absolute energy consumption, China reported the highest figure in 1996 at 95,760 ktoe, or 41.3 per cent of the reported total energy consumption. Far behind other major users are Russia with 15.6 per cent share, the United States with 12.3 per cent share and Japan with 10.1 per cent share (Table 10).

Table 10 Final Energy Consumption in the Iron and Steel Industry
APEC Economies; ktoe; 1980, 1986, and 1996.

	Energy Consumption ktoe			Average Annual Growth %		
	1980	1988	1996	1980 - 1988	1988 - 1996	1980 - 1996
Australia	3,049	2,092	2,479	-4.60	2.15	-1.29
Brunei	na	na	na	-	-	-
Canada	5,961	5,052	4,475	-2.05	-1.50	-1.78
Chile	426	476	555	1.40	1.94	1.67
China	58,016	72,282	95,760	2.79	3.58	3.18
Hong Kong, China	31	9	na	-14.11	-	-
Indonesia	155	499	1,911	15.78	18.27	17.02
Japan	28,071	22,377	23,353	-2.79	0.54	-1.14
Korea	2,469	3,589	8,286	4.79	11.03	7.86
Malaysia	20	20	204	-0.41	34.10	15.57
Mexico	1,606	4,926	5,814	15.04	2.09	8.37
New Zealand	342	706	827	9.50	2.00	5.68
Papua New Guinea	na	na	na	-	-	-
Peru	84.71	60.2	42.38	-4.18	-4.29	-4.24
Philippines	650	385	596	-6.33	5.61	-0.54
Russia	45,221	61,350	32,272	3.89	-7.72	-2.09
Singapore	24	30	74	2.82	11.83	7.23
Chinese Taipei	1,502	3,923	4,956	12.75	2.96	7.75
Thailand	95	220	636	11.07	14.19	12.62
United States of America	30,770	16,748	28,611	3.60	6.92	-0.45
Viet Nam	na	na	na	-	-	-
APEC total	178,493	194,744	210,851	1.10	1.00	1.05

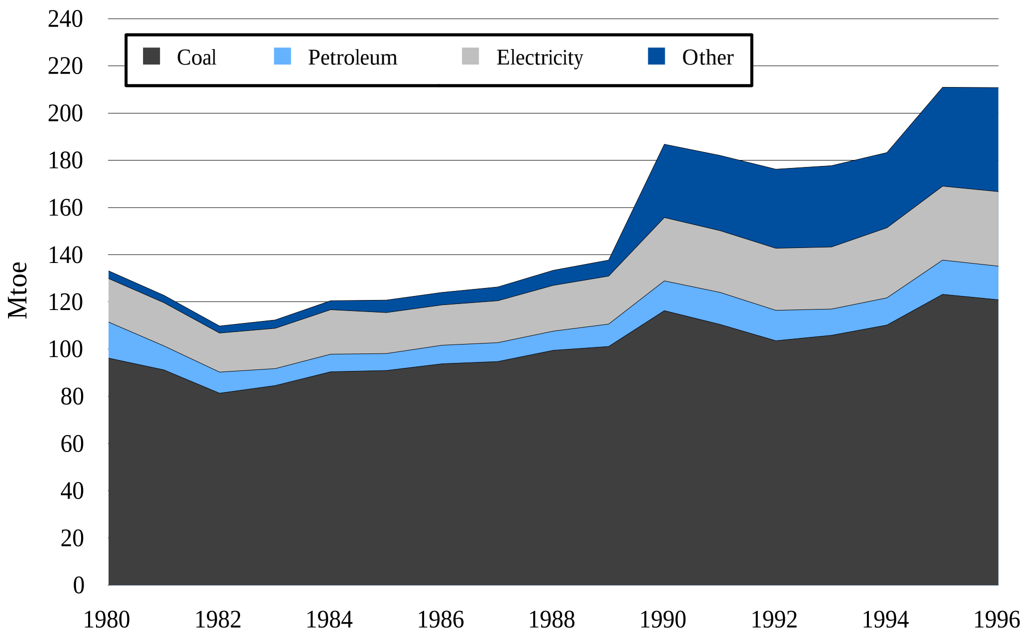
Notes: na: no data available
Source: IEA Database

ENERGY SOURCE MIX

The major fuel in the integrated iron and steel making process is metallurgical coal, which is used in blast furnaces to produce iron. Metallurgical coal is transformed to coke in coke ovens, but energy consumption in the process of making coke is not accounted for since it is treated as a part of the fuel transformation sector in energy balance tables. Natural gas is used as an input in Direct Iron Reduction process and also in the Basic Oxygen Furnace to provide additional heating along with the main inflow of oxygen. Electricity is the major energy input in the Electric Arc Furnaces.

Energy consumption by source in the iron and steel industry for APEC member economies is presented in Figure 15. The energy sources used in this industry, in descending order, are coal, electricity, other energy sources (gas mainly), and petroleum products. In response to the growing production of iron and steel in this region, energy consumption increased steadily for the period 1982-90.

Figure 15 Energy Consumption by Source in Iron and Steel Industry
APEC Region; Mtoe; 1980-96.



Note: a. Chinese data in 1991 is interpolated from 1990 and 1992 due to data unavailability.
b. Russian data is incorporated from 1990.

However, energy inputs in iron and steel industry accounted here do not include an energy content of raw and feedstock materials, such as iron ore and scrap limestone, which were estimated in the Russian iron and steel industry as 12 per cent and 6 per cent of total energy carriers input correspondingly (Stepanov, 1994).

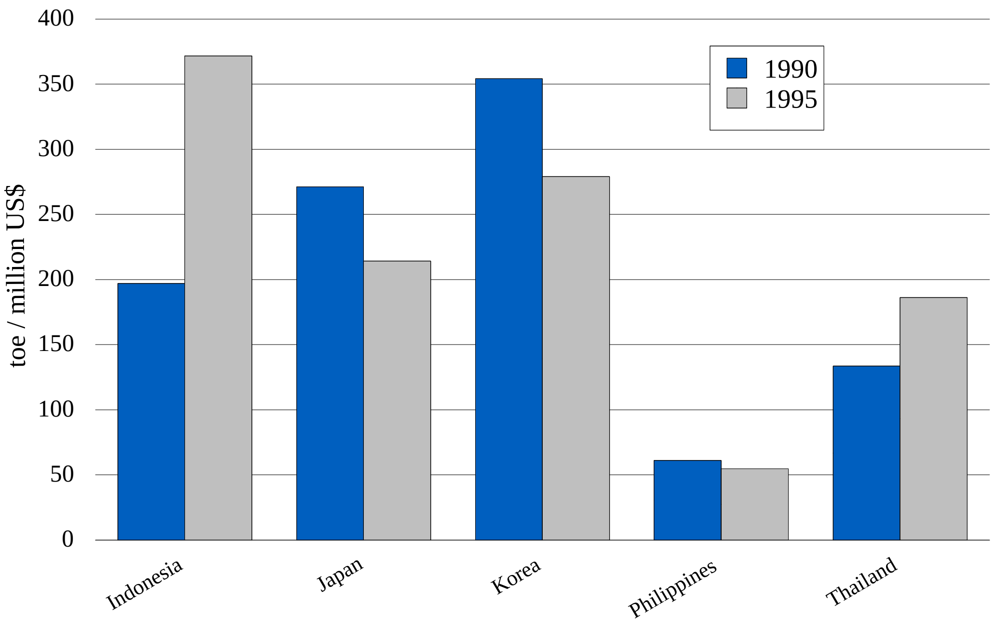
ENERGY INDICATORS

AGGREGATE ECONOMIC INDICATOR

Economic energy intensity indicator is defined as the amount of energy used per monetary unit of economic output. Following the findings that value added closely correlates with physical indicators in iron and steel sector (Worrell, 1999), it was used in this study as a measure of economic activity.

Given the availability of data, a general economic indicator comparing changes in intensities of five member economies for the years 1990 and 1995 is presented in Figure 16. Indonesia shows an almost double increase in energy intensity per unit value of iron and steel produced. Thailand follows the same trend, but with lower increment in intensity. On the other hand, Japan, Korea and the Philippines reduced their intensity during the period. The contributory factors to the variations are not clear with the existing data. The establishment of further data base for value added time series in APEC member economies is required to facilitate more detailed analysis and comparison with physical indicators.

Figure 16 Energy Intensity in Iron and Steel Industry
Selected APEC Economies; toe/million US$; 1990 and 1995.



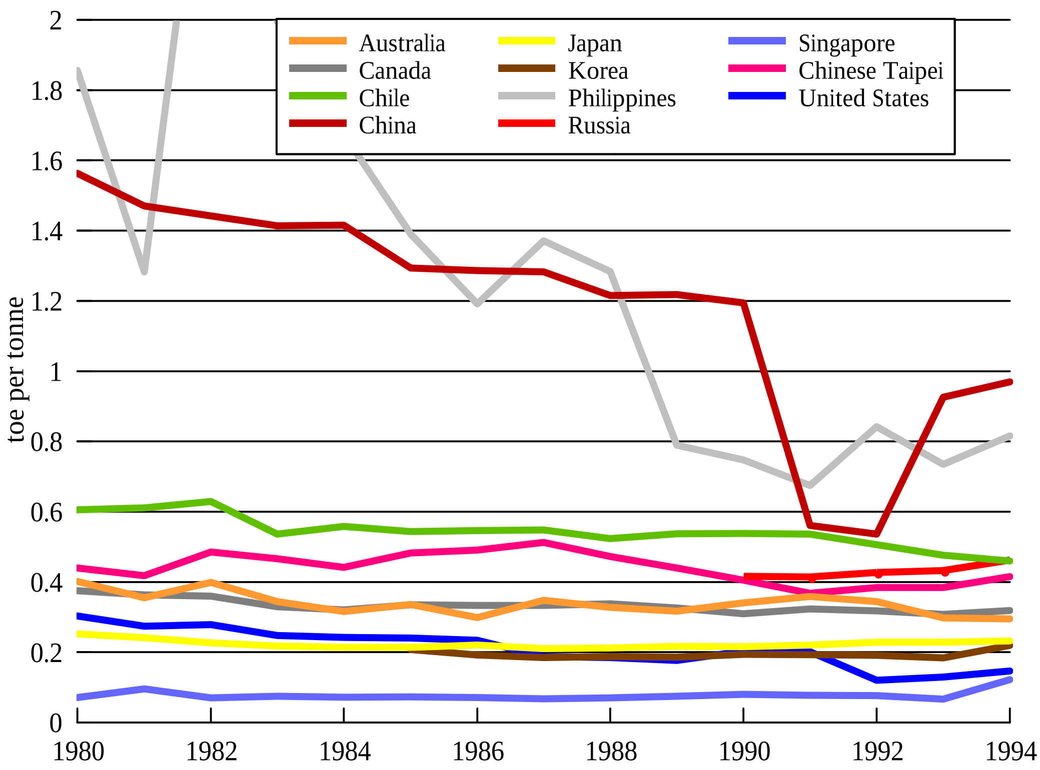
Variations in energy intensity in two transition economies, China and Russia, are incomparable with ones presented earlier. In China energy intensity dropped from 7,573 to 1,996 toe/MUS$ between 1990 and 1995, in Russia this indicator increased from 1,742 to 2,333 toe/MUS$ in the same period. Direct cross-country comparisons on the base of value added seems to be meaningless for economies with completely different commodity pricing systems.

PHYSICAL INDICATORS

OVERALL ENERGY INTENSITY

The majority of the economies included in iron and steel industry show a general trend of decreasing energy intensity (energy required to produce a ton of iron and steel) with the exception of a slight increasing trend for Russia in the 1990s. However, sharp fluctuations in the intensity are observed for Philippines before 1989. Nevertheless, Philippines had an impressive decreasing trend since 1982. The successive introduction of energy efficiency technologies into this sector might have influenced the seemingly improved efficiency level. China depicts a sharp drop in its energy intensity in 1991-1992, which could reflect a data problem rather than an actual increase in energy efficiency. Based on the physical indicators, energy intensities for the above-mentioned two economies appear higher than other economies. However, in Figure 17, economic energy intensity of iron and steel in Philippines is by far the lowest one among the five economies. It is apparent that economic and physical indicators reflect different underlying factors and thus following different trends, which implies that the treatment of economic and physical indicators needs to be further scrutinised.

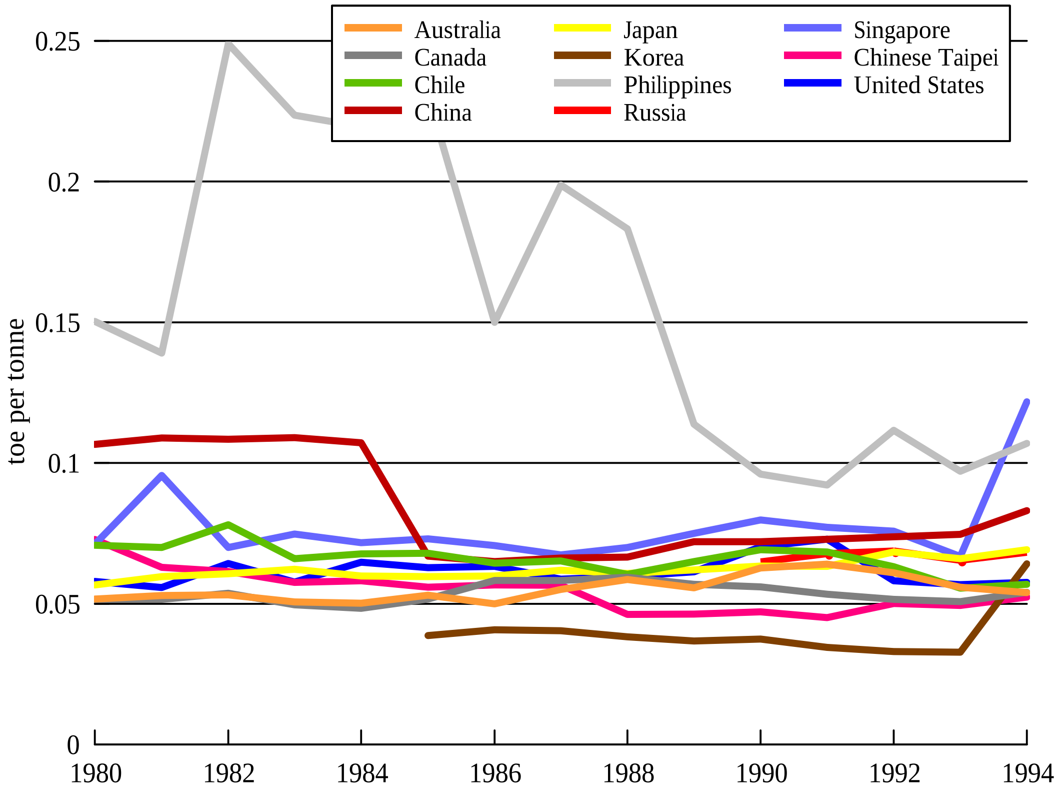
Figure 17 Energy Intensity in Iron and Steel Industry
Selected APEC Economies; toe per tonne; 1980-94.



ELECTRICITY INTENSITY

A number of economies show a stable trend in electricity intensity over the course of the period studied (Figure 18). This to some extent reflects the characteristics of iron and steel production. Taking the EAF route for example, without introducing new technologies into the production process, the trend in electricity intensity is expected to be quite flat over time with figures laying in the interval 0.05 – 0.07 toe/ton. Singapore and Philippines post higher electricity intensity. However, after 1989, electricity intensity of iron and steel sector in Philippines is not much higher than that of other economies. Korea displays an increase in its electricity intensity after 1993 after the previous period of lowest electricity intensity levels among APEC member economies, with values in the range of 0.035 – 0.04 toe/ton.

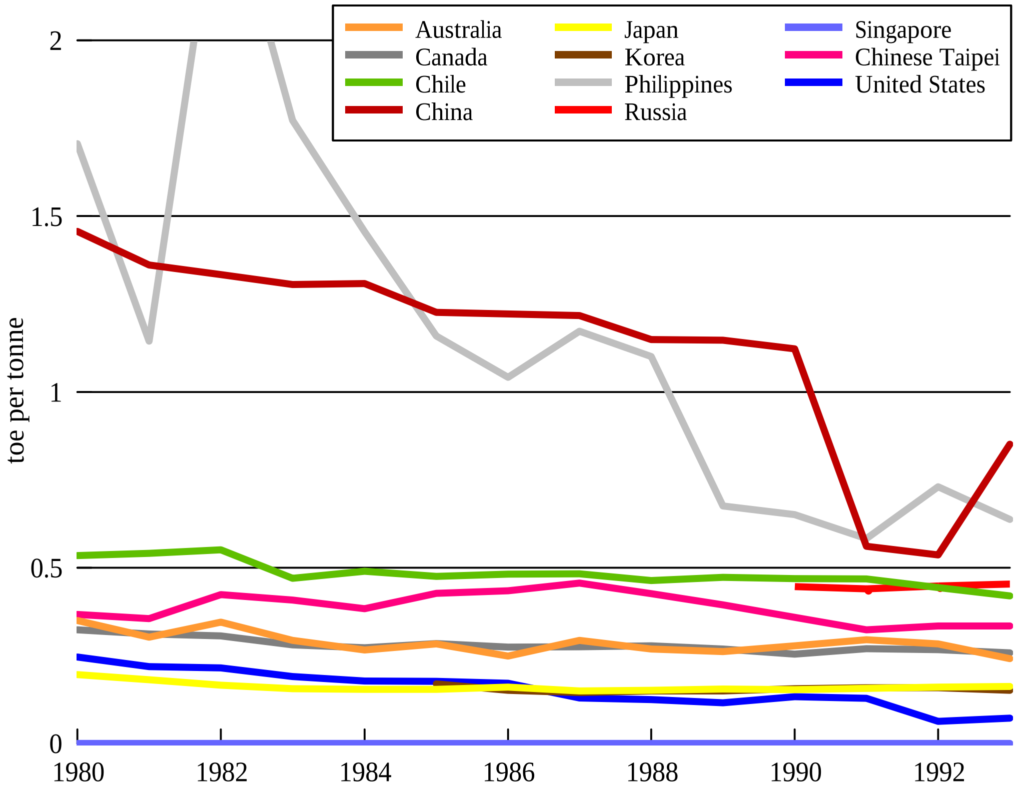
Figure 18 Electricity Intensity in Iron and Steel Industry
Selected APEC Economies; toe per tonne; 1980-94.



ENERGY INTENSITY (EXCLUDING ELECTRICITY)

Figure 19 illustrates the trend in the use of energy other than electricity of the member economies for the iron and steel industry. Basically, the trend is similar to what has been presented in the previous overall energy intensity section (Figure 17). This is simply because the share of electricity consumption in the overall energy consumption is relatively small for most of the member economies.

Figure 19 Energy Intensity (Excluding Electricity) in Iron and Steel Industry
Selected APEC Economies; toe per tonne; 1980-93.



CASE STUDY:
DECOMPOSITION OF RUSSIAN ENERGY CONSUMPTION IN THE IRON AND STEEL INDUSTRY

Russia experienced a sharp decline in iron and steel industry output in the 1990s. Crude steel production dropped from nearly 90 million tonnes in 1990 to 48.5 million tonnes in 1997, a decline of 47.2 per cent. This decline coincided with rapid structural change in the industry. The BOF process has been replacing an outdated OHF process. The share of BOF furnaces increased from 32 per cent in 1990 to 55 per cent in 1997 and OHF decreased from 57 per cent to 32 per cent in the same period (Figure C1).

However, energy consumption has decreased less than production – from 57.9 Mtoe in 1990 to 38.7 Mtoe in 1997 (-33.1 per cent). This means that specific energy consumption has increased over this period. Because of the availability of detailed data, the iron and steel sector can be disaggregated by process. The data is sufficiently detailed to allow the decomposition of specific energy consumption, and to identify the driving forces behind energy consumption patterns (Figure C2).

An activity effect was the main reason for the annual energy consumption decrease – up to 18 Mtoe in the year 1994. The structural effect was not significant, accounting for ± 1 per cent fluctuation in specific energy consumption (Figure C3). Pure intensity increased through the

1990s in the Russian iron and steel industry, reaching 10 per cent in the years 1994-1996. So the decline in physical output was followed by inefficient use of energy resources. The lack of energy conservation measures, coincides due mainly to low energy prices in Russia during the period under consideration.

Figure C1 Share of Crude Steel Production in Russia
By process; Per cent; 1987-97.

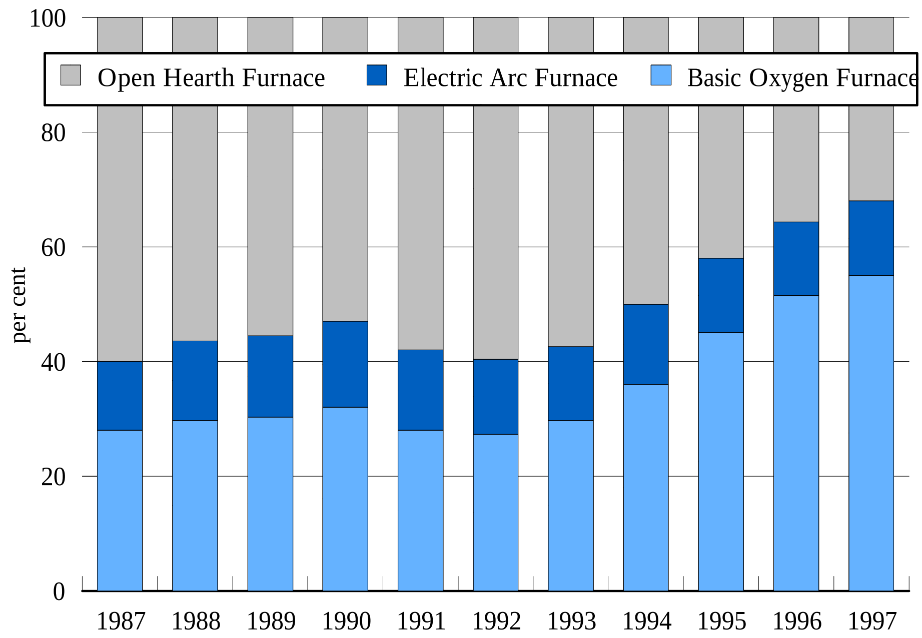


Figure C2 Decomposition of Energy Consumption in Iron and Steel Industry
ktoe; 1990-97.

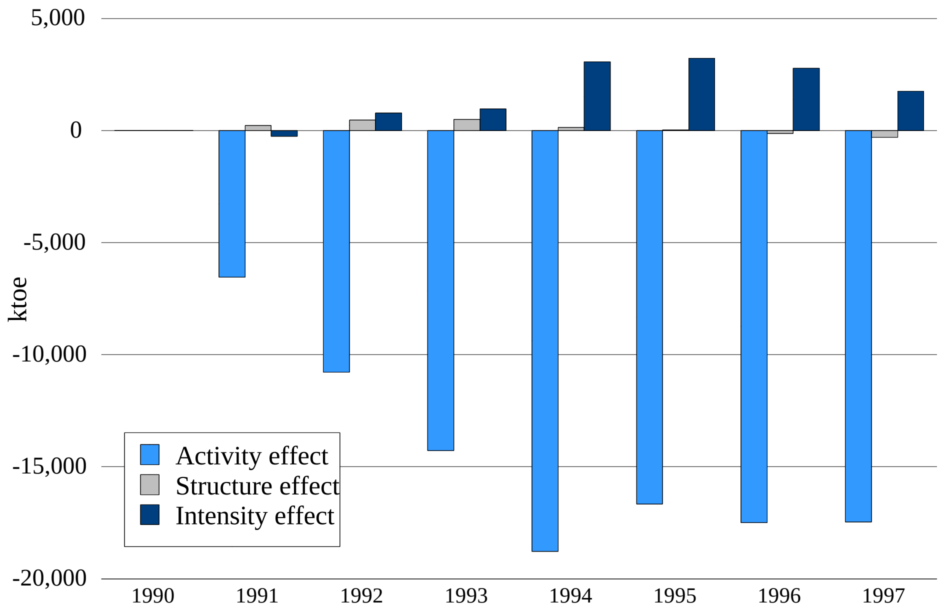
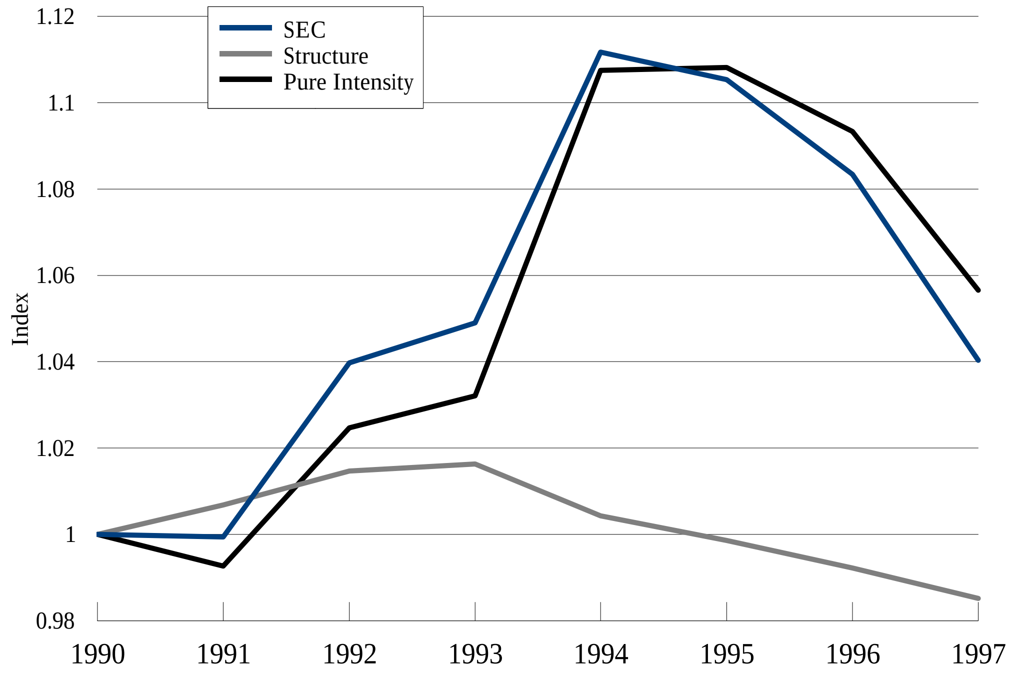


Figure C3 Decomposition of SEC in the Russian Iron and Steel Industry
Index (1990=1); 1990-97; Russia



ENERGY EFFICIENCY POTENTIALS AND MEASURES

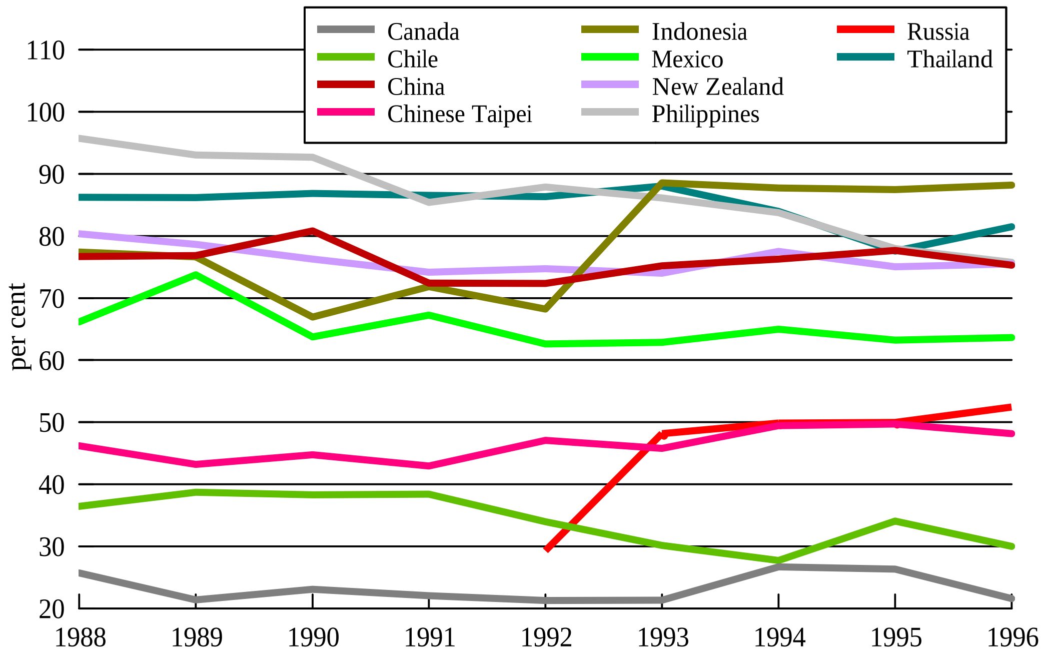
ENERGY SAVING POTENTIALS

Energy saving potentials can be obtained by comparing actual specific energy consumption levels (SEC) with best practice data (SEC_{BP}) for each economy. The SEC_{BP} trends were calculated on the basis of international best practice data for the iron and steel industry (Worrell, 1999) and sub-sectoral process mix information. Energy saving potentials are structurally adjusted and reflect improvements or deterioration in energy efficiency.

Energy saving potentials in the iron and steel industry for selected APEC economies are presented in Figure 20. The most significant conclusion that can be drawn from this analysis is that nearly all economies shown have relatively stable energy end use efficiency patterns. This is consistent with the fact that over this time period, energy intensities in this sector have remained relatively flat for all economies shown. Apart from this, some economies would appear to have significant room for improvement in terms of the energy efficiency of their steel-making operations.

The data for some major steel producers (the United States, Japan, Korea and Australia) have not been included because they plotted significantly below the best practice level (for at least some years), suggesting data problems. This could relate to non-accounting for co-generation or export-import flows in various related products.

Figure 20 Energy Saving Potentials in Iron and Steel Industry
Selected APEC Economies; per cent; 1988-96.



It is worthwhile to mention that the energy saving potential trend and pure intensity trend for the Russian iron and steel industry obtained through decomposition analysis tell the same story. The dynamics are identical when compared in the index form. This means the two methods, (1) comparison of actual SEC against structurally adjusted best practice data and (2) decomposition analysis are equivalent in an informational sense.

It should also be noted that there is no 'best practice' for the obsolete OHF process which in some instances is still used in China and Russia. This process has been largely eliminated by the BOF primary steel route, and in cases where the OHF process still exists, the study assumes that 'best practice' levels are equivalent to the BOF process.

ENERGY EFFICIENCY MEASURES

Iron and steel production is energy intensive and in some APEC economies it accounts for a significant share of the energy consumed by the industrial sector, and even the whole economy. In Japan, for example, the iron and steel industry consumes around 13 per cent of total energy demand and, considering Japan's energy import dependence, the industry has continuously implemented various energy-saving measures.

One of the major energy-saving technologies is reduction of the number of steps in the process. In the Steel Strip Mill process, conventional steel-making involved processing taking 10 days from ingot making through finish rolling including slabbing, reheating and rough rolling. However the introduction and improvement of Continuous Casting, has reduced the processing period to 1 hour.

The steel-making process utilises high-temperature energy and has much room to increase thermal efficiency. A number of technologies have been developed to recover waste heat. Three major technologies include:

COKE DRY QUENCHING (CDQ) SYSTEM

Previously heated coke taken from a coke oven was cooled down with water and the steam was discharged to the atmosphere. The Coke Dry Quenching system is a technology to recover the heat of the coke by cooling with an inert gas and use the heated gas to produce steam which could be used to generate electricity.

BLAST FURNACE TOP PRESSURE RECOVERY TURBINE (TRT)

Blast Furnaces are operated at a high pressure (two or three times of the atmospheric pressure) in order to achieve high productivity. This high pressure gas drives the turbines of generators. In Japan, 3 billion kWh of power is generated annually by TRTs, equivalent to 8 per cent of the electric power consumed by integrated steelworks.

RECOVERY OF HEAT FROM BASIC OXYGEN FURNACE (BOF) GAS

A large quantity of gas from BOF is fully recovered to use it as heating source for the equipment in steelworks.

FUTURE STEEL MAKING TECHNOLOGIES

Next generation steel-making technologies are Smelting Reduction process, New Coke Oven and Continuous Strip Casting.

SMELTING REDUCTION PROCESS

The conventional Blast Furnace process requires sintering and coking plants. The Smelting Reduction process technology produces molten iron with iron ore and coal directly without needing either the sintering or coking process, resulting in high energy efficiency with less-expensive investment.

NEW COKE OVEN

New Coke Oven technology produces coke at relatively low temperatures by heating the coal quickly before the charge into the coke oven. A wide selection of coal types can be used.

CONTINUOUS STRIP CASTING

This technology casts strips continuously without the conventional hot rolling process, resulting in shortening the processing period to 5 minutes.

The Iron and Steel Industry has endeavoured to develop useful technologies for energy-saving successfully and will make every effort to save energy by improving the efficiency of production facilities and the introduction of next-generation steel making technologies.

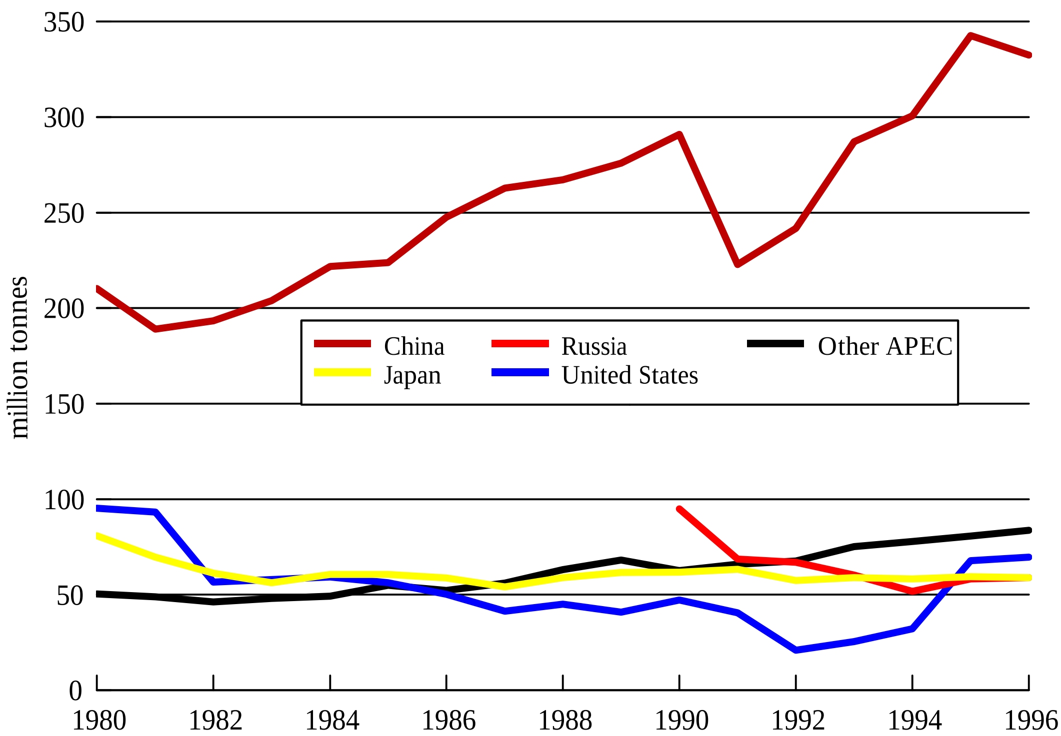
ENVIRONMENTAL IMPLICATIONS OF THE INDICATORS

Energy-use related CO_2 emissions of the iron and steel sector were determined from the data for energy consumption and fuel mix. The conversion factors that relate fossil fuel combustion to CO_2 emissions volumes that were used in this study are those recommended by IEA (IEA, 1996), namely:

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

Carbon dioxide emissions generated by energy use in the sector are shown in Figure 21. The decrease in the trend for China between 1990 and 1991 is probably explained by the uncertainty of data for that period. Increasing energy consumption in most of the economies brought about a rising trend in CO_2 emissions which reached 610 million tonnes in 1996 in absolute values.

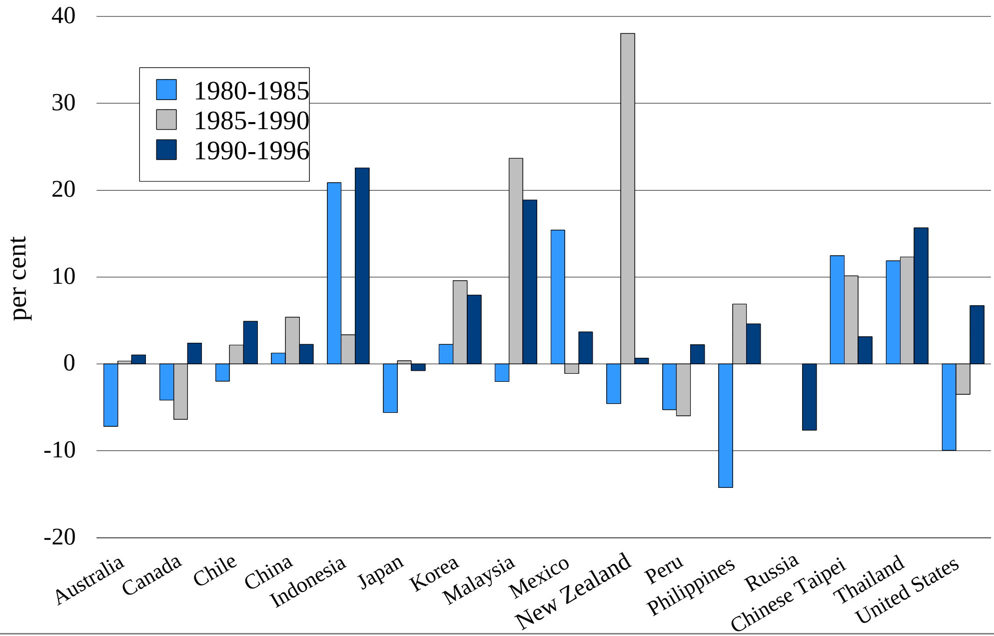
Figure 21 CO_2 Emissions in Iron and Steel Sector
Selected APEC Economies; million tonnes; 1980-93.



The major part of carbon emissions is generated in the Chinese iron and steel sector - 332.5 million tonnes or 54.4 per cent of total sectoral emissions in APEC. The next three economies generate: United States – 69.6 million tonnes of CO_2 or 11.4 per cent, Japan – 59 million tonnes of CO_2 or 9.7 per cent, Russia – 59 million tonnes or 9.7 per cent of total sectoral emissions in APEC in 1996. Combined emission share – 30.8 per cent is significantly less than Chinese emissions. The first three economies experienced a decline in sectoral carbon dioxide emissions.

Carbon emission dynamics for the groups is shown in Figure 22.

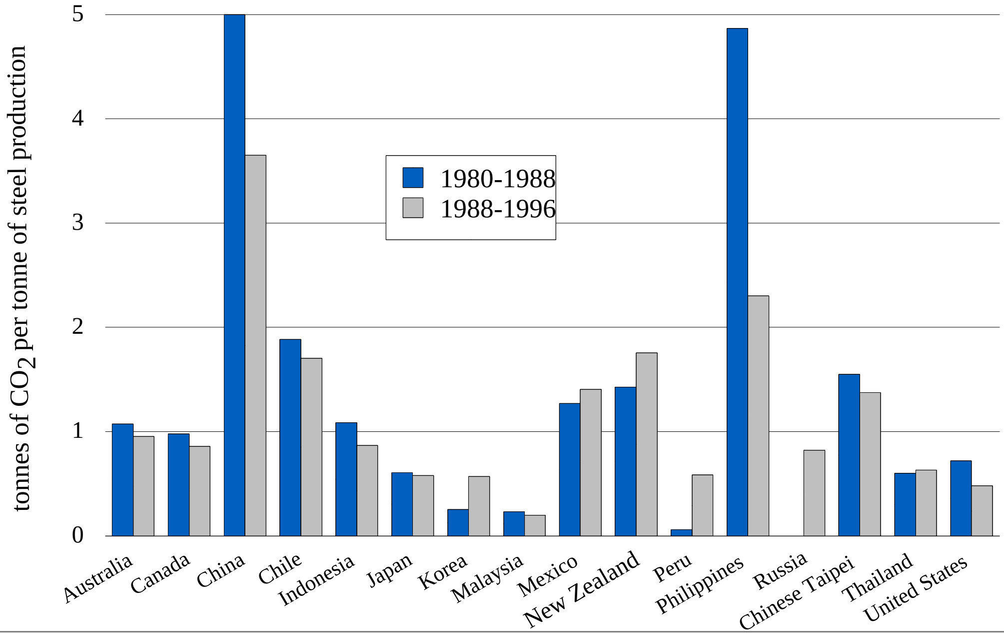
Figure 22 CO_2 Emissions Growth in the Iron and Steel Sector
Selected APEC Economies; per cent; 1980-85, 1985-90 and 1990-95.



Finally the CO_2 intensity for iron and steel production was determined by dividing CO_2 emissions by tonne of crude steel produced (Figure 23). For most economies the trends in this indicator are slightly decreasing with the values laying in the interval 0.7 - 1.7 tonnes CO_2 per tonne of produced crude steel. The Chinese iron and steel sector has substantially higher CO_2 intensities, although these have decreased from levels above 5 tonnes CO_2 / tonne steel in the early 1980s to around 3.2 tonnes CO_2 / tonne steel in 1996.

Figure 23 CO_2 Intensity in Iron and Steel Sector

Selected APEC Economies; CO_2 (tonnes) per tonne of steel produced, nine year averages.



CHAPTER 6

ENERGY EFFICIENCY IN THE APEC CEMENT SECTOR

PRODUCTION TRENDS AND PROCESSES

GENERAL DESCRIPTION OF RELEVANT PROCESS[2]

Cement production involves three main stages: (a) raw material processing, (b) clinker burning and finish grinding (Figure 24). Clinker burning is the main energy-consuming step in cement production.

Clinker is produced by burning a mixture of mainly limestone ($CaCO_3$), silicon oxides, aluminum and iron oxides (out of clay and coal shale). Production can take place in different process types: the wet process, the dry process and some intermediate forms (semi-wet or semi-dry). The name refers to the processing of raw materials. In the wet process, raw materials are mixed with water (in a ratio of about 2:1). The water is evaporated in kilns, after which the chemical reactions involved in clinker production take place. In the dry process, raw materials are mixed, dried, ground and fed to the kiln as a powder (raw meal) or as pellets. In modern processes, the raw material mix may be preheated and the limestone precalcined before being fed to the kiln.

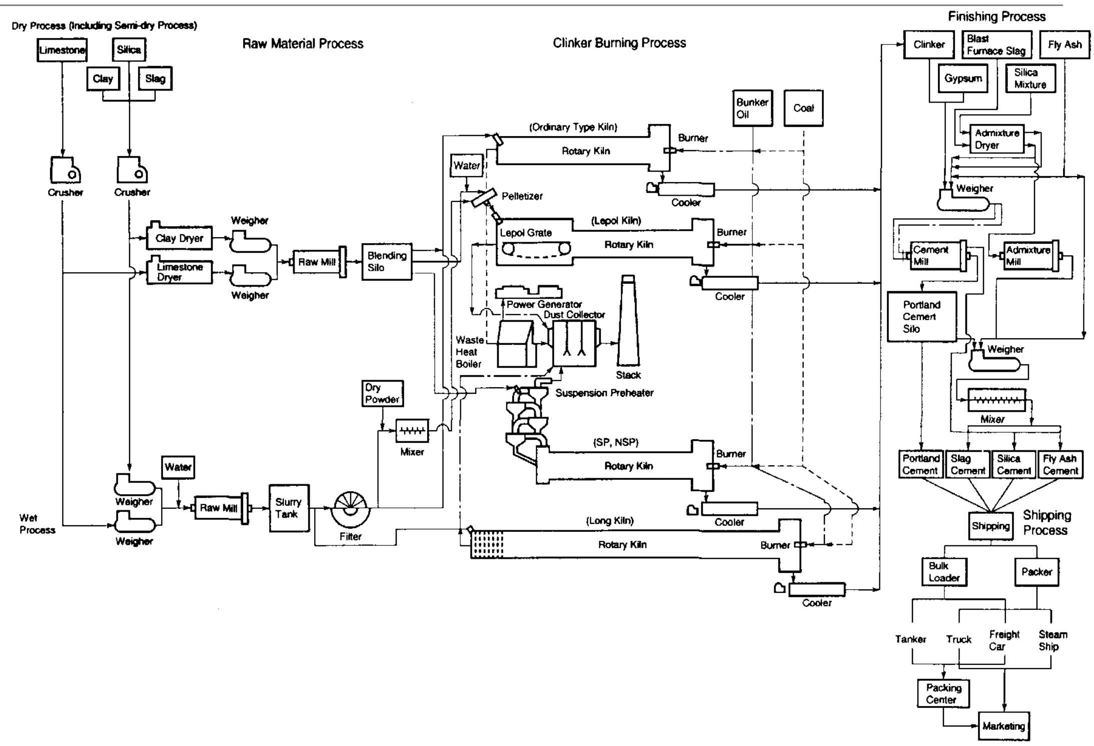
The types of kilns usually used in each type of process are the following:

- Wet: wet process kiln;
- Semi-dry: Lepol or shaft;
- Dry: dry long, short kiln with boiler, suspension preheater (SP), and NSP (SP with calciner).

The selection of process types considers the properties of raw materials, cost of fuel, conditions of location and others. The main advantages of the wet process are lower plant construction costs, higher feedstock flexibility and easier manufacture of high-quality products. Meanwhile, the dry process is more energy efficient and its running cost is lower. The trend that can be observed in many APEC economies is toward the elimination of the old wet process, being replaced by the dry process – especially with NSP kilns – considering that technological progress is reducing the difference in quality of the products manufactured through both processes, and the importance of energy in total costs in the cement industry. Figure 25 shows this trend for Japan from 1970 to 1993, while Figure 26 shows the share of each type of kiln in selected Asian economies.

[2] Based on ECCJ (1994), Phylipsen *et al* (1998) and WEC (1995).

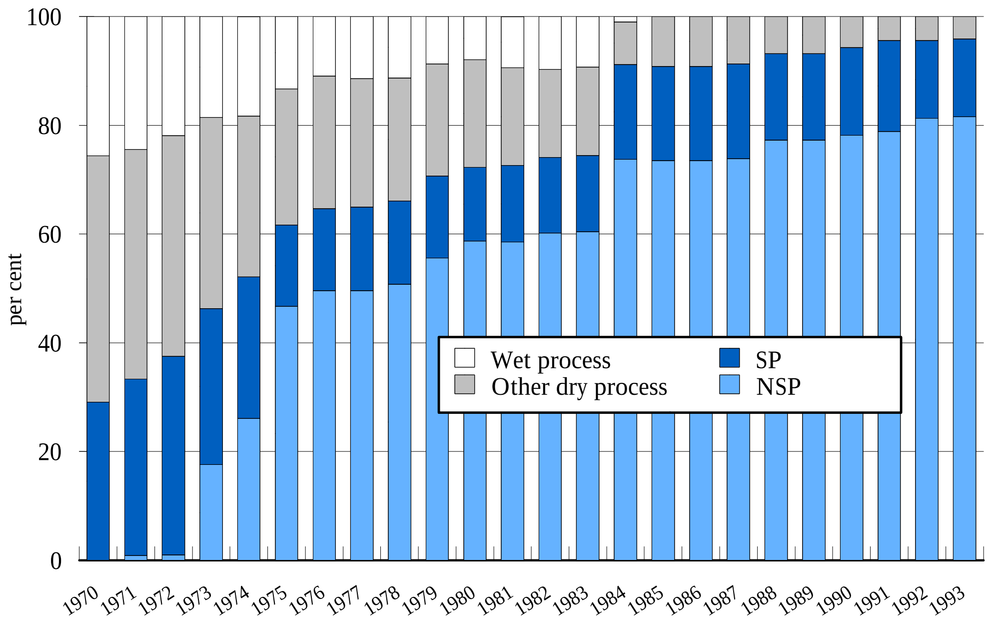
Figure 24 Process Routes in Cement Production



Source: ECCJ, 1994.

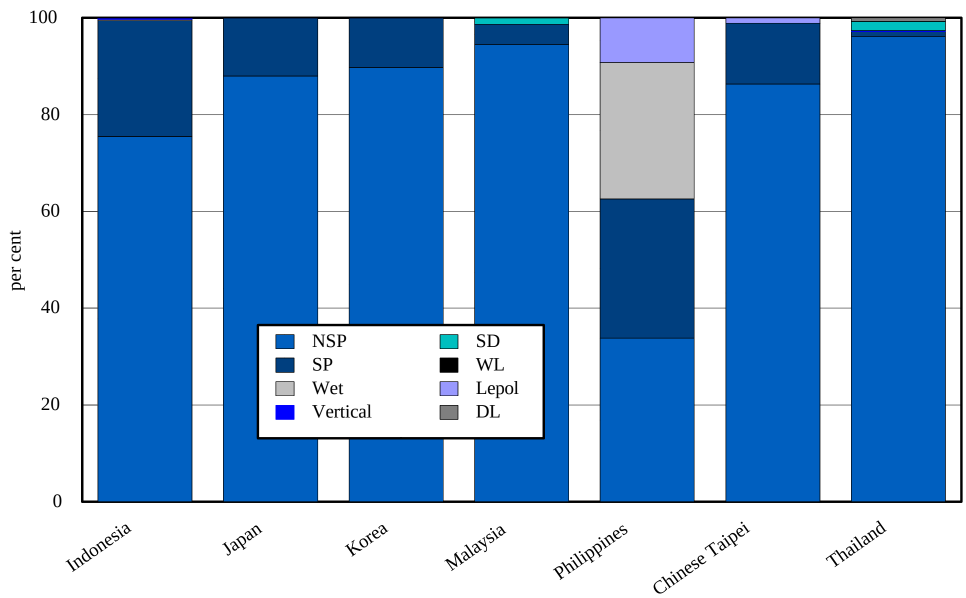
After the melt has cooled down, clinker is blended with gypsum and, depending on the desired product, with fly ash, blast furnace slag or other additives. Important products are Portland cement (usually containing 95 per cent clinker), Portland fly-ash cement (71 per cent clinker) and blast furnace cement (with clinker content of 30 per cent). In some cases, also composite cement is distinguished, which contains up to 20 per cent of clinker. The quality of blended cements is comparable to Portland cement. The main differences are lower early strength, but higher final strength and an improved resistance to sea water and sulphates for blended cements.

Figure 25 Transition of Clinker Manufacturing Capacity by Type in Japan
Percentage of production capacity; 1970-93.



Source: ECCJ (1994)

Figure 26 Clinker Manufacturing Capacity by Type
Selected APEC Economies; percentage of production capacity; 1999.

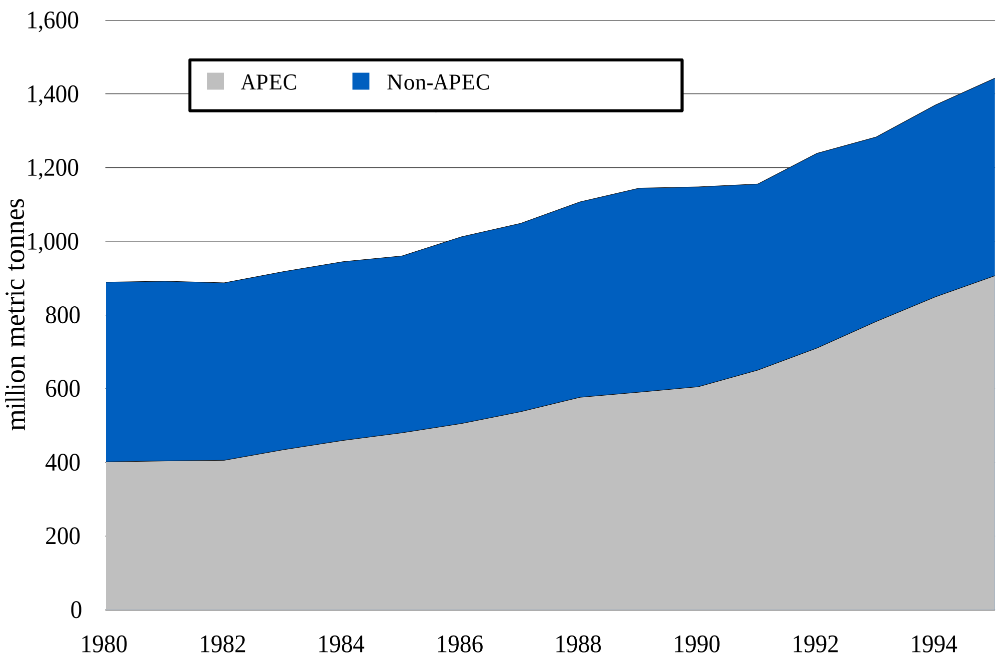


Note: Figures for Chinese Taipei correspond to 1998.
Source: Japan Cement Association (1999) and Department of Energy of the Philippines (2000)

PRODUCTION TRENDS[3]

World cement production has been rising steadily in the period 1980-1995, with an average annual growth rate of 3.3 per cent. For the APEC region, this rate has been 5.6 per cent in the same period. Consequently, APEC's share in world production has increased from 45 per cent in 1980 to 63 per cent in 1995 (see Figure 27).

Figure 27 World Cement Production
Million metric tonnes; 1980-94.

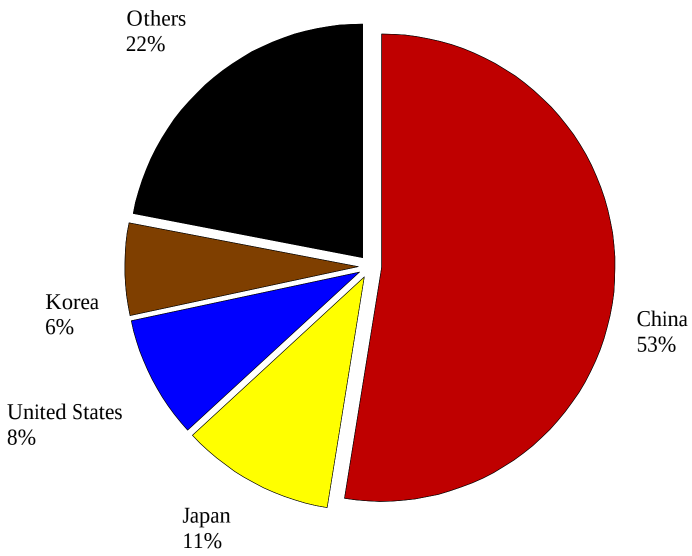


Source: APEC Database, Cembureau (1998, 1999)

In this period, China has become the world's biggest cement producer, passing from 9 per cent of world production in 1980, to 33 per cent in 1995, increasing its production almost six-fold. In the APEC region, China accounts for nearly 53 per cent of total production, followed by Japan, United States and Korea. These four economies represent nearly 80 per cent of the total cement production of the region (see Figure 28).

[3] Sources: APEC Database and Cembureau (1998, 1999).

Figure 28 Main Cement Producers in the APEC Region
Percentage shares of total APEC production; 1995.



Source: APEC Database, Cembureau (1998, 1999)

In the period from 1980 to 1995, Viet Nam, Thailand and China have had the highest growth rates among APEC economies. However, as the following table shows, the evolution of production levels among the economies of the region in this period has been varied.

Table 11 APEC Cement Production

APEC economies; 1980, 1988 and 1995.

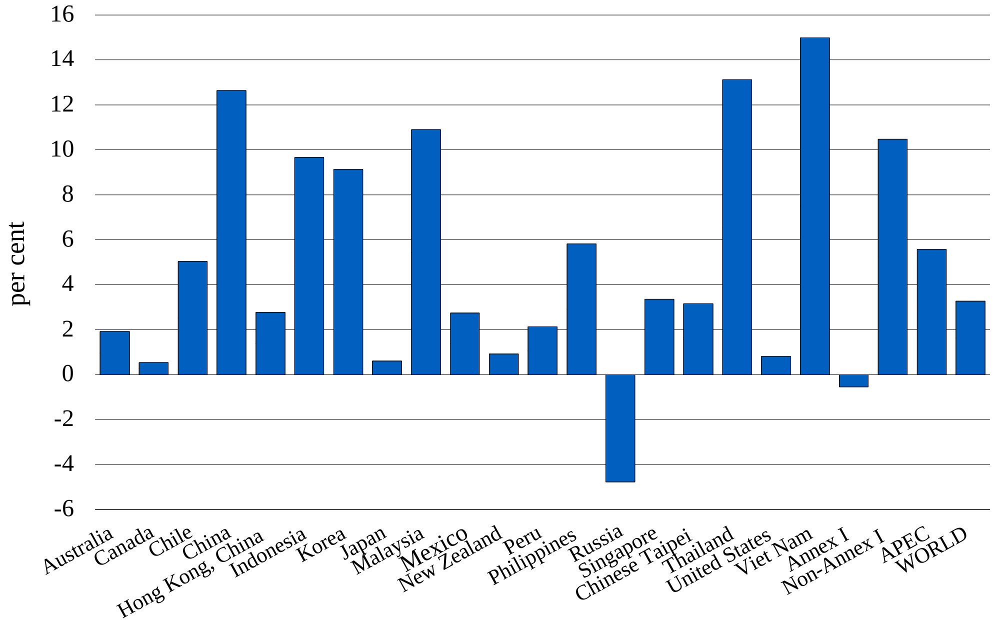
	Production '000 tonnes			Average Annual growth %		
	1980	1988	1995	1980-1988	1988-1995	1980-1995
Australia	5,560	6,620	7,400	2.21	1.60	1.92
Brunei Darussalam	na	na	na	-	-	-
Canada	11,000	12,264	11,933	1.37	-0.39	0.54
Chile	1,566	1,883	3,275	2.33	8.23	5.04
China	80,000	210,140	476,533	12.83	12.41	12.63
Hong Kong, China	1,279	2,226	1,927	7.17	-2.04	2.77
Indonesia	5,831	13,218	23,266	10.77	8.41	9.66
Japan	87,957	79,122	96,292	-1.31	2.85	0.61
Korea	15,573	29,854	57,843	8.47	9.91	9.14
Malaysia	2,349	3,828	11,088	6.29	16.41	10.90
Mexico	16,260	22,897	24,400	4.37	0.91	2.74
New Zealand	828	812	950	-0.24	2.27	0.92
Papua New Guinea	na	na	na	-	-	-
Peru	2,770	2,514	3,792	-1.20	6.05	2.12
Philippines	4,516	5,353	10,554	2.15	10.18	5.82
Russia	75,800	84,000	36,400	1.29	-11.26	-4.77
Singapore	1,831	1,595	3,000	-1.71	9.44	3.35
Chinese Taipei	14,062	16,832	22,406	2.27	4.17	3.15
Thailand	5,302	11,675	33,650	10.37	16.33	13.11
United States of America	68,243	69,734	76,906	0.27	1.41	0.80
Viet Nam	641	1,760	5,200	13.46	16.74	14.98
Annex I total	249,388	252,552	229,881	0.16	-1.33	-0.54
Non-Annex I total	151,980	323,775	676,934	9.92	11.11	10.47
APEC total	401,368	576,327	906,815	4.63	6.69	5.58
World total	889,666	1,107,129	1,442,555	2.77	3.85	3.27

Notes: na – data is not available.
Annex I and Non-Annex I include only APEC economies.

Source: APEC Database, Cembureau (1998, 1999)

The following figure shows the growth rate of cement production in APEC economies for the period 1980-95.

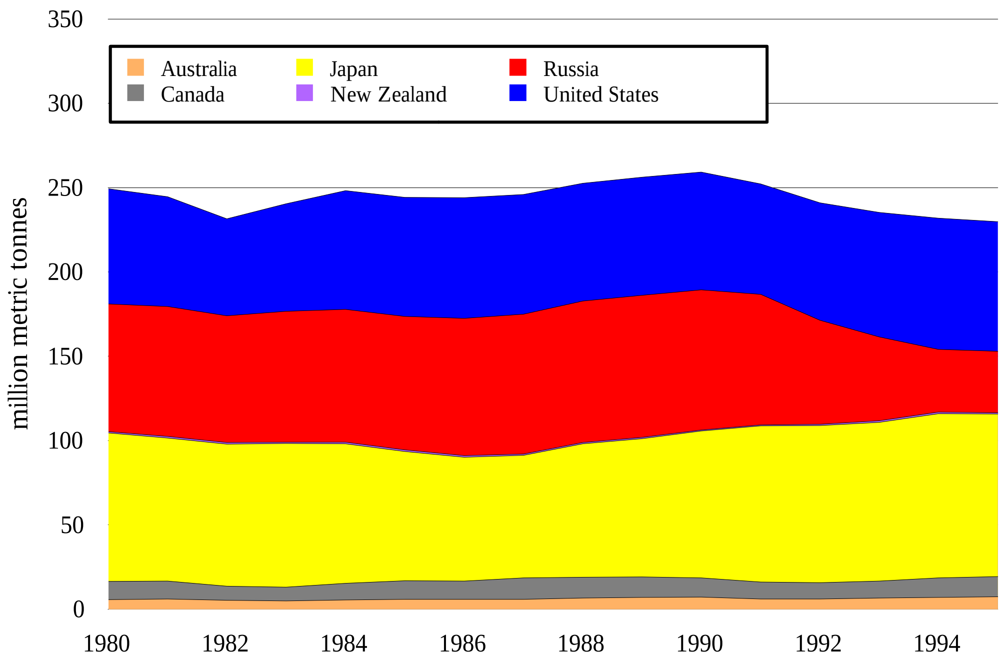
Figure 29 Cement Production Growth Rates in the APEC Region and World
APEC Region and World; percent; 1980-95.



Note: Annex I and Non-Annex I include only APEC economies.
Source: APEC Database, Cembureau (1998, 1999).

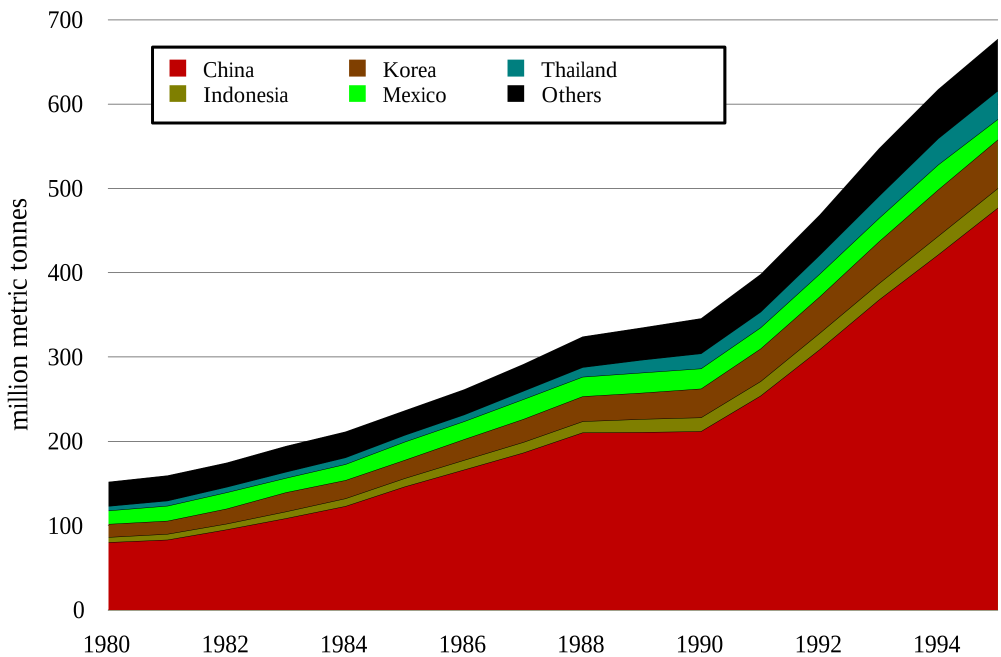
Two distinct groups can be observed, namely Annex I and Non-Annex I economies, where production has decreased in the former – due to the fall in Russian production – and highly increased in the latter – mainly due to the increase in China (see Figure 30 and Figure 31).

Figure 30 Evolution of Cement Production in Annex I APEC Economies
Million metric tonnes; 1980-95.



Source: APEC Database, Cembureau (1998, 1999).

Figure 31 Evolution of Cement Production in Non-Annex I APEC Economies
Million metric tonnes; 1980-95.



Source: APEC Database, Cembureau (1998, 1999).

ENERGY CONSUMPTION PROFILE

TOTAL ENERGY CONSUMPTION

According to recent estimates, cement production accounts for nearly 2 per cent of the world's total primary energy demand (WEC, 1995). In some economies such as China, it represents over 4 per cent of its total energy consumption. Cement production is usually classified as an energy-intensive industry, with energy costs in the range of 20 to 40 per cent of total manufacturing costs (WEC, 1995; ECCJ, 1994).

Total energy consumption of the cement sector in the 21 APEC economies is currently unavailable due to different classification systems used for this activity. Some economies and comprehensive databases classify it under non-metallic minerals (for example, the IEA database) or group it together with ceramics (namely the APEC database). Even though cement production is likely to account for a high percentage of these groupings, the use of these databases may introduce distortions when calculating efficiency indicators for this product. However, as an order of magnitude, the final energy consumption of the non-metallic minerals sector in APEC economies (excluding Brunei, Hong Kong China, Papua New Guinea, Peru, Singapore and Viet Nam) in 1995 amounted to approximately 149 Mtoe.

Energy consumption data was collected for 9 APEC member economies. It must be noted that no inter-economy comparisons should be made, as the sources used differ and are not necessarily consistent. Nevertheless, data for each economy is internally consistent, so trends can be validly derived.

Data sources used are the INEDIS database (for Canada, Mexico and the US), surveys submitted by the respective economies (for Australia, Chile, Korea, Philippines and Thailand), and the Ministry of International Trade and Industry, MITI, for Japan (MITI, 1982-96).

This approach deviates from the general methodology adopted for this study, given the limited information available in the database consulted, which would have circumscribed the study to only three economies.

In 1995, energy consumed by these 9 economies to manufacture cement reached 31,901 ktoe, from a level of 24,570 ktoe in 1981[4] (see Table 12). Two periods can be clearly distinguished. In the first, from 1981 to 1986, total energy consumption declined at an annual average rate of 3 per cent, explained mainly by the reduction in energy consumption of the US and Japan, which together account for more than 60 per cent of total energy consumption of the sample for those years. The annual average reduction in energy consumption for both economies was 3.8 per cent and 6.2 per cent, respectively. In this period, only Korea, Mexico and Thailand show an increasing trend.

The second period, from 1986 to 1995, shows significant increases in energy consumption in every economy of the sample, except for a comparatively marginal decrease in Australia. Total energy consumption increased at an annual rate of 4.7 per cent during this period. Both in absolute and relative terms, the biggest contributor to this increase was Thailand, followed by Korea. Average annual increases for the period were 18.9 per cent and 9 per cent, respectively. Together they explain more than 60 per cent of the total increase in energy consumption.

[4] Data for 1980 is not available for Japan, Korea and Thailand.

Table 12 Final Energy Consumption in the Cement Sector
APEC Economies; ktoe; 1981, 1986 and 95.

	Energy Consumption ktoe			Average Annual Growth %		
	1981	1986	1995	1981 - 1986	1986 - 1995	1981 - 1995
Australia	873	804	742	-1.6	-0.9	-1.2
Brunei	na	na	na	-	-	-
Canada	1,235	1,040	1,317	-3.4	2.7	0.5
Chile	156	101	161	-8.3	5.3	0.2
China	na	na	na	-	-	-
Hong Kong, China	na	na	na	-	-	-
Indonesia	na	na	na	-	-	-
Japan	7,665	5,580	7,011	-6.2	2.6	-0.6
Korea	2,461	2,865	6,216	3.1	9.0	6.8
Malaysia	na	na	na	-	-	-
Mexico	1,990	2,158	2,161	1.6	0.0	0.6
New Zealand	na	na	na	-	-	-
Papua New Guinea	na	na	na	-	-	-
Peru	na	na	na	-	-	-
Philippines	597	376	1,061	-8.8	12.2	4.2
Russia	na	na	na	-	-	-
Singapore	na	na	na	-	-	-
Chinese Taipei	na	na	na	-	-	-
Thailand	852	929	4,409	1.7	18.9	12.5
United States of America	8,741	7,198	8,823	-3.8	2.3	0.1
Viet Nam	na	na	na	-	-	-
Above total	24,570	21,051	31,901	-3.0	4.7	1.9

Notes: na: no data available
Sources: INEDIS database (Canada, Mexico, US), surveys submitted by each economy (Australia, Chile, Korea, Philippines, Thailand), and adapted from MITI (1982-1996) for Japan.

ENERGY SOURCE MIX

Energy consumption consists mainly of fuel input for clinker burning (pyroprocessing) and electricity used for clinker grinding, raw material processing and clinker burning. The major energy consuming process is clinker burning, consuming up to 99 per cent of the fuel energy and 79 per cent of the total energy required to manufacture one tonne of cement (WEC, 1995). The following table shows the energy breakdown for the major processes in a typical Portland cement plant using the dry process.

Table 13 Energy Consumption in Typical Dry Process Portland Cement Plant

The figures assume an average dry process with four-stage suspension preheater system with grate cooler. Drying performed with kiln waste gases. Cement to clinker ratio: 1.05.

	Fuel	Electricity	Total primary energy
	%	%	%
Raw material collection	1	5	2
Raw material processing		33	8
Clinker burning (pyroprocessing)	99	22	79
Clinker grinding		38	10
Conveying, packaging, etc.		5	1
Share of total primary energy	75	25	100

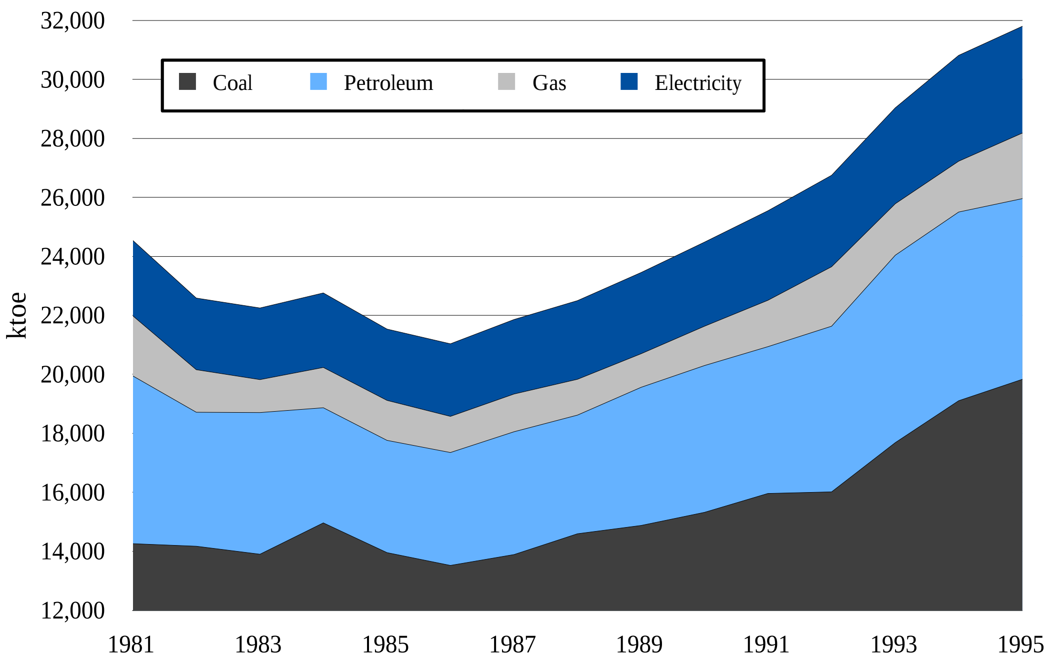
Source: WEC, 1995.

Due to its importance in manufacturing costs, energy mix in cement production is highly dependent on relative prices. After the two major oil crises, coal and coke replaced natural gas and heavy oil in many economies, including oil exporters such as Indonesia and Malaysia (WEC, 1995; ECCJ, 1994). Currently, waste products (for example, tires and municipal solid waste) and low-grade fuels are used extensively as energy sources. In 1992 in Japan, nearly 20 per cent of the waste tires were used for clinker burning (ECCJ, 1994).

The evolution of energy consumption by source in selected APEC economies is shown in Figure 32.

Figure 32 Energy Consumption by Source in the Cement Industry

APEC Region, ktoe; 1981-95.



Note: Coal includes solid waste products.
Source: INEDIS database, APERC survey, MITI (1982-1996)

The trend shows a substitution of liquid fuels to solid ones, together with a significant increase in the latter. Canada, Korea and Thailand account for most of this process, both in absolute and in relative terms. The share of liquid fuels passed from 27.0 to 3.1 per cent in Canada, from 50.4 to 25.6 per cent in Korea, and from 87.2 to 16.8 per cent in Thailand. In the case of Chile, a substitution from solid fuels to electricity takes place.

ENERGY INDICATORS

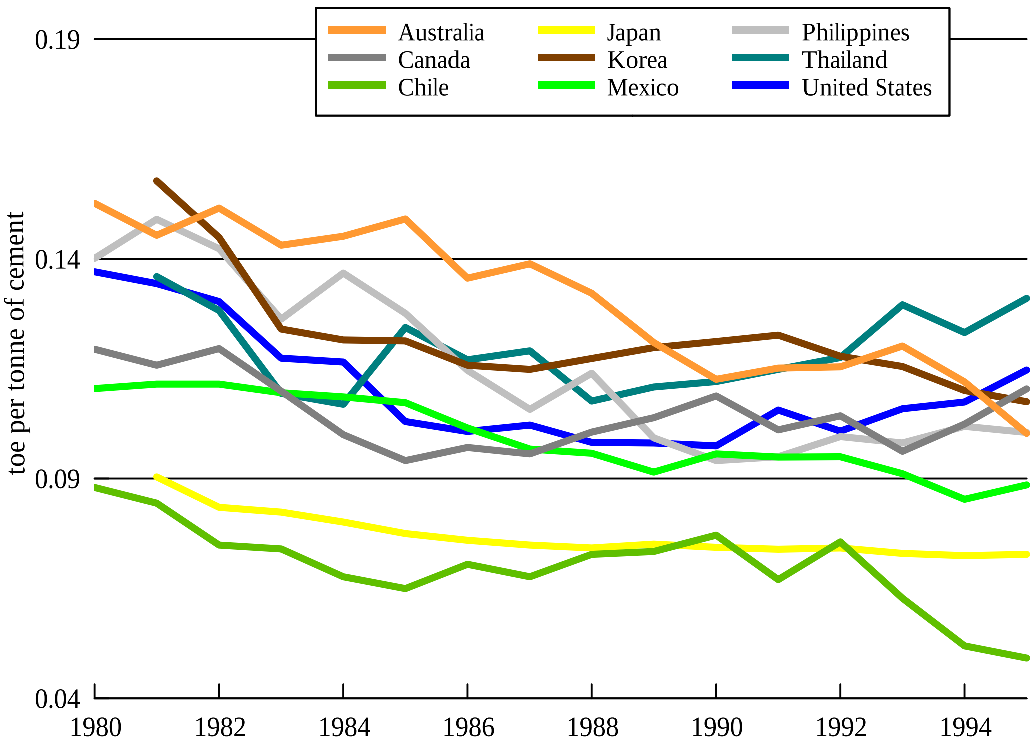
PHYSICAL INDICATORS

Many factors can explain changes in physical energy indicators in the cement sector, such as technology, characteristics of raw materials, clinker/cement ratio, composition of cement, and others. The approach to deal with these complexities is discussed elsewhere in this study. In this section, only descriptive indicators are calculated.

OVERALL ENERGY INTENSITY

As Figure 33 shows, most of the economies in the sample show decreasing energy intensities in the period 1980/81 to 1995.

Figure 33 Energy Intensity in the Cement Industry
Selected APEC economies, toe/tonne of cement; 1980-95.



Source: Elaborated from INEDIS database, APERC survey, MITI (1982-1996), APEC database and Cembureau (1998, 1999).

The most significant reductions of this indicator in the period 1981-95 were achieved by Chile (3.8 per cent average annual reduction), the Philippines (2.8 per cent), Korea (2.7 per cent) and Australia (2.6 per cent).

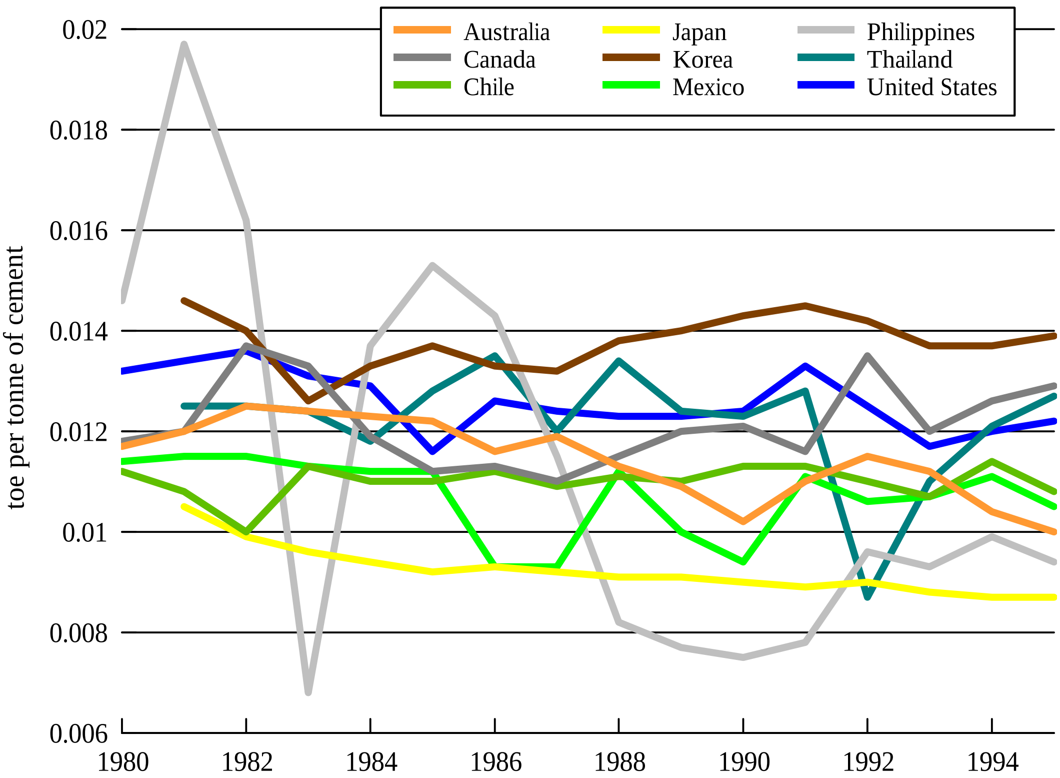
However, after an initial decline, three economies show an increase in the latter part of the period. Thailand's energy intensity starts to increase in 1988, the same happens in the US in 1990 and since 1992 in Canada.

Japan's asymptotic trend could indicate that further efficiency gains will require significant efforts and/or technological breakthroughs.

ELECTRICITY INTENSITY

Electricity intensity trends have decreased less than overall energy intensities or remained fairly constant for most of the economies in the sample. The highest reductions in this indicator correspond to Australia and Japan, both with an average annual decrease of 1.3 per cent. Given the high variability of the figures for the Philippines, no definite conclusion can be made.

Figure 34 Electricity Intensity in the Cement Industry
Selected APEC Economies, toe/tonne of cement; 1980-95.

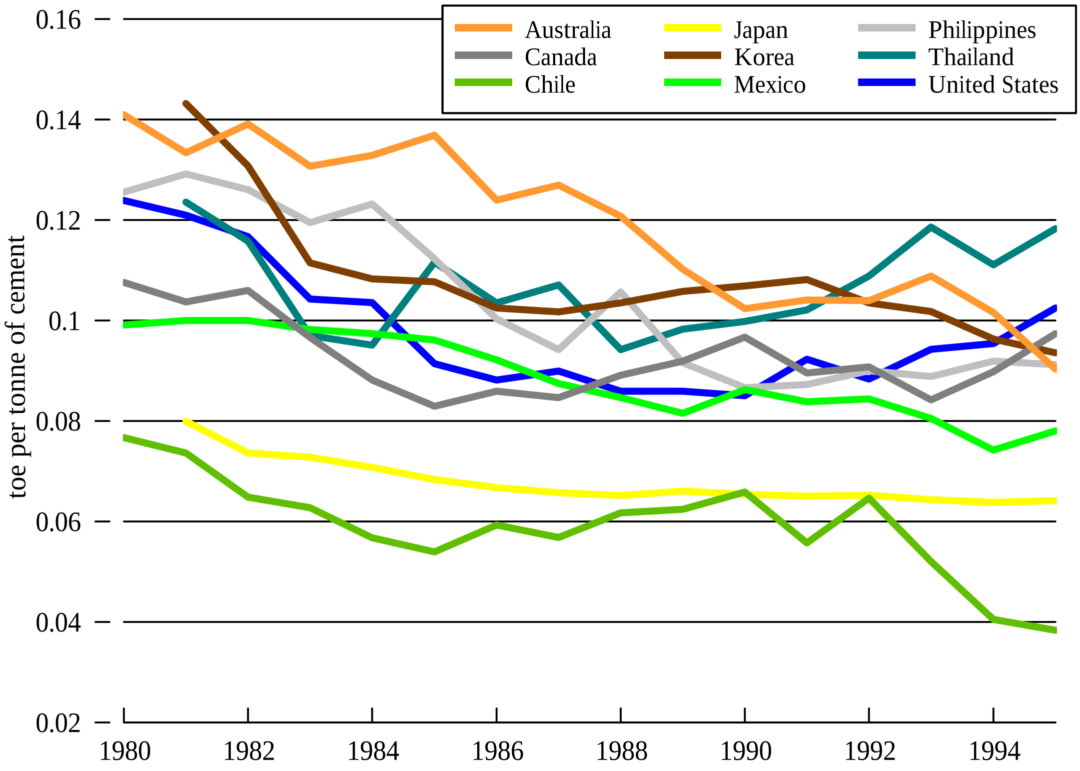


Source: Elaborated from INEDIS database, APERC survey, MITI (1982-1996), APEC database and Cembureau (1998, 1999).

ENERGY INTENSITY (EXCLUDING ELECTRICITY)

As Figure 35 shows, the indicator for energy intensity, excluding electricity, follows the same trend as the one that includes it, given the high share of fuels in the total specific energy consumption.

Figure 35 Energy Intensity (Excluding Electricity) in the Cement Industry
Selected APEC Economies; toe/tonne of cement; 1980-95.



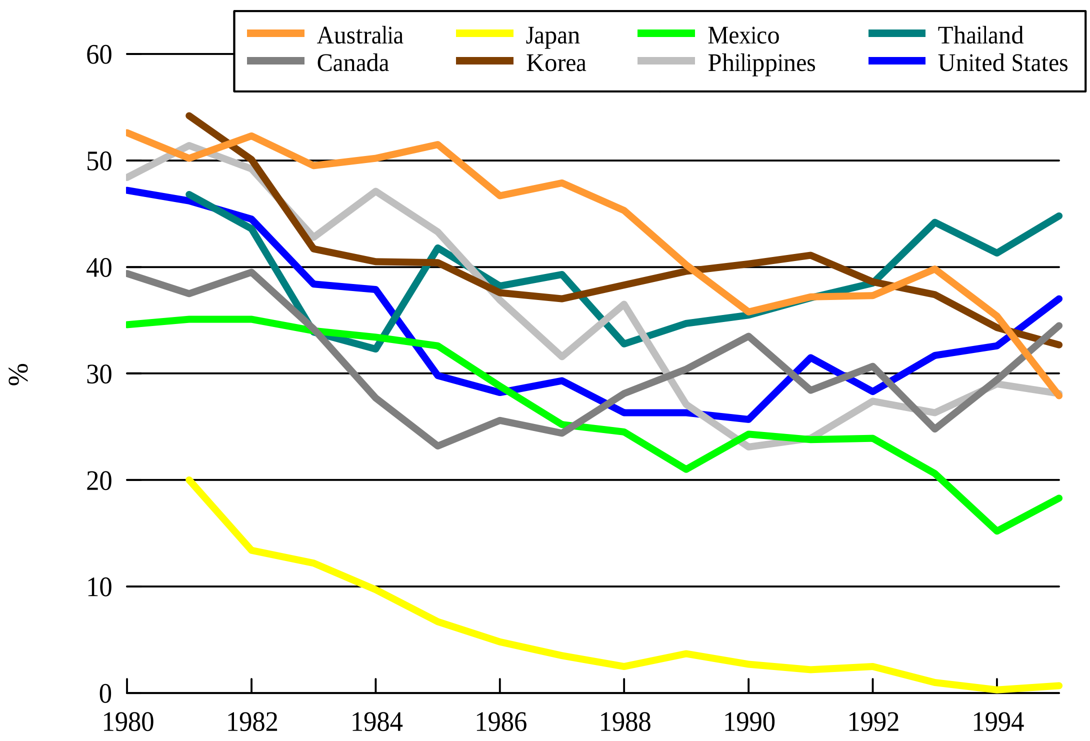
Source: Elaborated from INEDIS database, APERC survey, MITI (1982-1996), APEC database and Cembureau (1998, 1999).

ENERGY EFFICIENCY POTENTIALS AND MEASURES

ENERGY SAVING POTENTIALS

Figure 36 shows the results of comparing the specific energy consumption of the cement sector of selected economies with the best practice level for this industry. For the latter, a consumption of 3.03 GJ/tonne of cement, equivalent to 7.23×10^{-2} toe/tonne of cement, was considered (Worrell *et al*, 1995). This value results from the addition of fuel and electricity consumption in clinker making and electricity consumption in cement grinding, as per the best practice levels given in Table 3, supposing a clinker to cement ratio of 85 per cent. This latter value was adopted considering that CO_2 emissions are proportional to clinker/cement ratios, and that increasingly 'best practice' takes into account environmental impacts.

Figure 36 Energy Saving Potentials in the Cement Industry
Selected APEC Economies; Best practice = 0%; 1980-95.



Source: Elaborated from INEDIS database, APERC survey, MITI (1982-1996) and Worrell *et al* (1995).

The results corroborate and help to explain previous figures, especially in the case of Japan, which has reached best practice levels and where further significant improvements in energy efficiency levels will probably require technological breakthroughs. Underlying this curve is a sustained and significant energy efficiency effort, mixture of government policies and industry initiatives[5].

Most of the economies show a trend approaching best practice levels, consistent with the introduction of the dry process (especially NSP kilns) and other energy efficient technologies and practices. As noted earlier, actual potentials should be taken with care, as the bases used for deriving specific energy consumption may not be consistent among the economies considered, making comparisons misleading. The rising trends for Canada, Thailand and the US in the latter part of the period could not be explained.

Chile appears to have an energy efficiency level substantially better than the current best practice for most of the period considered. This indicates a data problem, therefore this economy was not included in the analysis.

[5] See ECCJ, 1999.

ENERGY EFFICIENCY MEASURES

Generally, energy efficiency efforts can be classified into the following three steps (ECCJ, 1994):

1) GOOD HOUSEKEEPING

Energy efficiency efforts are made without much equipment investment, including elimination of the minor energy waste, review of the operation standards in the production line, more effective management, improvement of employees' cost consciousness, group activities and improvement of operation technique. For example, such efforts include management to prevent unnecessary lighting of the electric lamps and idle operation of the motors, repair of steam leakage, as well as reinforcement of heat insulation.

2) EQUIPMENT IMPROVEMENT

This is the phase of improving the energy efficiency of the equipment by minor modification of the existing production line to provide waste recovery and gas pressure recovery devices or by introduction of efficient energy conservation equipment, including replacement by advanced ones. For example, efforts include an effective use of the waste heat recovery in combustion furnaces and waste heat recovery generator in the cement plant.

3) PROCESS IMPROVEMENT

This is intended to reduce energy consumption by substantial modification of the production process itself by technological development. Needless to say, this is accompanied by a large equipment investment. However, this is linked to modernisation of the process aimed at energy efficiency, high quality, higher value added, improved product yield and manpower saving.

The following table exemplifies the energy efficiency measures that can be taken in each of the above three phases:

Table 14 Energy Efficiency Measures in the Cement Industry

Type of measure	Raw material process	Clinker burning process	Finish process
Good housekeeping	Selection of raw material Management of fineness Management of optimum grinding media	Prevention of stop due to failure Selection of fuel Prevention of air leak	Management of fineness Management of optimum grinding media
Equipment improvement	Use of industrial waste material (fly ash) Replacement of fan rotor Improvement of temperature and pressure control system Improvement of mixing and homogenising system	Use of industrial waste material (waste tires) Recovery of preheater exhaust gas Recovery of cooler exhaust gas (drying of raw material and generation of electricity) Replacement of cooler dust collector from multicyclone to EP	Installation of closed circuit (dynamic separator) Installation of feed control system
Process improvement	From wet to dry process From ball and tube mills to roller mill	From wet to dry process Conversion of fuel (e.g. from heavy oil to coal or natural gas) From SP to NSP Use of industrial waste (slag and pozzolan) From planetary and under coolers to grate cooler	

Source: ECCJ (1994).

The degree to which these measures contribute to energy efficiency will depend on the characteristics of the particular cement plant considered. However, the following table gives orders of magnitude of the energy savings that can be achieved with state-of-the-art and advanced technologies in the United States. These values must be compared with the specific energy consumption shown in Figure 33.

Table 15 Energy Savings in the United States Cement Industry

Estimated savings associated with the implementation of state-of-the-art and advanced technologies for the U.S. cement industry, compared to current practices

Process	State of the Art		Advanced	
	Technology	**Savings**	**Technology**	**Savings**
Raw materials	Improved grinding media and linings	0.005 – 0.01 GJ/tonne	Differential grinding (limestone, clay)	0.01 GJ/tonne
preparation	Roller mills	0.01 – 0.02 GJ/tonne	Computer automation and information technologies	0.01 – 0.02 GJ/tonne
	High-efficiency classifiers in closed-circuit grinding plants	0.01 – 0.03 GJ/tonne	Fluidised-bed drying with low-grade fuels –when kiln waste heat unavailable	Displace up to 0.26 GJ/tonne
	Waste heat drying using preheater exit gases	0.26 GJ/tonne	Non-mechanical comminution	n.a.
	Wet process slurry dewatering with filter presses and slurry thinners	1.04 – 1.30 GJ/tonne		
Clinker production	Low pressure-drop cyclones for suspension preheaters	0.02 GJ/tonne	Computer automated sensors for online analysis of kiln exhaust, temperature, and clinker quality	0.16 – 0.33 GJ/tonne
	Material recirculation in flash precalciners	0.05 – 0.22 GJ/tonne	Alkali specification modification	0.24 GJ/tonne
	Kiln combustion system improvements	0.07 – 0.33 GJ/tonne	Stationary clinkering systems: fluidised bed kilns, trough kilns	0.5 GJ/tonne
	Enhancement of internal heat transfer in kiln	0.11 GJ/tonne	All-electric kilns/hybrid fossil-electric kilns	0.6 GJ/tonne
	Kiln shell heat loss reduction	0.33 GJ/tonne		
	Optimise heat transfer in clinker cooler	0.48 GJ/tonne		
	Use of waste fuels	0.65 GJ/tonne		
	Dry-suspension preheater kilns	1.53 GJ/tonne		
	Dry precalciner kilns	1.72 GJ/tonne		
	Blended cements	Strongly depends upon		
	Cogeneration (steam rankine & organic rankine bottoming cycles utilising exhaust heat)	~0.05 GJe/tonne		
	High-temperature ceramic filters for exhaust	n.a.		
Finish grinding	Modified ball mill configuration	0.01 GJ/tonne	Computer automation and information technologies	– 0.03 GJ/tonne for
	Particle size distribution control	0.01 GJ/tonne	Modified fineness specification	– 0.04 GJ/tonne with
	Improved grinding media and linings (for example, high chrome alloys)	0.01 – 0.02 GJ/tonne	High-pressure roller press	0.04 GJ/tonne
	High-pressure roller press for clinker pre-grinding	0.02 – 0.03 GJ/tonne	Non-mechanical comminution	n.a.
	High-efficiency classifiers in closed circuit plants	0.02 – 0.03 GJ/tonne		

Notes: n/a – not available

Source: WEC (1995), citing a study by the United States Department of Energy, OIT (1990).

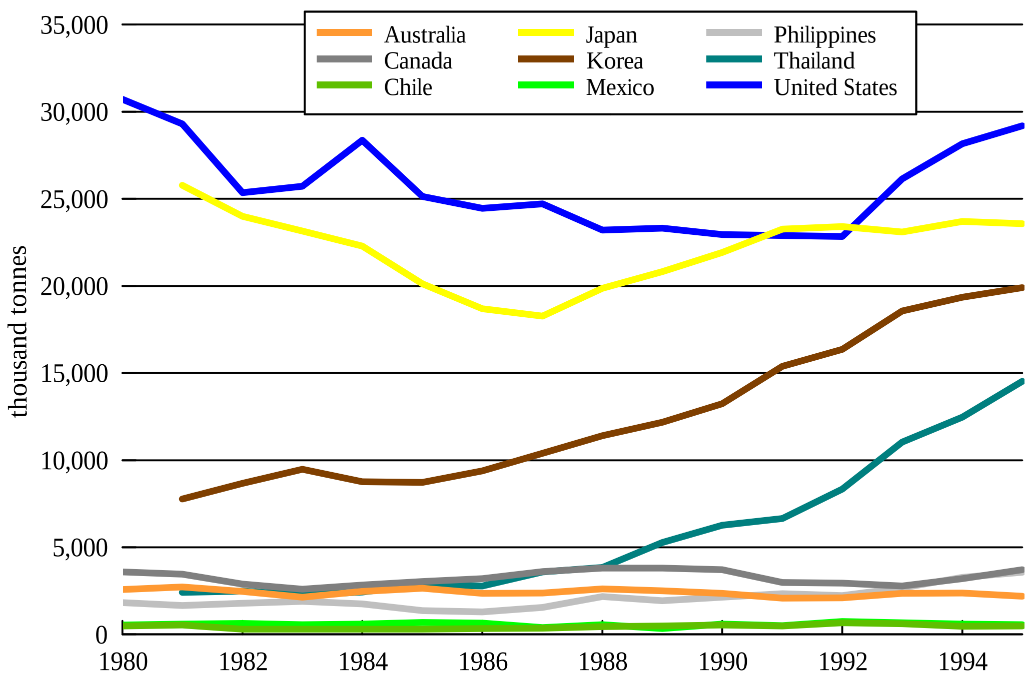
ENVIRONMENTAL IMPLICATIONS OF THE INDICATORS

The cement industry is a major emitter of CO_2. According to Hendriks *et al* (1998), this industry is responsible for 5 per cent of total global emissions of this gas. Emissions arise from calcination[6] (process emissions, not considered in the following analysis) and from fuel combustion. According to the same source, of the total CO_2 emitted by this industry in the world, 52 per cent were process emissions and 48 per cent due to energy use.

The trend of total CO_2 emissions for the sample considered in this study[7] has moved in tandem with total energy consumption. It increased from 74,218 ktonnes in 1981 to 97,728 ktonnes in 1995 (almost 32 per cent as compared to a 30 per cent increase in energy consumption), showing two distinct periods. The first, of declining emissions until 1986, and a second of increasing ones until 1995.

Even though base data is not necessarily consistent, two opposing tendencies can be seen. In the first period, most of the reductions in CO_2 emissions were driven by Japan and the US, being partially counterbalanced by the increase in Korean emissions. However, in the second period emissions in the US stabilise until 1992, when they begin to increase, while a significant growth is maintained in Korea (two-fold increase). In this period, Thailand increases its emissions more than five-fold, being in 1995 the fourth biggest contributor. Figure 37 shows this situation.

Figure 37 Cement Industry CO_2 Emissions
Selected APEC Economies, Thousand tonnes; 1980-95.



Source: Elaborated from INEDIS database, APERC survey and MITI (1982-1996).

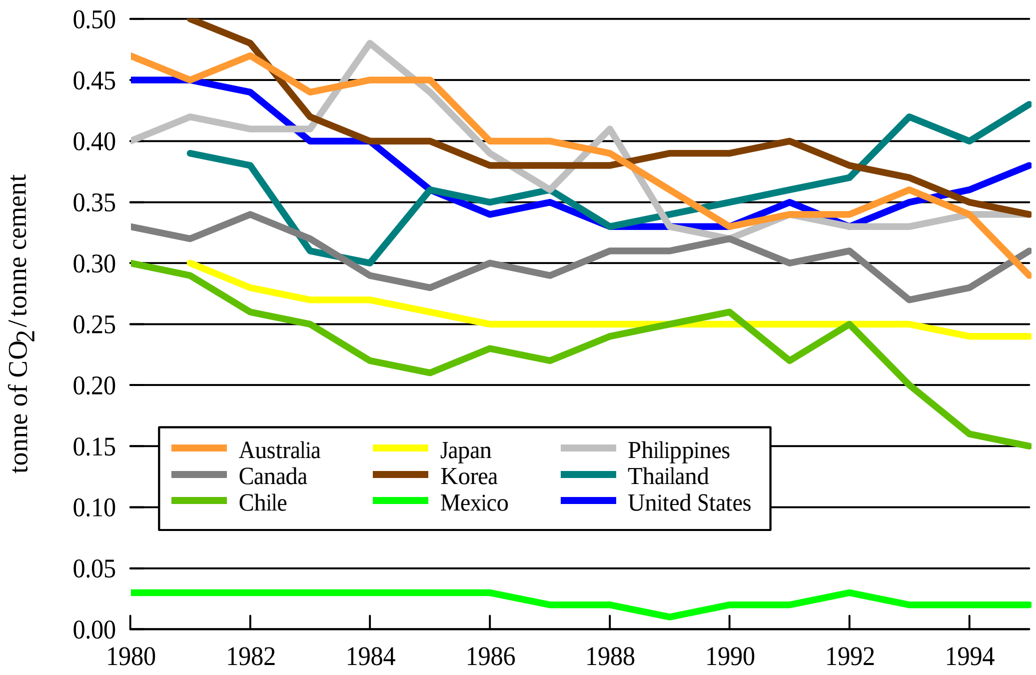
[6] Calcination is the chemical transformation of $CaCO_3$ into CaO and CO_2, that occurs during clinker production. The CO_2 emission factor is approximately 0.5 kg CO_2/kg of clinker (Hendriks *et al*, 1998).

[7] Due to data limitations, the emissions from the world's biggest producer, China, were not calculated.

These trends have been the result of the combined effect of energy consumption, mix, and efficiency.

The following figure shows CO_2 intensities, in terms of tonnes of CO_2 per tonne of cement produced. A declining trend can be observed for most of the economies in the sample, which is a result of the combined effect of the factors mentioned.

Figure 38 CO_2 Intensity of the Cement Industry
Selected APEC Economies, tonne of CO_2/tonne cement; 1980-95.



Source: Elaborated from INEDIS database, APERC survey, MITI (1982-1996), APEC database and Cembureau (1998, 1999).

Several alternatives can be considered to reduce CO_2 emissions from this industry, among which the following can be cited (Hendriks *et al*, 1998):

- Improvement of the energy efficiency of the process;
- Change to a more energy efficient process;
- Replace high carbon fuels by low carbon ones;
- Apply a lower clinker/cement ratio (by increasing the ratio of additives in the cement);
- Application of alternative cements (mineral polymers); and
- Removal of CO_2 from the flue gas.

The energy savings potentials calculated earlier can give an estimate of the emissions reductions attainable through energy efficiency. However, actual reduction measures will likely be a combination of the above options.

CHAPTER 7

ENERGY EFFICIENCY IN THE APEC PULP AND PAPER SECTOR

PRODUCTION TRENDS AND PROCESSES

GENERAL DESCRIPTION OF RELEVANT PROCESSES

Energy is used mainly for steam generation and process heating, and to run the electric motors used to drive machinery. The energy consumption required to manufacture pulp depends on the type of pulping process used.

The feedstock for paper making usually comprises a mixture of wood pulp and waste paper. The relative amount of waste paper used depends on the desired type of paper products.

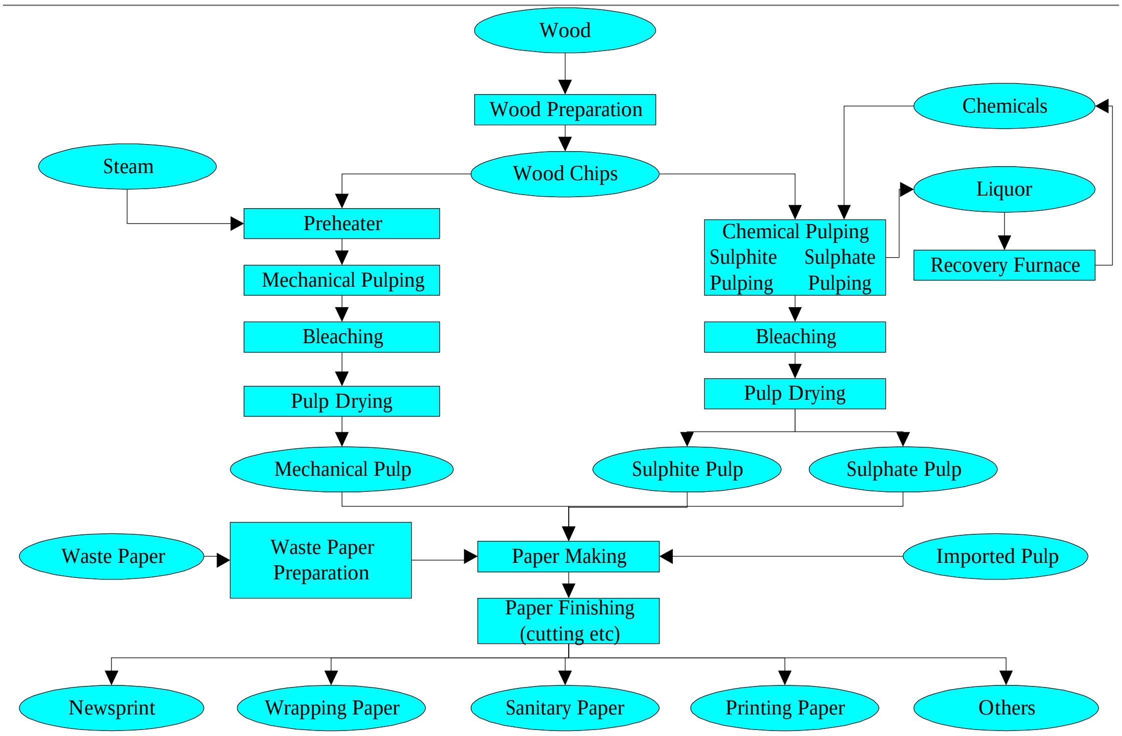
Wood is prepared for pulping via debarking and chipping steps. These require only a small amount of energy. Wood is ground and pulped to separate the fibres from each other and to suspend them in water. Pulping breaks apart the wood fibres and cleans them of unwanted residues.

Pulping can be carried out using chemical, mechanical, or combined chemical-mechanical techniques. Mechanical pulping is a relatively simple and cheap process, but wood fibres suffer a significant degree of damage. Wood may be pre-treated with steam to soften the lignin (which acts as a binder between the wood fibres). The lignin remains in the pulp (increasing the yield), but it will degrade in time. The resulting lower fibre quality limits the use of mechanical pulp largely to newsprint.

In chemical pulping wood chips are cooked in either an aqueous solution of sodium hydroxide and sodium sulphide (the Kraft process), or sulphurous acid and sodium bisulphite ion (the sulphite process). The chemicals are used to dissolve the lignin without damaging the fibres. This results in higher quality paper, but with a lower yield (40-50 per cent dry weight). A waste stream of inorganic chemicals and wood residues is produced, which is called liquor. (This is black, red, green, etc - depending on the chemicals used.) Liquor is concentrated and subsequently incinerated in heat recovery furnaces. The wood residues serve as fuel, while pulping chemicals are recovered.

Raw mechanical pulp is usually bleached with hydrogen peroxide or sodium hydro-sulphate, and chemical pulp is bleached with oxidising agents and alkali solutions. Sulphite pulp is easier to bleach than sulphate pulp. Therefore, the former is mainly used to produce high quality printing paper, and the latter packaging paper. Cardboard and corrugated board are produced from waste paper with a relatively small amount of sulphate pulp added.

Figure 39 Schematic Diagram of Pulp and Paper Processes



Source: Worrell *et al*, 1997.

Paper production can take place at the pulp production site (integrated paper mill) or at another location. If paper is produced at a different location, the pulp must be transported to the paper production site (or even imported). For transport, the pulp is dried. It must then be dispersed in water and refined for paper-making. Waste paper is heated with steam and de-inked. A step is normally required to separate plastics from the waste paper. Refining is usually not necessary.

PULP AND PAPER PRODUCTION TRENDS

Demand for paper and paper products in the Asia Pacific region is growing in step with economic growth. Information technology advances have not reduced demand for paper, demand has actually grown along with growth in dissemination of computer and communications technologies.

In 1993, pulp and paper production in 14 APEC member economies reached 275 million tonnes, with an annual growth rate of almost 3.0 per cent. (Note: data for some economies is not available). Three economies in Southeast Asia namely Singapore, Indonesia and Malaysia recorded very significant growth rates between 1980 and 1993 of 23.7 per cent, 21.4 per cent and 20.0 per cent, respectively.

In terms of absolute production volume, the United States accounts for about 48.8 per cent of total APEC production, at 134.1 million tonnes. Other major producers are Canada (14.7 per cent, - 40.4 million tonnes), Japan (13.9 per cent, - 38.4 million tonnes), and China (12.3 per cent - 33.9 million tonnes) (1993 figures).

Table 16 Pulp and Paper Production
APEC Economies; 1980, 1987 and 1993.

	Production '000 tonnes			Average annual growth %		
	1980	1987	1993	1980-1987	1987-1993	1980-1993
Australia	2,184	2,642	n.a.	2.8	-	-
Brunei	n.a.	n.a.	n.a.	-	-	-
Canada	33,333	39,058	40,431	2.3	0.6	1.5
Chile	988	1,305	2,395	4.1	10.6	7.0
China	10,540	18,811	33,969	8.6	10.4	9.4
Hong Kong, China	17	40	n.a.	13.0	-	-
Indonesia	313	1,163	3,900	20.6	27.3	21.4
Japan	27,876	32,270	38,359	2.1	2.9	2.5
Korea	1,879	3,478	6,241	9.2	10.2	9.7
Malaysia	75	92	803	3.0	43.5	20.0
Mexico	2,424	3,963	6,146	7.3	7.6	7.4
New Zealand	1,502	1,752	2,204	2.2	3.9	3.0
Papua New Guinea	n.a.	n.a.	n.a.	-	-	-
Peru	n.a.	n.a.	n.a.	-	-	-
Philippines	505	454	618	-1.5	5.3	1.6
Russia	n.a.	n.a.	n.a.	-	-	-
Singapore	6	10	95	7.6	45.5	23.7
Chinese Taipei	1,756	3,153	4,088	8.7	4.4	6.7
Thailand	418	760	1,618	8.9	13.4	11.0
United States	102,861	121,560	134,141	2.4	1.7	2.1
Viet Nam	n.a.	n.a.	n.a.	-	-	-
Total	186,677	230,511	275,008	3.1	3.0	3.0

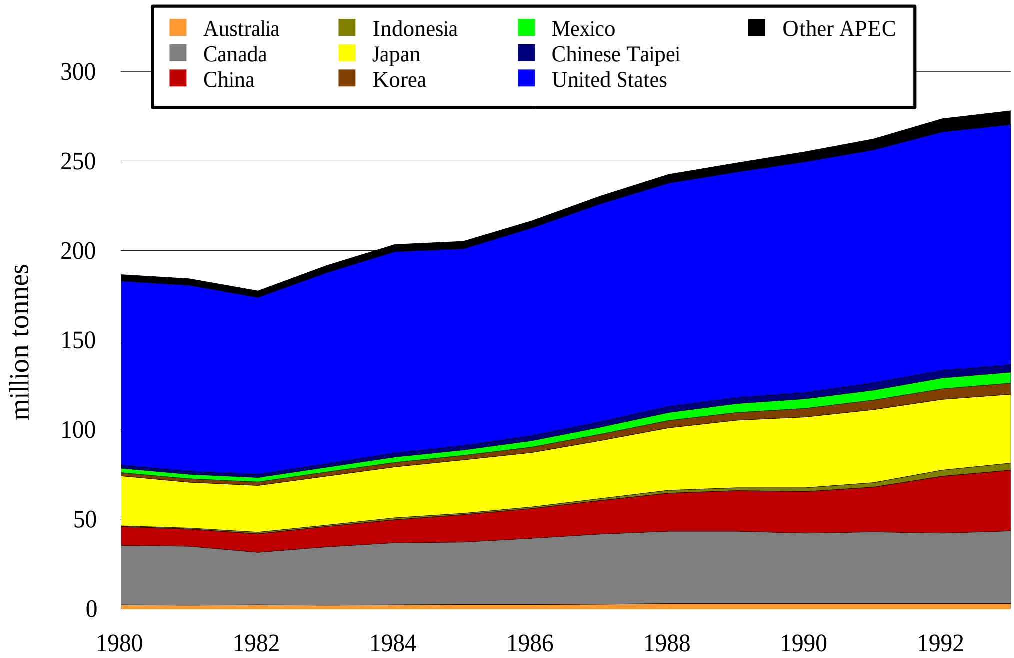
Notes: n.a. - data is not available.
Source: APEC database

Production volumes are almost equally divided between pulp and paper and paper by-products. In 1993, the United States accounted for over half of total APEC pulp production (51.0 per cent), followed by Canada (20.5 per cent) and China (13.7 per cent).

United States leads paper and paper products production, with 47.3 per cent of the APEC total. Japan is second (17.0 per cent), and China third (11.5 per cent).

The four Annex I APEC economies jointly accounted for 78.2 per cent of total APEC pulp and paper production in 1993, while the balance largely came from China with a 12.3 per cent share.

Figure 40 Pulp and Paper Production
Selected APEC Economies; Million tonnes, 1980-93.



Source: APEC database, 1999.

ENERGY CONSUMPTION PROFILE

TOTAL ENERGY CONSUMPTION

In 1993, the energy consumed by the sample of APEC economies to manufacture pulp and paper reached 62,119 ktoe, from a level of 44,604 ktoe in 1980. The average growth rate in energy consumption between 1980 and 1987 was 2.4 per cent. For the six years to 1993, rate averaged 2.8 per cent.

Over the period 1987-1993, two member economies recorded double digit energy consumption growth rates in the pulp and paper sector. New Zealand registered a large increase in energy use (36.1 per cent), after a declining average of 3.4 per cent from 1980-1987. Korea maintained a high average growth rate of 14.7 per cent, significantly down from the 26 per cent average growth posted in the early and mid 1980s.

Australia and Canada recorded a small decline in energy consumption over the period 1987–1993. The reason for this in Canada appears to be very slow growth in pulp and paper production over this period (0.7 per cent per annum), from an average growth of 1.3 per cent for the period 1980-1987.

Table 17 Pulp and Paper Final Energy Consumption
APEC Economies; ktoe; 1980, 1987 and 1993.

	Energy Consumption			Share of APEC	Average Annual Growth		
		ktoe		%		%	
	1980	1987	1993	1993	1980-1987	1987-1993	1980-1993
Australia	1,022	1,359	1,351	2.2	4.2	-	2.2
Brunei	n.a.	n.a.	n.a.		-	-	-
Canada	13,890	15,199	15,121	24.3	1.3	-0.1	0.7
Chile	626	667	755	1.2	0.9	2.1	1.5
China	4,708	8,264	11,736	18.9	8.4	6.0	7.3
Hong Kong, China	9	n.a.	n.a.		-	-	-
Indonesia	n.a.	n.a.	n.a.		-	-	-
Japan	4,382	8,138	9,277	14.9	9.2	2.2	5.9
Korea	132	662	1,510	2.4	25.9	14.7	20.6
Malaysia	n.a.	n.a.	n.a.		-	-	-
Mexico	*	1,129	1,211	1.9	-	1.2	-
New Zealand	45	35	222	0.4	-3.4	36.1	13.2
Papua New Guinea	n.a.	n.a.	n.a.		-	-	-
Peru	n.a.	n.a.	n.a.		-	-	-
Philippines	204	157	193	0.3	-3.7	3.5	-0.4
Russia	n.a.	n.a.	1,432	2.3	-	-	-
Singapore	n.a.	n.a.	n.a.		-	-	-
Chinese Taipei	700	769	1,053	1.7	1.4	5.4	3.2
Thailand	100	151	205	0.3	6.1	5.2	5.7
United States	18,786	16,065	18,053	29.1	-2.2	2.0	-0.3
Viet Nam	n.a.	n.a.	n.a.		-	-	-
Total	44,604	52,595	62,119	100	2.1	2.8	2.6

Notes: n.a. - data is not available.
Source: IEA database.

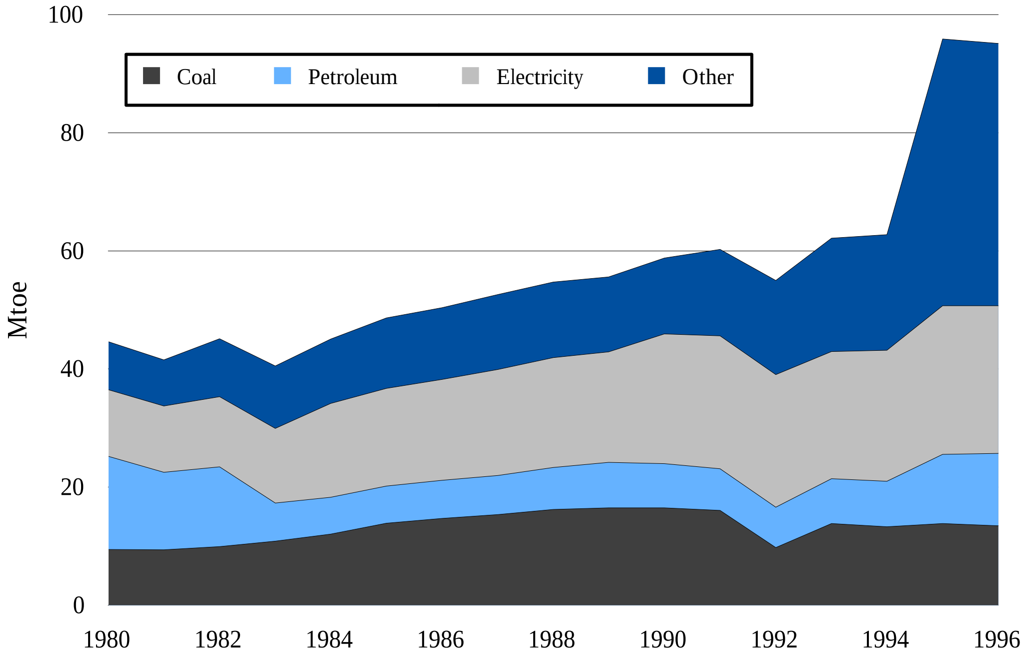
ENERGY SOURCE MIX

The energy sources used in the pulp and paper industry are coal, electricity and petroleum. There has been a significant growth in the use of other energy sources, including renewables. Figure 41 shows energy consumption trends for the period 1980-96.

Coal use has declined slightly, from 15,325 ktoe in 1987 to 13,832 ktoe in 1993, an average reduction of 1.7 per cent per annum. This represents a reversal of the trend of increasing use of coal during the years from 1980. China accounted for 66.9 per cent of the total coal used in the industry in 1993 for the APEC region, followed by the United States with a share of 21.1 per cent and Japan with 7.3 per cent.

The average growth in electricity consumption showed a significant decline in the second half of the period 1980-1987. Over this period, there was a significant shift in the use of other fuels, such as wood wastes and black liquor.

Figure 41 Pulp and Paper Sector Energy Consumption by Source
APEC Region; Mtoe; 1980-99.



Source: IEA database.

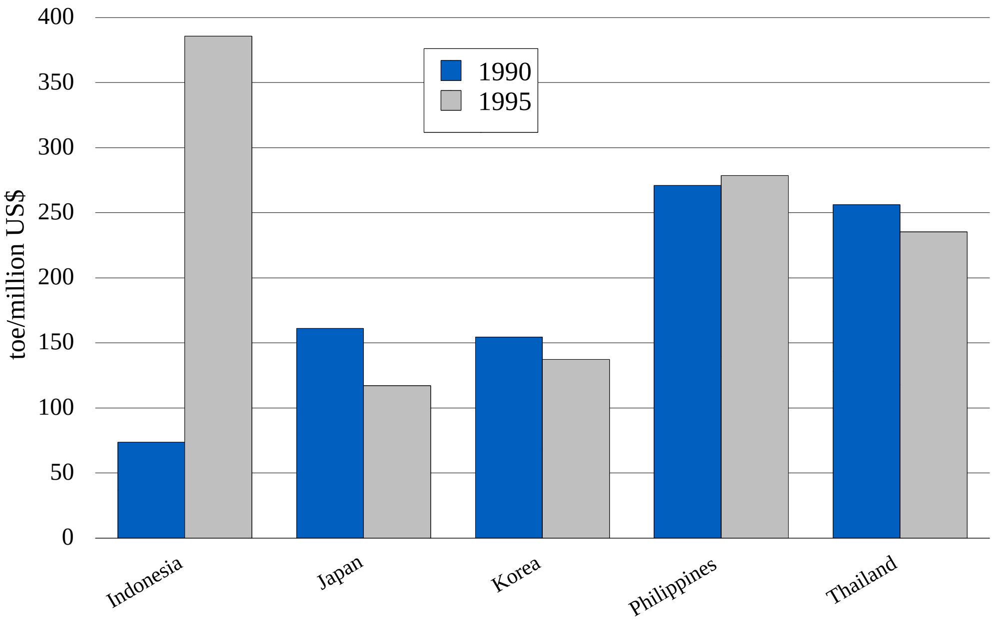
As the previous table shows, the US as the largest producer of pulp and paper, also consumes the most energy (29.1 per cent of the total energy consumed in the sector in 1993). Other big users of energy in this sector are Canada, China and Japan.

ENERGY INDICATORS

AGGREGATE ECONOMIC INDICATOR

A general economic indicator comparing changes in intensities of five member economies is presented in Figure 42. From 1990 to 1995 Indonesia showed a large increase in energy intensity per unit value of pulp and paper produced (toe/million US$). On the other hand, Japan, Korea and Thailand managed to increase the efficiency with which energy is used to manufacture pulp and paper.

Figure 42 Energy Intensity in the Pulp and Paper Sector
Selected APEC Economies; toe/million US$; 1990 and 1995.



Source: IEA database.

PHYSICAL INDICATORS

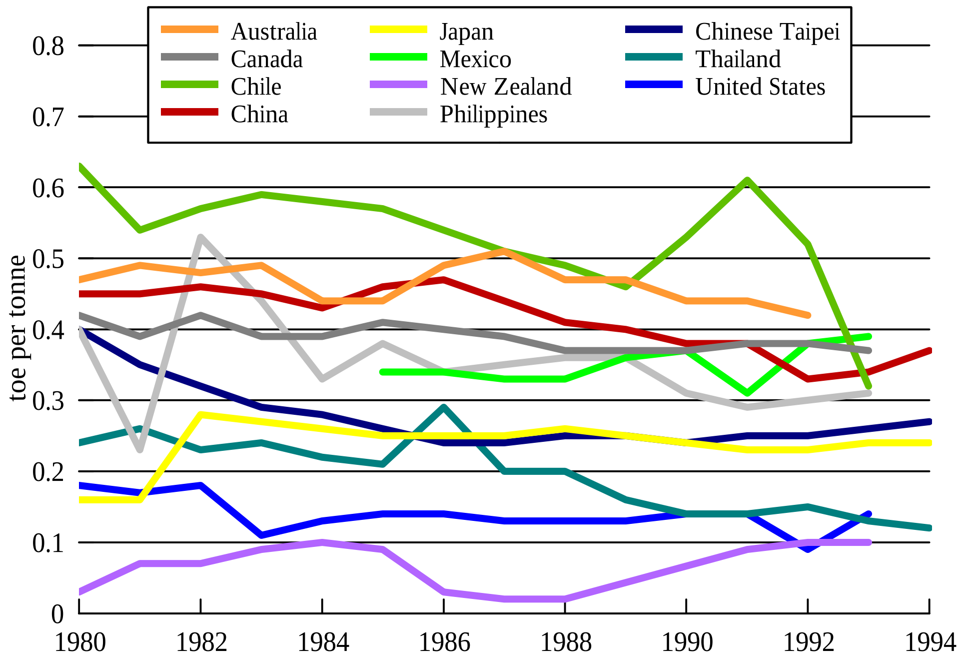
OVERALL ENERGY INTENSITY

The majority of APEC economies show a general trend of declining pulp and paper sector energy intensities, although the extent and consistency of the trend varies significantly between economies.

Some economies show sharp fluctuations in energy intensity levels, and it is not entirely clear why this is so. For example, in 1990 the energy intensity of Chile's pulp and paper sector appears to increase substantially for a two-year period, only to drop sharply over the next two years. Ignoring this short-term fluctuation in energy consumption, Chile has demonstrated a long-term trend of significant decline in energy intensity levels, suggesting significant efficiency improvements in the industry with time.

Another economy exhibiting large fluctuations in energy intensity over time is the Philippines. Between 1980 and 1982, energy consumption per kilo-tonne of production appeared to oscillate greatly. This is more likely to represent inaccuracies in the data than variations in energy intensity. The general trend for the Philippines, as for other developing economies in the region, has been an overall improvement in energy efficiency in this sector with time.

Figure 43 Pulp and Paper Sector Energy Intensity Trends
Selected APEC Economies; toe per tonne; 1980-94.



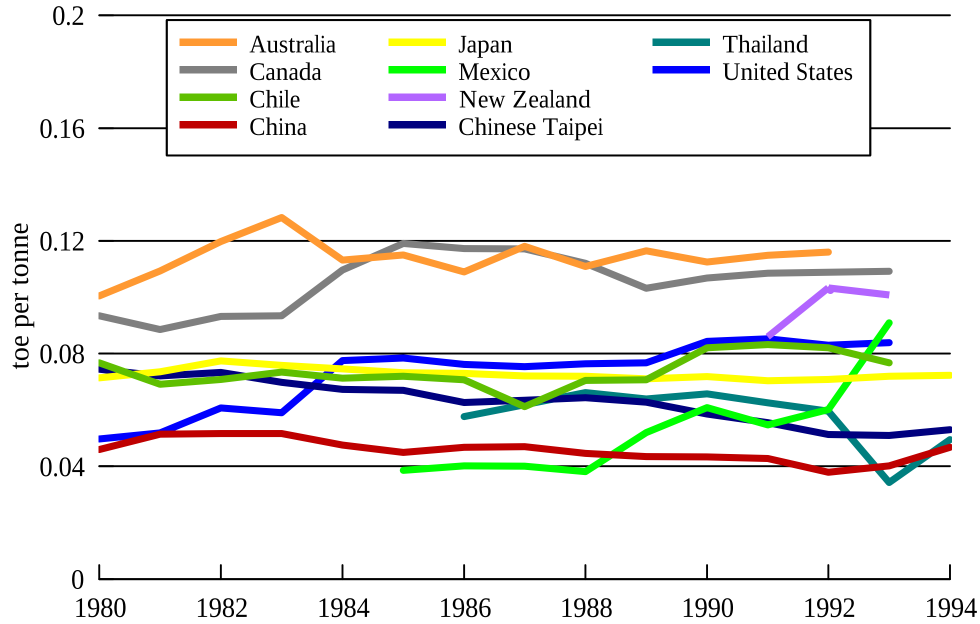
Source: APEC database, 1999,
IEA database.

ELECTRICITY INTENSITY

Regional electricity intensities in the pulp and paper sector have declined steadily over the 1980s, although some economies had rising intensities in the latter part of the decade.

For example, in Mexico, electricity intensity increased significantly between 1988 and 1993. Chile followed a similar pattern, but then electricity intensity began declining after 1992. In Thailand electricity intensity declined until 1993, but increased sharply the following year. Japan, on the other hand, has managed to maintain a very stable trend (Figure 44).

Figure 44 Pulp and Paper Sector Electricity Intensity
Selected APEC Economies; toe per tonne; 1980-94.



Source: APEC database, 1999,
IEA database.

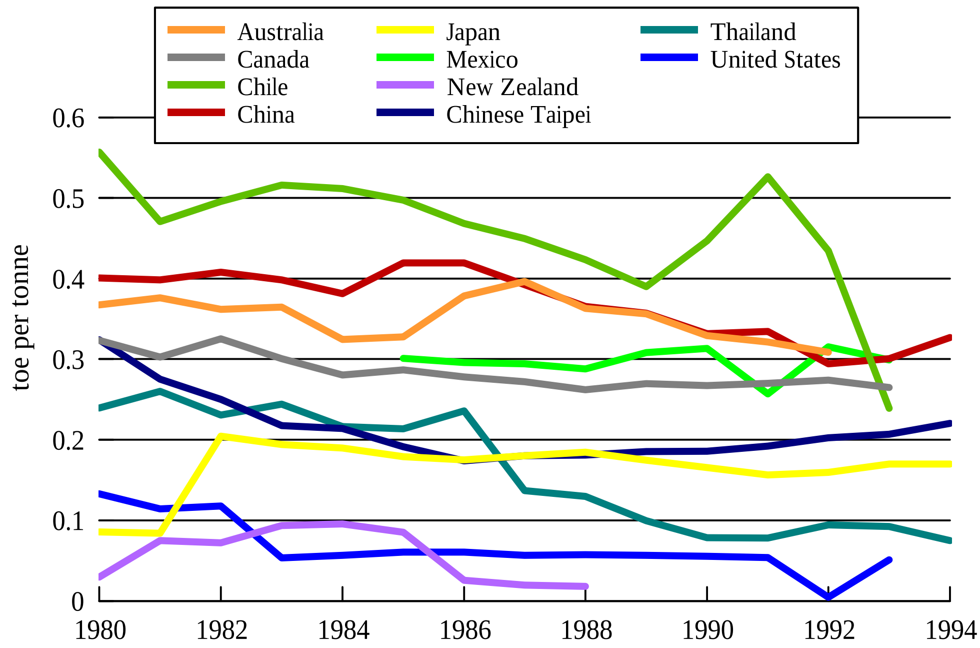
ENERGY INTENSITY (FUELS OTHER THAN ELECTRICITY)

Chile has apparently experienced significant fluctuations in energy intensity levels in the pulp and paper sector, much of it due to large variations in non-electricity fuel use in relation to overall production levels. Two other economies, China and Australia, have shown significant declines in non-electricity fuel intensities, suggesting a declining use of these fuels with time. As disaggregated data for this sector is very limited, it is difficult to undertake a process-level evaluation of energy savings potential.

Overall, the data suggests that energy intensities for fuels other than electricity have remained fairly constant or declined moderately in the more developed economies. Declining intensity over time is more marked for developing economies (especially China, Thailand, and Chinese Taipei). This suggests substantial improvements in efficiency levels are occurring in the sector in the developing economies with time.

What is less clear, are the reasons for a relatively large variation in absolute intensity levels between economies. There is no clear demarcation between developed and developing economies in terms of absolute efficiency levels. For example, Canada, China, Mexico and Australia appear to have similar intensity levels in 1994 of around 0.3 toe/tonne. Japan and Chinese Taipei are close together at around 0.2 toe/tonne, and the United States and Thailand are around 0.1 toe/tonne of product.

Figure 45 Pulp and Paper Sector Energy Intensity for Fuels other than Electricity
Selected APEC Economies, toe per tonne; 1980-94.



Source: APEC database, 1999,
IEA database.

ENERGY EFFICIENCY POTENTIALS AND MEASURES

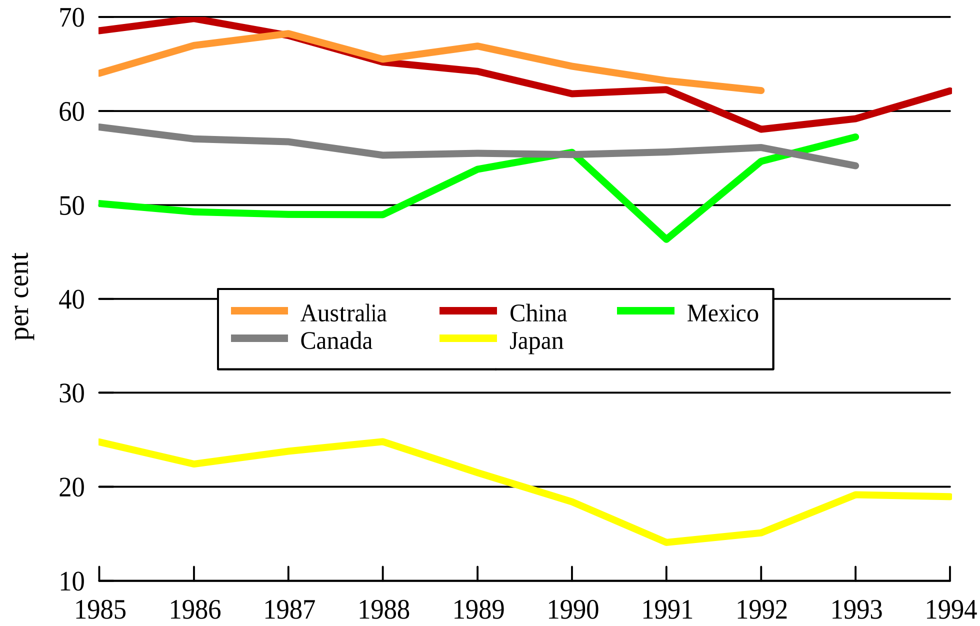
ENERGY SAVING POTENTIALS

It is possible to compare energy efficiency indicators with those calculated as "Best Practice" for a particular industrial sector. This has been done for selected APEC economies with respect to best practice in the pulp and paper industry.

Data from the US and Thailand was not included in this analysis. When analysed against best practice, both economies would appear to have pulp and paper industry energy efficiency levels substantially better than current best practice. As this is unlikely for either economy, it must be concluded that significant problems exist with respect to the reliability of data from these economies.

What Figure 46 shows is the fact that the Japanese pulp and paper industry operates quite close to the optimum, while the industry in other economies is substantially less efficient. One of the reasons for the Japanese success in lowering energy consumption in the sector is the high price of energy. Another is the low interest rate loans for energy efficiency investments - called the "Fiscal Investment and Loan Program" (FILP) – launched in the middle 1970s. Through this program, government financial institutions made loans directly to companies, often at attractive rates of interest.

Figure 46 Energy Savings Potentials for Selected APEC Economies
Selected APEC Economies; Per cent; 1985-94.



ENERGY EFFICIENCY MEASURES

Efforts adopted by APEC member economies to improve energy efficiency in the pulp and paper industry vary significantly. In general, the enhancements achieved are largely tied to technological advancements adopted by pulp and paper manufacturers in different economies.

A number of industry studies have revealed a large potential for improved energy efficiency in the pulp and paper sector. However, further examination of the status of the industry in various economies demonstrates that the level of savings achievable varies widely.

INFORMATION DIFFICULTIES

Depending on the technology employed, the direct energy cost as a percentage of sales can vary widely. Also, although this is an energy-intensive industry, energy costs are normally only a relatively small percentage of total operating costs. Any energy efficiency investment must show a clear short-term benefit, or the investment may not be made. This is especially the case where a large investment in the upgrading of major components within the plant is required (for example, high efficiency electric motors).

In economies where intense sector competition exists (either internally or against international competitors), the desire to improve energy efficiency may be greater.

Access to information explaining how to take advantage of cost-effective energy efficiency technologies has been cited as a major reason firms do not implement energy efficiency measures.

Many decision-makers within firms are not familiar with leading edge industry practise on the energy efficiency front. This can be a particular problem in developing economies, where technology diffusion can be somewhat slower than in the developed world.

The pulping process employed, the degree to which the mill utilises waste heat from steam plant (co-generation is a natural option for pulp and paper mills, which use large amounts of power and heat), and the extent to which feedstock wastes are used, are all important factors with respect to energy efficiency. Improvement in information dissemination in each of these areas could bring about significant improvements in energy efficiency. Exchange of information, and other assistance initiatives from the developed to the developing parts of the APEC region are of major relevance in increasing the penetration of energy efficient technologies.

Energy efficient technologies and methods of operation include: prevention of heat loss, and re-use of emitted heat at each stage of the production process; installation of energy-saving equipment, such as continuous digesters; efficient use of black liquor, through the introduction of high efficiency boilers; introduction of high efficiency electric motors, promotion of waste paper recycling methods that are most economical in terms of energy consumption.

ENERGY EFFICIENCY TECHNOLOGIES IN THE PULP AND PAPER INDUSTRY

Kraft pulp is now prevailing among the processes for chemical pulping, due to advantages such as its ability to produce high quality pulp, as well as short digestion period, and its applicability to almost all kinds of wood. There are also established technologies for recovery of chemicals and heat from waste liquor (black liquor). In this process, installation of continuous digesters and use of black liquor in efficient recovery boilers are very effective for energy saving. At present in Japan, black liquor from digesters supplies one third of the total energy consumed in the industry.

Refiner ground wood pulp (mechanical pulp) is made by grinding woodchips with a refiner which has two discs driven by an electric motor. Saving electric energy depends on rotary speed.

As for boilers, fluidised bed combustion technologies have the advantage of accommodating a wider variety of fuel, including woodchips, sludge or other wastes in the paper mills - resulting in replacement of purchased fuels.

In order to recover the emitted heat at all stages of the production processes, the installation of closed dryer hoods is also effective for energy saving. Increasing utilisation of wastepaper not only saves forest resources, but also energy. The energy consumed in the production of recycled paper is just one third that needed to produce paper from wood.

There are four major processes involved in the recycling of wastepaper:

- Defiberisation by pulping;
- Removal of foreign material by screening;
- De-inking by floatation or washing; and,
- Bleaching with chemicals, commonly hydrogen peroxide.

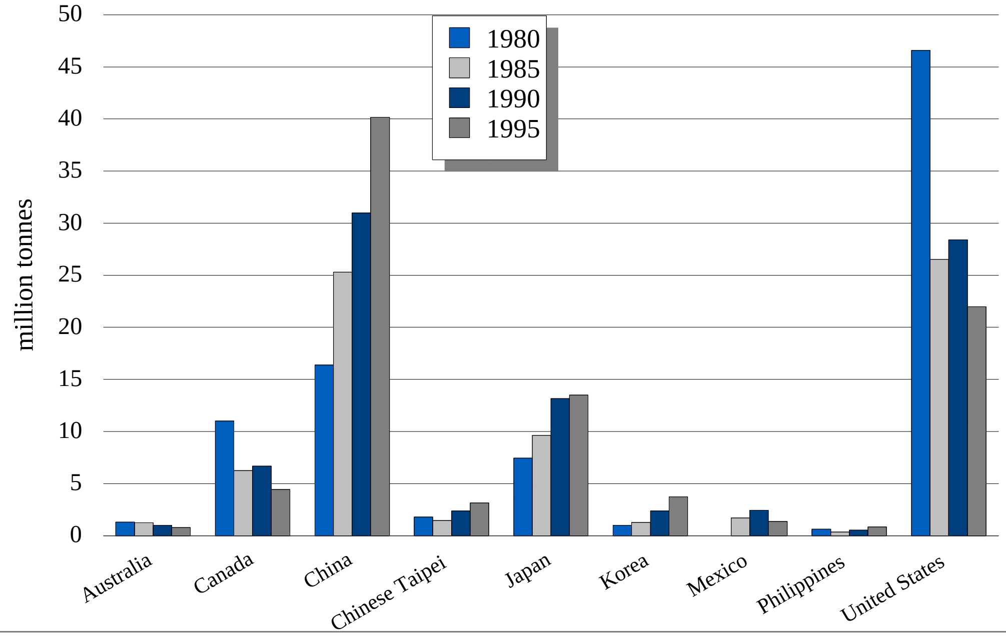
In this process, installation of a high density pulping machine is effective and flotation for de-inking is preferable to washing due to use of less water and chemicals.

ENVIRONMENTAL IMPLICATIONS OF THE INDICATORS

Emissions of CO_2 from the pulp and paper sector have been increasing steadily in the region, and reached 78,287,000 tonnes in 1993. The rise is being driven almost solely by the very large increase in emissions from China, as its pulp and paper sector expands rapidly (a three-fold production increase from 1980 to 1993).

Emissions of CO_2 from the sector in other non-Annex I economies are rising, but only marginally in comparison to China. For Annex I economies, as Figure 47 shows, CO_2 emissions are declining with the exception of Japan.

Figure 47 CO_2 Emissions from Coal and Oil in Pulp and Paper Manufacture
Selected APEC Economies; Million tonnes; 1980, 1985, 1990 and 1995.



There are significant data problems with the United States. For example petroleum consumption data for the period 1983-1998 are not available, and the coal data appears anomalous for some years (1983, 1992-94). However, if one ignores the suspect data points, a substantial decline in CO_2 emission levels in the United States pulp and paper sector has occurred over the period studied. A straight line interpolation would suggest that CO_2 emissions have declined at an average of 6 per cent over a fifteen year period.

Canada's continuing shift to the use of other fuels (wood and wood-wastes) has resulted to an average decline in its total emissions of 11.4 per cent over the period 1980 to 1995.

CHAPTER 8

CONCLUSIONS

This study developed from a desire expressed within the forum of the APEC Energy Working Group, for each economy to investigate opportunities to improve overall energy efficiency, and in so doing, contribute to the economic well-being of individual economies and the wider APEC region. As one means of achieving this goal, experts within the 21 APEC member economies proposed that energy end use information be gathered for each economy, and databases be developed which could be used to develop a set of region-wide energy efficiency indicators.

APERC's research aimed to facilitate a broader understanding of energy efficiency in the APEC region through the analysis of three important industrial sectors: iron and steel, cement and pulp and paper. Macro-economic indicators were also analysed and their usefulness assessed. Another facet of the research has been an effort to draw together experts from APEC member economies and facilitate an exchange of information by creating a network of energy efficiency experts.

Because the development and maintenance of reliable and comprehensive databases takes time, as well as funds, APERC has had to rely, for this study, on pre-existing information – supplemented by information gathered from a simple survey circulated at the beginning of the study. Information is kept by a number of research and financial agencies with interests in the Asia Pacific: the International Energy Agency, the World Bank and the Asian Development Bank. Other authorities, including government ministries and statistical sources have information on general economic statistics and industrial data, and this information was also sought.

During the course of the effort to gather the information available regionally that can be used to construct a basic set of energy efficiency indicators, three things became apparent: (1) the information is patchy, (2) it is not entirely consistent between economies, and (3) its reliability is doubtful. Although information is available based on widely used industrial classification systems, there are a number of classification systems in use in the Asia Pacific region. For example: the International Energy Agency (IEA) uses the International Standard Industry Classification (ISIC), Australia and New Zealand use the Australian and New Zealand Standard Industrial Classification (ANZSIC) 1983, Canada uses the North American Industry Classification System (NAICS), Japan uses the Japanese Standard Industrial Classification (JSIC), while USA uses the US Standard Industrial Classification (US SIC 1987).

As noted previously, the inclusion of cement production under non-metallic minerals in the statistics of some economies and major databases (namely the IEA database, where ISIC Division 26 is used and includes cement, glass, ceramics, etc.) posed a serious problem with respect to the inclusion of many relevant economies in the analysis made for this sector, most notably China which is the world's largest cement producer.

Most surprising, information for some of the more highly developed economies has not been gathered consistently over time, so information gaps exist. In some cases, information is gathered, but confidentiality agreements prevent its dissemination to the public domain. Also, when one analyses energy end use information for specific large industries, it is apparent that the reliability of some of the information is in doubt. For example, energy intensity data for the large industrial sectors in this study show variations, in some instances, of more than 100 per cent from one year to the next (either up or down). This is an indication that the data is suspect, not that the industry is cycling through periods of high and low energy consumption per tonne of output.

If this project has achieved any significant outcomes, it is to confirm that energy end use data could be a very valuable tool in analysing changes in the industrial structure of an economy and the relationship between industrial output and energy consumption - but that to achieve this, data must exist that is: (1) reliable; (2) consistent across all economies; and (3) routinely collected.

Achieving these goals will require the coordination of effort by experts in each economy. This may require more than occasional meetings between experts to discuss data problems, it may be necessary for a core group of experts to get together and agree on a common set of energy efficiency indicators, for training seminars to be organised to demonstrate to experts within each APEC member economy what is needed, and to follow this up to ensure that the information is gathered, verified and made available in a suitable archiving system accessible to a wide range of potential users. The usefulness of energy efficiency information at a macro-economic scale may also need to be demonstrated.

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APPENDIX A

ENERGY EFFICIENCY BARRIERS AND POLICIES

INTRODUCTION

Energy efficiency indicators can be very useful tools in evaluating the success of energy efficiency policies and programs.

When the oil crisis hit in the 1970s, energy conservation and energy efficiency were topics of significant interest to the public, industry and policymakers. During the period from the mid 1970s until the mid 1980s, energy efficiency policy programs and technological advances contributed to a substantial decline in energy intensity in almost all sectors of the economy in the developed world, as well as fundamentally influencing energy consumption patterns in developing economies.

More recently, concerns about greenhouse gas emissions have largely replaced concern for energy efficiency improvements. Today, sustainable development is becoming an important public concern, and improvements in energy efficiency may become an important goal within that context. There are, however, a number of barriers to the implementation of energy efficiency programs, and a number of possible policy options. These are discussed briefly below.

IMPLEMENTATION BARRIERS

As energy efficiency activities involve millions of end-use consumers, it is quite difficult to detail every implementation barrier. The major barriers are summarised below.

FINANCIAL BARRIERS

PAYBACK PERIOD

Energy is typically a relatively small percentage of total operating costs in industrial processes, accounting for around 5-10 per cent of operating costs. As a result, energy savings may not rank highly on the investment decision-making scale of most industrial companies.

In many cases, the introduction of energy efficient technologies will involve replacing existing equipment, incurring costs which may exceed the potential benefits if the old equipment has not been fully depreciated. Consequently, energy efficient equipment is usually installed incrementally, as existing equipment reaches the end of its useful life. However, even then any extra costs in installing energy efficient technology must be weighed against the potential benefits. Often the payback period is sufficiently long to make the investment doubtful, or unattractive. This is particularly a problem in the domestic sector, where the installation of energy efficient equipment in homes can be difficult to justify in terms of the cost with respect to the expected payback period.

LIMITED CAPITAL

Even firms in developed economies operate with scarce capital, this being more so for firms in developing economies. With scarce capital, and many urgent demands on it, especially the need to increase production capacity, energy efficient equipment and programs are likely to have relatively low priority. This situation is exacerbated by relatively low energy prices.

TECHNICAL BARRIERS

LIMITED TECHNOLOGICAL CAPABILITY

Energy efficiency programs and associated technologies require skills that can be in poor supply in developing economies. Even where new, energy efficient technologies have been installed, there may be a lack of skilled experts to keep the equipment operating at maximum efficiency, negating many of the potential benefits.

More commonly, firms continue to utilise old equipment they are familiar with until maintenance costs make replacement an attractive alternative. In areas with low levels of industrialisation in developing economies, old obsolete equipment will continue to be used because replacement may not be a feasible option financially.

SOCIAL BARRIERS

LACK OF INFORMATION

Even in developed economies, people may lack information about energy efficient equipment and practices. Recent studies show that consumers tend to repeat prior decisions when faced with unfamiliar choices and to avoid cost minimising choices that have higher up-front costs (Channele, 2000). Information gathering and analysing consume time and human resources. The public often has insufficient information to measure energy efficiency profitability, particularly in developing economies. Two kinds of information problems generally exist. One is that energy efficiency information is not readily available, the other is that the information is not satisfactorily transferred to the public.

POLICY INSTRUMENTS

Four policy instruments can be considered: economic measures, mandatory regulations, voluntary agreements, and information and technical assistance.

ECONOMIC INSTRUMENTS

ENERGY PRICE

As input costs are very important factors with respect to firm profitability, the price of energy can influence demand for it. A recent study undertaken by the IEA (IEA, 1999) looked at energy prices in a sample of economies. On average, energy end-use prices were found to be approximately 20 per cent below opportunity-costs or a market-based reference level. The authors concluded that removal of energy price subsidies would:

- Reduce primary energy consumption by 14 per cent;

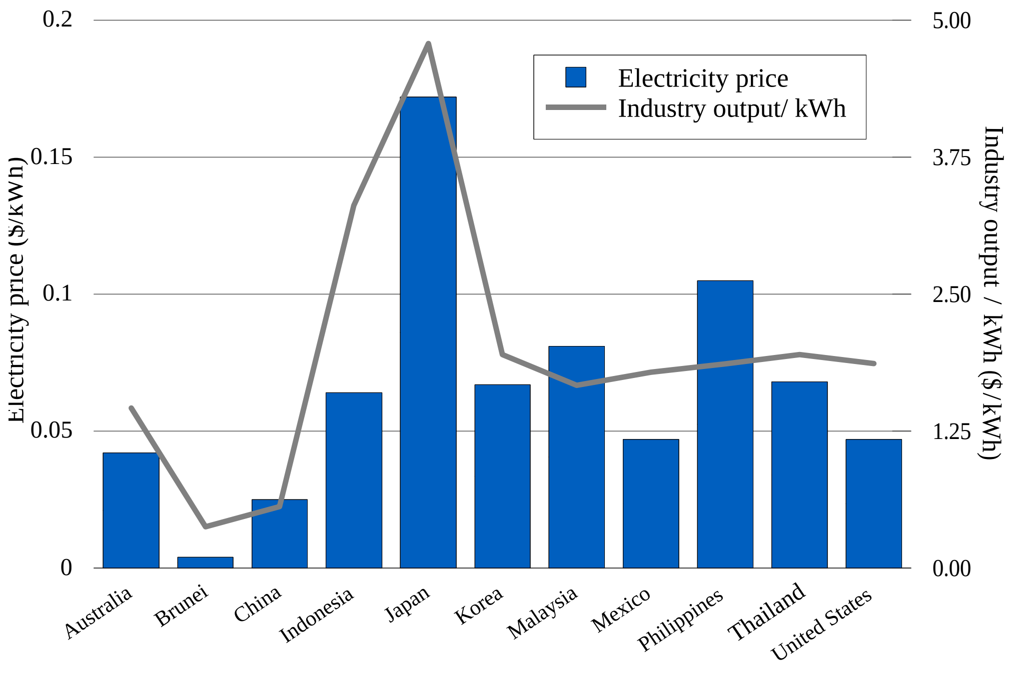
- Increase GDP through higher economic efficiency by almost 1 per cent;
- Lower CO_2 emissions by 17 per cent; and
- Produce domestic environmental benefits.

It was further concluded that subsidy removal in the economies studied would cut energy consumption by 3.5 per cent at a global level, thus improving world energy intensity significantly. Global CO_2 emissions would fall by 4.6 per cent.

Often energy prices do not reflect full costs because of subsidies or lack of inclusion of environmental costs. Almost all industrial activities involve electricity use, so the price of electricity is an insensitive factor with respect to the performance of industrial firms.

Figure 48 shows the relationship between electricity price and industrial output/kWh in selected APEC economies. Many factors, such as industrial structure, the macro-economic environment, organisation management, technology level, etc influence industrial output per unit of electricity consumed, and it is not simple to separate these influences. However, the graph still demonstrates a basic relationship, the correlation between electricity price and industrial output per unit of electricity consumed.

Figure 48 Electricity Price and Industrial Output
Selected APEC Economies; $/kWh; 1994.



Source: World Bank, 1996.

FINANCIAL INCENTIVES AND TAX CREDITS

Financial incentives and tax credits are the traditional ways of promoting particular activities. However, the risk exists that the costs exceed the social benefits. For energy efficiency projects that may be small or have uncertainty with respect to payback, financial incentives can promote markets to engage in energy efficiency projects.

MANDATORY REGULATION

Although the market plays a crucial role in energy efficiency activities, there are situations where markets can be perceived by policymakers to fail to deliver desired social outcomes. For example, energy efficiency programs may not always bring direct and immediate economic benefits to consumers, particularly if the goal is environmental or has a long-term goal. In these cases mandatory regulations may be necessary.

VOLUNTARY AGREEMENTS

Voluntary agreements are generally contracts between governments and firms. Companies promise to attain certain energy efficiency objectives within a defined period (Kim, 1998). Stokey (1997) defined four major types of voluntary agreements: target-based; performance-based; cooperative R&D; and monitoring and reporting.

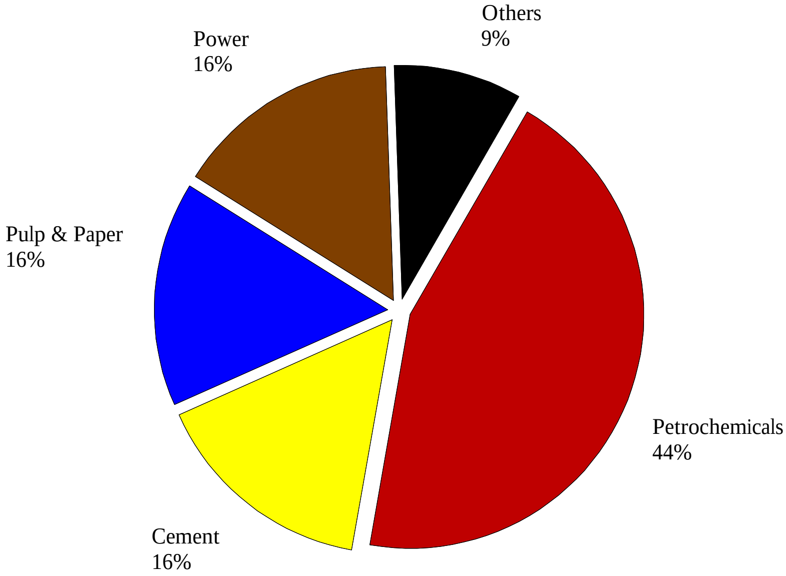
INFORMATION AND TECHNICAL ASSISTANCE

Information programs aim to demonstrate to energy consumers the importance of energy efficiency and how to achieve it. Information programs by themselves have been shown to result in energy saving of 0-2 per cent (Collins *et al*., 1985). For the industrial sector, many economies provide information and related technical assistance to improve energy efficiency.

CASE STUDY: JAPANESE FISCAL INVESTMENT AND LOAN PROGRAM

In the mid 1970s, the Japanese Government launched an energy efficiency program, involving low interest rate loans, called the "Fiscal Investment and Loan Program" (FILP) (Inaba, 1994). Government financial institutions made loans directly to firms. For example, the Japan Development Bank (JDB) invested in energy efficiency projects with loans at interest rates 0.3 - 0.5 per cent lower than commercial banks. The condition was that the energy efficiency project be financially viable. In the period between 1975 and 1993, this program dispensed 360.8 billion yen. The loans were distributed mainly to five major industries, as shown below.

Figure 49 FILP Loan Distribution by Industry



Source: Inaba, 1994.

It is difficult to calculate the actual energy savings. The estimates of the original plan were that at least 40 thousand barrels of oil equivalent per day were saved between 1975 and 1993. The loan program contributed to at least a 1 per cent reduction in energy consumption in the industrial sector in Japan.

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APPENDIX B

CHINESE TAIPEI CASE STUDY

INTRODUCTION

In response to the worldwide growing concern about environmental problems associated with energy consumption, Chinese Taipei has taken positive actions to the confronting problems. To harmonize the conflicting objectives of 3Es (i.e. economic development, energy security, and environmental protection) from the international perception has been and will be an indispensable component of energy policy in Chinese Taipei.

Historically, energy consumption by the industrial sector accounted for more than 50 per cent of the total final energy consumption in Chinese Taipei. Of which, in turn, about 70 per cent is consumed by the four most energy-intensive industries (namely, chemical materials, basic metal industry, non-metallic mineral products, and pulp and paper) yet their overall contribution to gross domestic product (GDP) is only around 6.5 per cent. It is inevitable that these industries will get priority over other sectors in promoting energy productivity, despite these industries are important in accumulating capital and deriving inter-industrial effects in the overall economy.

Promoting energy efficiency has been one of the specific guidelines of energy policy in Chinese Taipei since the government promulgated its first energy policy in 1973. The "Energy Management Law", proclaimed in 1980 put even more attention on demand-side energy management, especially for the industrial sector. Thereafter, the government has implemented a comprehensive energy conservation program and has gained steadily improvements in energy productivity. Energy productivity, defined as the GDP created by the consumption of per unit energy, in Chinese Taipei was raised from 77.70 (NT$/LOE) in 1981 to 89.97 (NT$/LOE) in 1997, representing an average annual growth rate of 0.92 per cent.

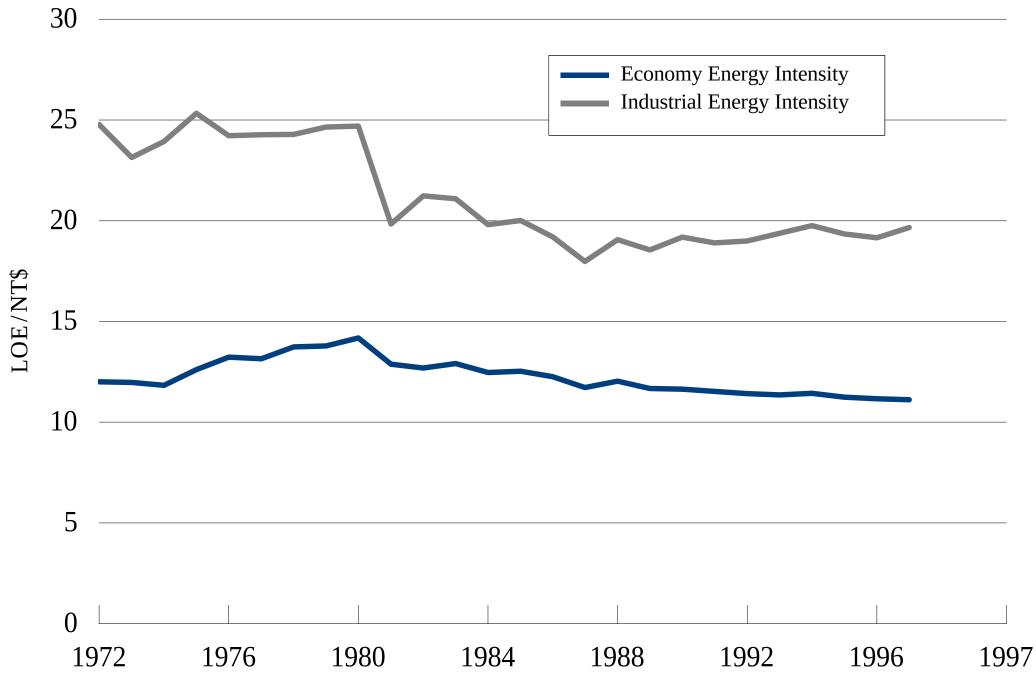
Despite its past remarkable achievements in energy conservation, Chinese Taipei set a more aggressive target of energy saving of 16 per cent by 2010 after national energy conference held in May 1998. A broadened spectrum of measures will be implemented, including energy efficiency management, tax and financial incentives, reinforcing energy technology R & D, and promoting energy education and dissemination. To establish a review system for energy-intensive industries is a prerequisite for implementing compulsive or autogenous measures for enhancing energy efficiency. It is considered that energy efficiency indicator for industry might provide the vivid tools and serve that purpose.

Various energy efficiency indicators have been developed to serve as benchmark for energy efficiency in Chinese Taipei. For example, energy efficiency standards have been stipulated for selected electric appliances, vehicles and fishing boats. However, mandatory energy efficiency indicators for specific industry are still deficient.

DESCRIPTIVE INDICATORS

The historic trends of energy intensities for the entire economy and industrial sector in Chinese Taipei are displayed in Figure 50. Overall, during the period of two oil crises, Chinese Taipei experienced an upward trend in aggregate energy intensity, due primarily to the successive implementation of 'the Ten Big Projects', including petrochemical, iron and steel, and other heavy industries. A clear disparity of aggregate energy intensity appeared in 1980. Since then, aggregate energy intensity decreased steadily, implying an increase in energy efficiency. However, the oil price collapse in 1985 has impeded energy conservation. The energy intensities for the entire economy and industrial sector slightly declined after 1985.

Figure 50 Energy Intensity of the Chinese Taipei Economy
LOE/NT$, 1972-1997.



The economic indicators and physical indicators over time for three selected sectors; iron and steel, cement, and pulp and paper are illustrated in Figure 51. For the iron and steel sector, trends over time for economic indicator and physical indicator show some consistency. After 1988, both indicators have a decreasing trend. As to the cement sector, two indicators appear closely correlated. Both trends are declining over time, implying an improvement of energy productivity. The pulp and paper sector experienced a downward trend for both indicators before 1986. The converse is true after 1986 only for economic indicator. Due to the shrinkage of output in monetary terms, the numeric values of economic indicator sharply increase after 1990. On the other hand, physical indicator fluctuates within limited range. Based on the above observations, it seems that physical indicator can provide a basis for a more robust analysis for the energy intensive industries. However, further studies are required to verify the situation.

Figure 51 Economic and Physical Growth Indicators in Chinese Taipei
Index (1981= 1) 1972-1997.

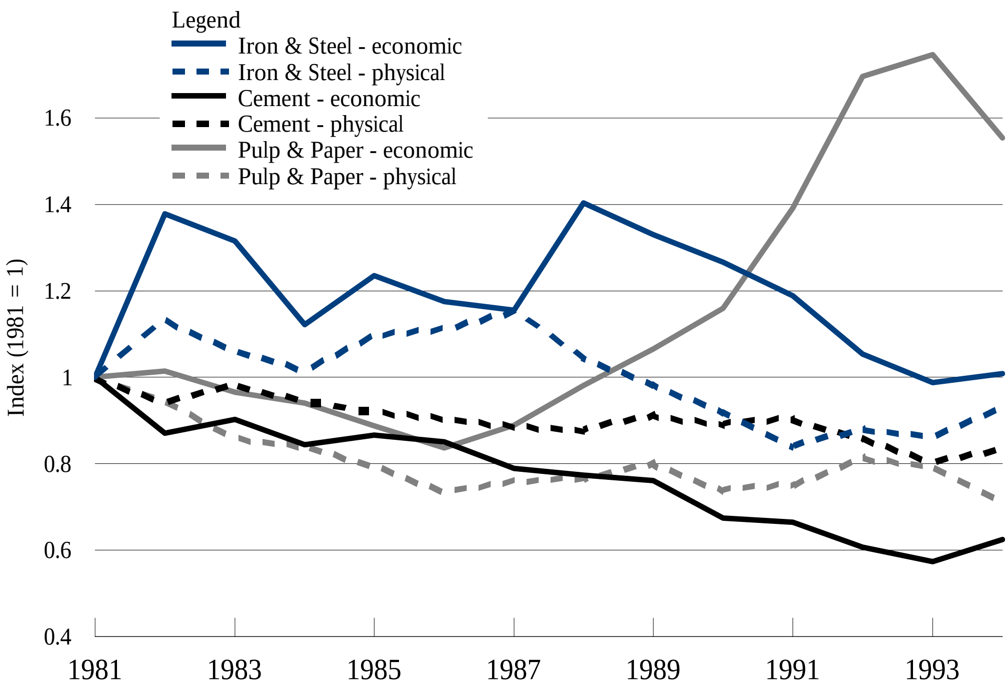


Table 18 shows the energy intensities for iron and steel, cement, and pulp and paper derived from the hybrid-unit formulations of energy input-output (I-O) analysis for the period 1971-1984 (Wu & Chen, 1989). Over the study period, energy intensities for the three sectors decreased significantly, implying that the energy productivity had been improved at a satisfactory rate concurrent with economic development.

Table 18 Energy Intensities for Energy Intensive Industries
Unit: kcal/1981 NT dollars.

Sector	1971	1976	1981	1984
Iron and Steel	323	174	157	151
Cement	772	519	554	444
Pulp and paper	270	267	197	175

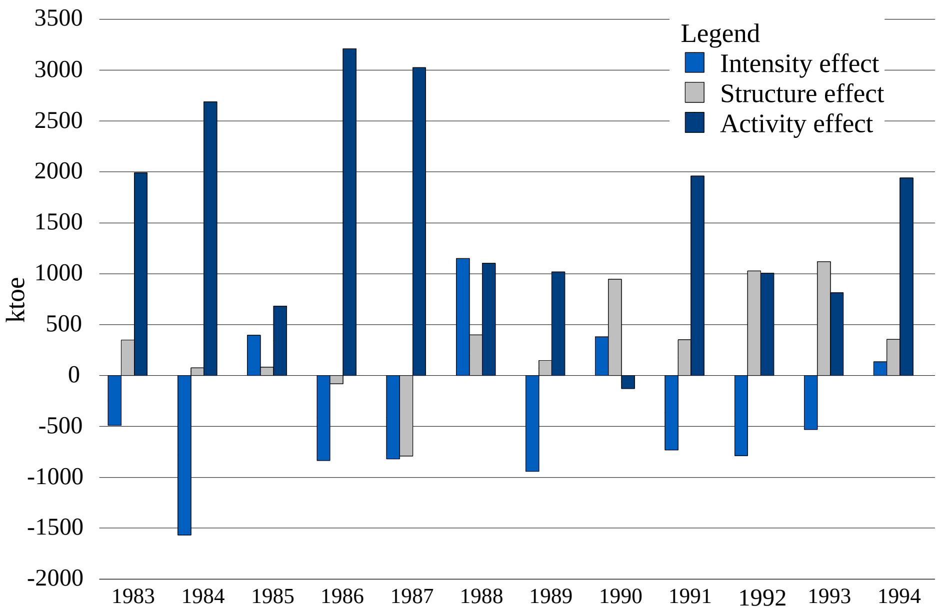
Source: Wu and Chen, 1989.

EXPLANATORY INDICATORS

DECOMPOSITION OF ENERGY CONSUMPTION

Decomposition approaches are widely employed to study how energy consumption has evolved, and how the influential effects have changed over time. In this part of the study, an average parametric Divisia method 2 (AVE-PDM2) (Ang, 1994) has been used for the decomposition analysis of Chinese Taipei. Figure 52 to Figure 55 present the relative contributions of intensity, structure and activity effects on change in energy consumption in industrial sector, iron and steel, cement, and pulp and paper sectors, respectively. Over the study period of 1982-1994, the main pulling factor for increasing energy consumption in the industrial sector was the ever lasting increases in the industrial outputs (activity effect), followed by expansion of the energy-intensive industries (structure effect) although which was partly offset by a strong energy conservation effect (intensity effect), as is shown in Figure 52 (Energy Commissions, 1996). Figure 53 to Figure 55 show that the influential factors behind the changes in energy consumption in energy intensive sectors vary over time. Nevertheless, if one looks at the variations of intensity effect, which to some extent reflect the evolution of energy efficiency, for the three sectors between 1981 to 1994, some consistency might be found. For example, cement sector experienced mainly negative intensity effect during 1981-1994, the converse is true for the pulp and paper sector during the period of 1986-1994 as was stated before.

Figure 52 Decomposition of Energy Use for the Industrial Sector
ktoe, 1983-94



An input-output structural decomposition model has been developed to analyse the sources of change in energy use for energy-intensive sectors for the period 1981-1991 (Wu and Chen, 1995). The relative prominence of 17 sources in changing energy use was determined. The results show that economic growth and substitution effects had positive effects on energy use, effects due to technological changes had an adverse effect being much weaker than that resulting from the former. Hence, the energy intensive sectors witnessed significant positive percentage changes in energy use. Except for cement sector, export demand represents an equal important positive effect on energy use as that of domestic demand. Primarily, this reflects the success of Chinese Taipei's export promotion efforts. In contrast to other energy intensive sectors, technological change in energy, or energy conservation, in the cement sector has a significant downward effect on energy use, this finding is conformable with the above-mentioned results from decomposition approach.

Up to now, studies using a decomposition analysis based on physical indicators for process type and product mix are not reported in Chinese Taipei; despite recent research results appear promising (Worrell *et al*., 1997; Phylipsen *et al*., 1997; Eichhammer and Mannsbart, 1997).

Figure 53 Decomposition of Energy Use for the Iron and Steel Sector
ktoe, 1984, 1988, 1992 and 1996.

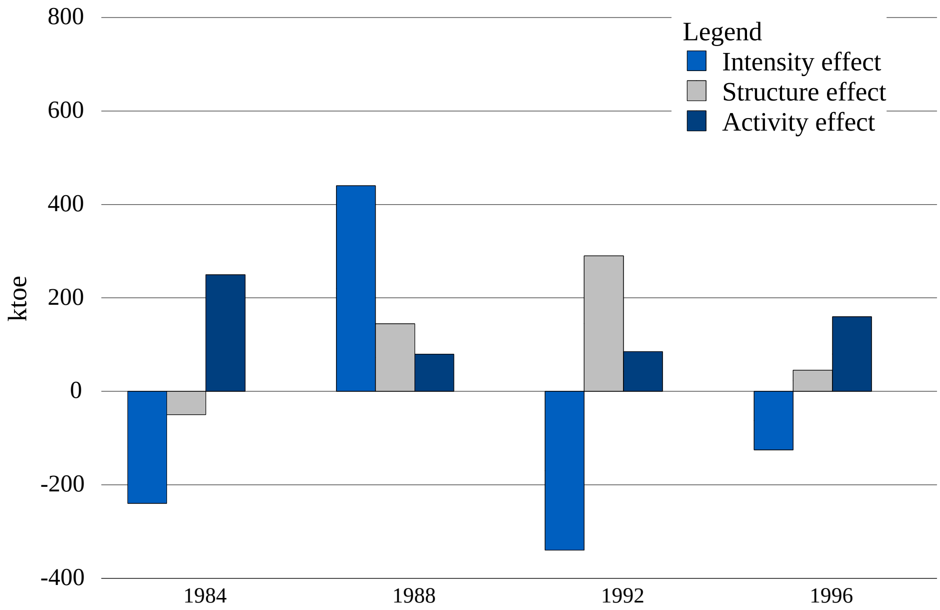


Figure 54 Decomposition of Energy Use for the Cement Sector
ktoe, 1984, 1988, 1992 and 1996.

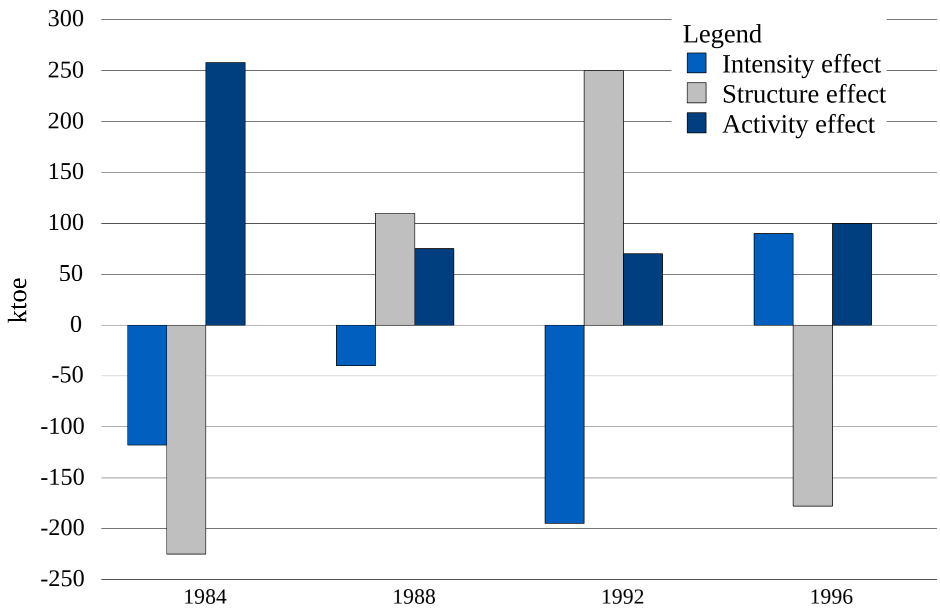
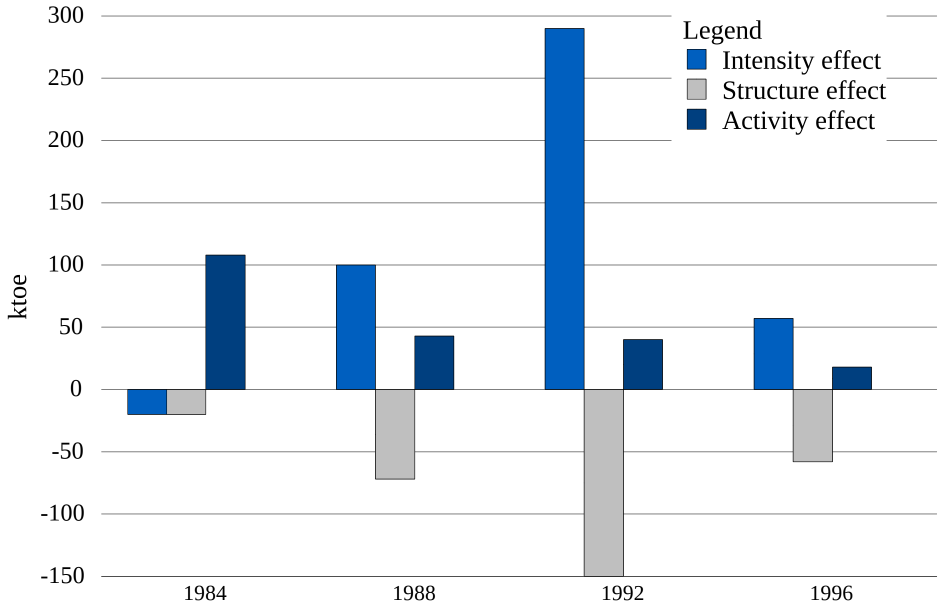


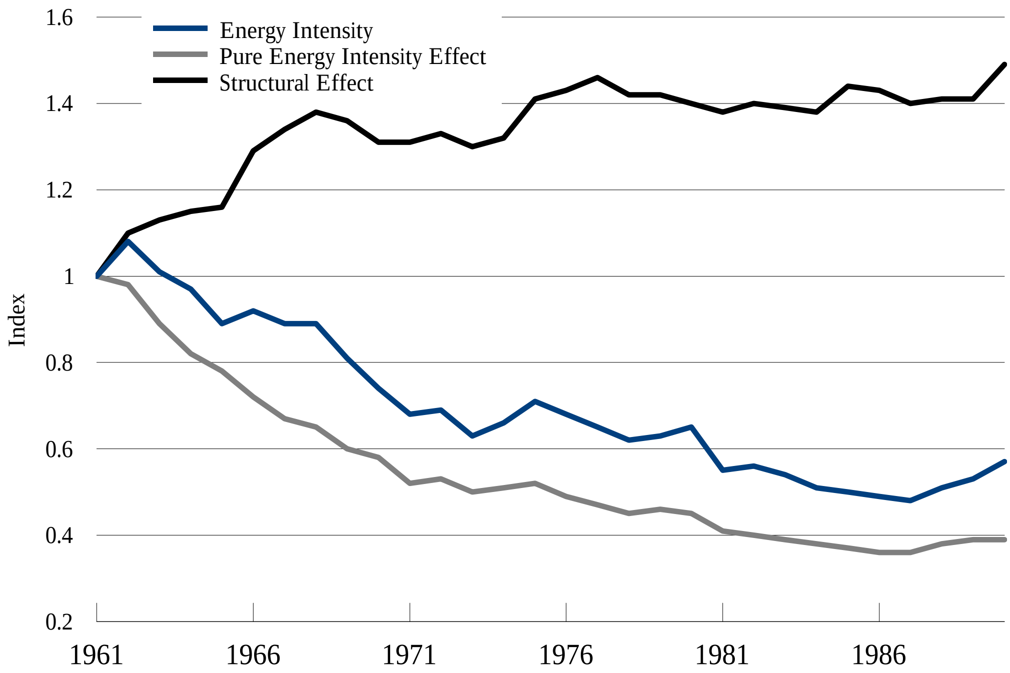
Figure 55 Decomposition of Energy Use for the Pulp and Paper Sector
ktoe, 1984, 1988, 1992 and 1996.



DECOMPOSITION OF ENERGY INTENSITY

Decomposition approach can also be used to analyse the change in energy intensity. In Figure 56, energy intensity is disaggregated into the pure intensity effect and structural effect for the industrial sector in Chinese Taipei. The trend on pure intensity is similar to aggregate energy intensity, implying the former is the main driving force of the latter. Both aggregate energy intensity and pure intensity effects before 1987 have a decreasing trend, however, after 1987 energy intensity has increased and industrial structure has shifted to energy intensive sectors. This reflects the relatively low energy price in recent years and highlights the need for proper policy instruments to be adopted to mitigate this trend (George Hsu and Hsu, 1993).

Figure 56 Decomposition of Energy Intensity in Chinese Taipei
Index: 1961 = 1, 1961-90.



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APPENDIX C

INPUT-OUTPUT ANALYSIS

Input-Output analysis is a suitable tool for assessing energy and greenhouse gas emissions (GHG) embodiments in goods and services on a macroeconomic scale. The initial data for national economy is reported for selected years and contains information about national economic structure with expenditure and distribution vectors for economic sectors. The Input-Output Tables are the part of National Accounts covering disaggregated sectoral level.

The basic concept has been discussed in detail by Leontief (1966) and applied to energy intensity assessment by Chapman (1974). The main equations in the model are stated below.

Let y be a vector (n x 1) of final demand from industry sectors i = 1, … , n and X_{ij} be the elements of a matrix (n x n) of intermediate demand of industries j = 1, … , n from industries i = 1, … , n. The total (intermediate plus final) demand x_i from industry i is then:

Eqn. 1

$$x_i = \sum_{j=1}^{n} X_{ij} + y_i$$

Let A be a matrix (n x n) of technological or direct requirement coefficients a_{ij}, which relate the output of industry j to its inputs from industries i by:

Eqn. 2

$$_{ij} = \; _{ij} \qquad (2)$$

Eqn. 3

$$x = \; \times x + y \qquad (3)$$

Solving for x yields

Eqn. 4

$$x = (I - A)^{-1} \times y \qquad (4)$$

where I denotes the (n x n) unity matrix and $(I - A)^{-1}$ is called the Leontief inverse. Since:

Eqn. 5

$$(I - A)^{-1} = I + A + A^2 + A^3 + A^4 + \ldots\ldots$$

The total output x can be written as a sum of final demand, direct requirements and indirect requirements

Eqn. 6

$$x = y$$ ← final demand

$$+ Ay$$ ← direct requirements

$$+ A^2 y + A^3 y + ...$$ ← indirect requirements

where $A^n y$ is the n-th order requirement for the production of final demand y. Therefore the Leontief inverse is also called the matrix of total requirements.

The input-output (I-O) technique has gained considerable attention in developing energy intensities. The I-O technique, in contrast to conventional process energy analysis, can efficaciously provide a panorama of both direct and indirect energy flows throughout the entire economic system.

The hybrid-unit formulation of the energy I-O framework is widely employed to calculate energy intensities. As early as in 1974 Chapman (1974) and Wright (1974) pointed out that matrices of intersectoral transactions in monetary units do not correctly reflect supplies from energy industries, because the energy price varies for different industries. This problem could be avoided if monetary values in distribution vectors of energy industries are replaced by values in energy units (Miller and Blair, 1985). The mixed energy intensity calculation yields in direct energy intensity, defined as primary energy consumption referred to the total output of industrial sector, and in total energy intensity, defined as a primary energy consumption referred to the final demand for industrial sector. Both values are expressed in energy per unit of economic activity in monetary terms – [toe/$] for instance. To obtain direct and total CO_2 emission intensity vectors in $kgCO_2/\$$ units, energy inputs are substituted by related CO_2 emissions from fossil-fuel combustion.

APPENDIX D

IRON AND STEEL PRODUCTION AND ENERGY CONSUMPTION DATA

Table 19 Crude Steel Production

Thousand tonnes

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Australia	7,594	7,635	6,371	5,657	6,302	6,407	6,674	6,100	6,387	6,735	6,676	6,184	6,877	7,830	8,493	8,460	8,415	8,831
Canada	15,901	14,811	11,871	12,832	14,699	14,532	13,988	14,737	14,971	15,332	12,184	12,895	13,840	14,296	13,800	14,415	14,735	15,554
Chile	704	644	492	618	690	684	706	726	909	800	772	807	1,013	1,069	1,041	1,014	1,178	1,168
China	37,120	35,600	37,160	40,020	43,360	46,700	51,900	55,250	59,460	61,587	66,349	71,000	80,935	89,539	91,532	95,360	101,237	108,911
Hong Kong, China	120	120	120	120	120	120	120	120	120	150	150	150	150	150	150	150	100	
Indonesia	360	621	693	983	1,171	1374	1,729	2,059	2,054	2,383	2,892	3,089	2,949	3,802	3,900	4,130	4,109	3,816
Japan	111,395	101,676	99,548	97,179	105,586	105,279	98,275	98,513	105,681	107,908	110,339	109,649	98,132	99,623	98,295	101,640	98,801	104,545
Korea						13,539	14,554	16,782	19,117	21,872	23,124	26,001	28,054	33,026	33,744	36,772	38,903	42,554
Malaysia	210	210	210	350	350	400	450	680	925	1,000	1,100	1,130	1,559	1,807	1,850	2,450	3,216	2,962
Mexico	7,156	7,673	7,506	6,917	7,560	7,399	7,225	7,642	7,779	7,852	8,734	7,964	8,459	9,189	10,246	12,147	13,172	14,254
New Zealand	230	221	252	234	280	227	287	409	560	682	719	806	758	853	766	842	808	758
Peru									430	364	270	404	343	417	509	512	578	605
Philippines	350	350	200	250	250	250	250	250	300	550	600	650	497	623	640	923	920	980
Russia									90,000	89,500	89,591	73,900	67,029	58,346	48,812	51,589	49,253	48,442
Singapore	340	263	359	305	362	365	390	441	432	495	489	658	709	876	530	521	531	383
Chinese Taipei	3,417	3,157	4,152	5,031	5,008	5088	5,545	5,550	8,313	9,047	9,747	11,083	10,705	11,970	11,590	11,605	12,350	15,994
Thailand	150	300	312	244	381	380	463	534	552	600	650	711	929	954	1,391	2,134	2,143	2,101
United States	101,457	109,615	67,656	76,763	83,941	80,068	74,033	80,877	90,650	88,852	89,276	79,738	84,322	88,792	91,243	95,191	95,535	98,485
Viet Nam									74	85	102	183	219	270	301	271	311	314
TOTAL	**294,356**	**291,690**	**246,752**	**258,533**	**282,415**	**282,812**	**276,589**	**290,670**	**408,714**	**415,794**	**423,764**	**407,002**	**407,479**	**423,432**	**418,833**	**440,126**	**446,295**	**470,657**

Source: APEC Database, Statistical Yearbook 1998, Korea, 1980-1984 from Hi Chun Park (1998)

Table 20 Energy Consumption in the Iron and Steel Industry

ktoe

APEC ECONOMY	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Australia																	
Coal	2,009	1,751	1,785	1,341	1,343	1,482	1,265	1,318	1,385	1,450	1,487	1,477	1,614	1,557	1,626	1,539	1,530
Oil	407	226	111	54	37	38	50	35	36	35	24	33	30	32	41	36	31
Gas	200	304	298	259	288	287	343	433	296	272	344	314	302	301	375	392	447
Electricity	392	404	338	287	316	340	334	336	374	374	419	396	420	438	457	478	471
Others	41	24	5	5	6	5	0	0	0	0	0	0	0	0	0	0	0
Total	3,049	2,709	2,537	1,946	1,989	2,152	1,992	2,122	2,092	2,131	2,274	2,219	2,365	2,327	2,500	2,445	2,479
Canada																	
Coal	2,864	2,544	2,199	2,230	2,534	2,531	2,277	2,307	2,397	2,283	1,580	1,928	1,965	1,893	1,780	2,000	1,693
Oil	813	676	335	246	285	290	315	328	345	422	333	224	232	241	230	204	199
Gas	1,465	1,392	1,096	1,113	1,185	1,301	1,248	1,420	1,421	1,415	1,176	1,324	1,490	1,543	1,645	1,675	1,818
Electricity	820	764	637	637	710	751	816	857	889	873	682	689	713	726	747	745	765
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	5,961	5,376	4,266	4,227	4,713	4,873	4,656	4,912	5,052	4,993	3,771	4,165	4,400	4,403	4,402	4,624	4,475
Chile																	
Coal	248	229	191	243	289	275	287	308	338	283	308	342	411	415	374	386	414
Oil	129	119	80	48	50	50	53	42	84	95	54	35	38	34	45	55	67
Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electricity	50	45	38	41	47	46	45	47	55	52	53	55	64	59	59	62	74
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	426	393	309	331	385	372	385	398	476	430	415	433	513	508	478	503	555

Table 21 Energy Consumption in the Iron and Steel Industry (cont.)

ktoe

APEC ECONOMY	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
China																	
Coal	49,835	45,055	46,223	48,754	53,187	54,097	59,594	63,364	64,934	66,510	70,208	52,604	57,443	68,468	71,650	82,072	79,915
Oil	3,354	2,724	2,697	2,847	2,927	2,544	3,132	3,157	2,527	3,334	3,303	4,512	4,401	4,134	4,435	4,513	3,976
Gas	872	687	645	637	603	436	553	603	603	612	795			1,028	1,008	1,124	1,170
Electricity	3,955	3,875	4,028	4,363	4,650	3,124	3,375	3,657	3,956	4,436	4,779	5,039	5,655	6,684	7,607	7,786	7,905
Others	0	0	0	0	0	206	140	110	262	171	168	2,774	2,194	2,575	4,006	2,562	2,794
Total	58,016	52,341	53,594	56,601	61,368	60,406	66,794	70,891	72,282	75,062	79,253	64,929	69,693	82,890	88,706	98,058	95,760
Hong Kong, China																	
Coal																	
Oil																	
Gas																	
Electricity	31	32	33	31	35	36	41	8	9	48	48	48	46				
Others																	
Total	31	32	33	31	35	36	41	8	9	48	48	48	46				
Indonesia																	
Coal	23	20	20	17	19	21	21	21	23	29	33	27	21	38	33	0	0
Oil	132	137	138	145	104	104	104	104	104	254	448	576	488	575	630	787	849
Gas	0	0	0	664	717	372	380	402	372	277	0	0	0	1,213	1,079	1,022	1,062
Electricity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	155	157	158	827	839	497	504	527	499	560	480	603	509	1,826	1,742	1,809	1,911

Table 22 Energy Consumption in the Iron and Steel Industry (cont.)

ktoe

APEC ECONOMY	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Japan																	
Coal	16,127	14,969	12,532	11,693	12,600	12,764	12,294	11,014	11,991	12,407	12,326	12,857	11,539	11,818	11,560	11,925	11,526
Oil	4,916	2,786	3,063	2,551	2,690	2,426	2,417	2,564	2,860	3,010	3,096	2,805	2,549	2,443	2,393	2,356	2,427
Gas	707	676	908	843	967	1,043	1,054	1,076	1,101	1,256	1,386	1,538	1,614	1,905	2,086	2,030	2,427
Electricity	6,321	6,065	6,035	6,040	6,317	6,280	5,881	6,097	6,425	6,687	6,996	6,937	6,709	6,579	6,804	6,895	6,974
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	28,071	24,495	22,538	21,127	22,574	22,512	21,645	20,751	22,377	23,359	23,803	24,137	22,412	22,744	22,843	23,206	23,353
Korea																	
Coal	1,462	2,003	1,663	1,700	1,791	1,709	1,590	1,819	2,191	2,602	2,727	3,152	3,236	3,716	3,692	3,836	4,234
Oil	605	713	688	607	621	577	608	608	667	657	876	969	1,199	1,275	1,544	1,470	1,472
Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electricity	403	425	438	474	518	523	592	679	731	803	866	898	926	1,083	2,166	2,377	2,579
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	2,469	3,141	2,789	2,781	2,930	2,809	2,790	3,106	3,589	4,062	4,469	5,019	5,361	6,073	7,401	7,684	8,286
Malaysia																	
Coal	20	27	20	9	14	18	20	22	20	38	53	70	73	72	72	68	68
Oil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	84	88	105	136
Electricity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	20	27	20	9	14	18	20	22	20	38	53	70	73	156	160	173	204

Table 23 Energy Consumption in the Iron and Steel Industry (cont.)

ktoe

APEC ECONOMY	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Mexico																	
Coal	1,606	1,704	1,587	1,994	1,951	1,924	1,610	1,750	1,304	1,610	1,421	1,280	1,398	1,406	1,568	1,714	1,850
Oil	0	0	0	0	0	445	415	446	707	838	716	661	382	464	516	610	663
Gas	0	0	0	0	0	1,719	1,613	1,802	2,287	2,790	1,917	1,862	1,829	1,910	2,130	2,393	2,535
Electricity	0	0	0	0	0	383	393	388	629	640	704	570	573	539	604	722	765
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,606	1,704	1,587	1,994	1,951	4,471	4,031	4,387	4,926	5,878	4,758	4,373	4,182	4,318	4,818	5,439	5,814
New Zealand																	
Coal	74	63	70	70	61	55	124	170	248	309	327	336	355	347	328	368	348
Oil	6	6	4	3	3	2	2	2	3	10	9	14	1	0	0	0	0
Gas	9	12	13	14	16	17	0	0	0	0	0	0	0	0	0	0	0
Electricity	252	254	291	373	391	385	408	428	455	462	458	459	425	466	467	471	479
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	342	335	378	461	472	460	535	600	706	781	794	809	781	813	795	839	827
Peru																	
Coal	66	57	53	44	35	51	55	54	60	49	37	75	67	118	49	40	42
Oil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electricity	18	19	21	19	22	0	0	0	0	0	0	0	0	0	0	0	0
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	85	76	74	63	57	51	55	54	60	49	37	75	67	118	49	40	42

Table 24 Energy Consumption in the Iron and Steel Industry (cont.)

ktoe

APEC ECONOMY	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Philippines																	
Coal	217	140	177	126	137	57	55	69	94	111	126	126	103	112	121	127	130
Oil	380	261	325	317	227	233	205	224	236	261	265	252	260	285	332	394	391
Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electricity	53	49	50	56	55	58	38	50	55	63	58	60	55	60	68	72	75
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	650	449	552	499	419	348	298	343	385	434	448	439	418	458	522	593	596
Russia																	
Coal											10,651	5,513	4,835	6,289	5,882	6,872	6,660
Oil											3,002	2,747	2,269	607	336	367	320
Gas											18,416	16,223	17,297	14,177	11,605	12,655	13,390
Electricity											4,818	4,605	4,318	3,903	4,561	4,697	4,560
Others											6,967	11	11	9,599	7,751	7,452	7,341
Total											43,853	29,099	28,730	34,574	30,134	32,043	32,272
Singapore																	
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electricity	24	25	25	23	26	27	28	30	30	37	39	51	54	58	65	69	74
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	24	25	25	23	26	27	28	30	30	37	39	51	54	58	65	69	74

Table 25 Energy Consumption in the Iron and Steel Industry (cont.)

ktoe

APEC ECONOMY	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Chinese Taipei																	
Coal	846	803	1,457	1,670	1,486	1,806	1,981	2,078	3,143	3,154	3,025	3,067	2,842	3,163	3,343	3,334	3,439
Oil	406	317	301	382	430	365	425	449	396	408	463	510	732	815	834	801	734
Gas	1	1	1	1	1	1	1	0	0	0	3	3	3	23	32	76	106
Electricity	249	199	255	290	291	284	314	314	384	419	460	498	537	592	607	646	677
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,502	1,320	2,014	2,342	2,208	2,456	2,721	2,842	3,923	3,980	3,951	4,077	4,114	4,592	4,816	4,856	4,956
Thailand																	
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oil	47	44	25	37	88	82	98	103	117	122	146	154	234	266	252	240	349
Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electricity	49	52	40	44	45	32	81	97	103	116	125	136	139	173	224	282	287
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	95	95	66	81	133	114	179	200	220	239	271	290	373	438	476	522	636
United States																	
Coal	20,719	21,805	13,245	14,610	14,916	14,174	12,650	10,417	11,334	10,281	11,872	10,206	5,264	6,392	8,084	8,965	9,088
Oil	4,172	2,158	1,266													2,646	2,671
Gas																10,215	10,733
Electricity	5,879	6,118	4,352	4,427	5,428	5,032	4,690	4,748	5,414	5,443	6,268	5,813	4,900	5,042	5,255	6,007	5,956
Others	0	0	0	0	0	0	0	0	0	0	0	0	8	8	9	163	162
Total	30,770	30,081	18,863	19,037	20,345	19,206	17,340	15,165	16,748	15,724	18,140	16,019	10,172	11,442	13,347	27,995	28,611

Table 26 Total Energy Consumption in the Iron and Steel Industry

ktoe

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Australia	3,049	2,709	2,537	1,946	1,989	2,152	1,992	2,122	2,092	2,131	2,274	2,219	2,365	2,327	2,500	2,445	2,479
Canada	5,961	5,376	4,266	4,227	4,713	4,873	4,656	4,912	5,052	4,993	3,771	4,165	4,400	4,403	4,402	4,624	4,475
Chile	426	393	309	331	385	372	385	398	476	430	415	433	513	508	478	503	555
China	58,016	52,341	53,594	56,601	61,368	60,406	66,794	70,891	72,282	75,062	79,253	64,929	69,693	82,890	88,706	98,058	95,760
Hong Kong, China	31	32	33	31	35	36	41	8	9	48	48	48	46				
Indonesia	155	157	158	827	839	497	504	527	499	560	480	603	509	1,826	1,742	1,809	1,911
Japan	28,071	24,495	22,538	21,127	22,574	22,512	21,645	20,751	22,377	23,359	23,803	24,137	22,412	22,744	22,843	23,206	23,353
Korea	2,469	3,141	2,789	2,781	2,930	2,809	2,790	3,106	3,589	4,062	4,469	5,019	5,361	6,073	7,401	7,684	8,286
Malaysia	20	27	20	9	14	18	20	22	20	38	53	70	73	156	160	173	204
Mexico	1,606	1,704	1,587	1,994	1,951	4,471	4,031	4,387	4,926	5,878	4,758	4,373	4,182	4,318	4,818	5,439	5,814
New Zealand	342	335	378	461	472	460	535	600	706	781	794	809	781	813	795	839	827
Peru	85	76	74	63	57	51	55	54	60	49	37	75	67	118	49	40	42
Philippines	650	449	552	499	419	348	298	343	385	434	448	439	418	458	522	593	596
Russia											43,853	29,099	28,730	34,574	30,134	32,043	32,272
Singapore	24	25	25	23	26	27	28	30	30	37	39	51	54	58	65	69	74
Chinese Taipei	1,502	1,320	2,014	2,342	2,208	2,456	2,721	2,842	3,923	3,980	3,951	4,077	4,114	4,592	4,816	4,856	4,956
Thailand	95	95	66	81	133	114	179	200	220	239	271	290	373	438	476	522	636
United States	30,770	30,081	18,863	19,037	20,345	19,206	17,340	15,165	16,748	15,724	18,140	16,019	10,172	11,442	13,347	27,995	28,611
TOTAL	133,272	122,756	109,803	112,380	120,458	120,808	124,014	126,358	133,394	137,805	186,857	156,855	154,263	177,738	183,254	210,898	210,851

Source: APEC Database, IEA database

Table 27 Energy Source Mix in the Iron and Steel Industry

ktoe

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Coal	96,116	91,170	81,222	84,501	90,363	90,964	93,823	94,711	99,462	101,116	116,181	93,060	91,166	105,804	110,162	123,246	120,937
Oil	15,367	10,167	9,033	7,237	7,462	7,156	7,824	8,062	8,082	9,446	12,735	13,492	12,815	11,171	11,588	14,479	14,149
Gas	3254	3072	2961	3531	3777	5176	5,192	5,736	6,080	6,622	24,037	21,264	22,535	22,184	20,048	31,687	33,824
Electricity	18,496	18,326	16,581	17,105	18,851	17,301	17,036	17,736	19,509	20,453	26,773	26,254	25,534	26,402	29,691	31,309	31,641
Others	41	24	5	5	6	211	140	110	262	171	7,135	2,785	2,213	12,182	11,766	10,177	10,297
Total	133,274	122,759	109,802	112,379	120,459	120,808	124,015	126,355	133,395	137,808	186,861	156,855	154,263	177,743	183,255	210,898	210,848

Table 28 Energy Intensity of the Iron and Steel Industry

toe/ton

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Australia	0.402	0.355	0.398	0.344	0.316	0.336	0.298	0.348	0.327	0.316	0.341	0.359	0.344	0.297	0.294		
Canada	0.375	0.363	0.359	0.329	0.321	0.335	0.333	0.333	0.337	0.326	0.310	0.323	0.318	0.308	0.319		
Chile	0.605	0.610	0.629	0.536	0.558	0.543	0.546	0.548	0.524	0.537	0.538	0.536	0.506	0.475	0.459		
China	1.563	1.470	1.442	1.414	1.415	1.293	1.287	1.283	1.216	1.219	1.194	0.561	0.536	0.926	0.969		
Indonesia	0.429	0.252	0.228	0.841	0.717	0.362	0.292	0.256	0.243	0.235	0.166	0.195	0.173	0.480	0.447		
Japan	0.252	0.241	0.226	0.217	0.214	0.214	0.220	0.211	0.212	0.216	0.216	0.220	0.228	0.228	0.232	0.228	0.236
Korea						0.207	0.192	0.185	0.188	0.186	0.193	0.193	0.191	0.184	0.219	0.209	0.213
Malaysia	0.096	0.127	0.093	0.026	0.041	0.046	0.043	0.033	0.021	0.038	0.048	0.062	0.047	0.086	0.086		
New Zealand	1.485	1.514	1.498	1.971	1.686	2.024	1.864	1.466	1.260	1.146	1.104	1.004	1.031	0.953	1.038		
Philippines	1.856	1.283	2.759	1.996	1.675	1.390	1.191	1.371	1.284	0.789	0.747	0.675	0.842	0.734	0.816		
Russia											0.416	0.414	0.427	0.432	0.462	0.465	0.451
Singapore	0.071	0.095	0.070	0.075	0.072	0.073	0.071	0.067	0.070	0.075	0.080	0.077	0.076	0.067	0.122		
Chinese Taipei	0.439	0.418	0.485	0.466	0.441	0.483	0.491	0.512	0.472	0.440	0.405	0.368	0.384	0.384	0.416		
Thailand	26.108	14.330	15.037	19.051	13.234	14.007	11.650	10.704	11.189	12.938	13.367	13.338	11.246	12.450	10.213		
United States	0.303	0.274	0.279	0.248	0.242	0.240	0.234	0.188	0.185	0.177	0.203	0.201	0.121	0.129	0.146		

Table 29 Electricity Intensity of the Iron and Steel Industry

toe / ton

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Australia	0.052	0.053	0.053	0.051	0.050	0.053	0.050	0.055	0.059	0.056	0.063	0.064	0.061	0.056	0.054		
Canada	0.052	0.052	0.054	0.050	0.048	0.052	0.058	0.058	0.059	0.057	0.056	0.053	0.052	0.051	0.054		
Chile	0.071	0.070	0.078	0.066	0.068	0.068	0.064	0.065	0.060	0.065	0.069	0.068	0.063	0.056	0.057		
China	0.107	0.109	0.108	0.109	0.107	0.067	0.065	0.066	0.067	0.072	0.072	0.071	0.070	0.075	0.083		
Hong Kong, China	0.259	0.269	0.276	0.262	0.295	0.300	0.340	0.064	0.077	0.321	0.318	0.319	0.308				
Indonesia																	
Japan	0.057	0.060	0.061	0.062	0.060	0.060	0.060	0.062	0.061	0.062	0.063	0.063	0.068	0.066	0.069	0.068	0.071
Korea						0.039	0.041	0.040	0.038	0.037	0.037	0.035	0.033	0.033	0.064	0.065	0.066
Malaysia	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
New Zealand	1.096	1.148	1.155	1.596	1.398	1.698	1.423	1.047	0.812	0.677	0.637	0.570	0.561	0.547	0.609		
Philippines	0.150	0.139	0.249	0.224	0.219	0.231	0.150	0.199	0.183	0.114	0.096	0.092	0.112	0.097	0.107		
Singapore	0.071	0.095	0.070	0.075	0.072	0.073	0.071	0.067	0.070	0.075	0.080	0.077	0.076	0.067	0.122		
Chinese Taipei	0.073	0.063	0.061	0.058	0.058	0.056	0.057	0.057	0.046	0.046	0.047	0.045	0.050	0.049	0.052		
Thailand	0.325	0.172	0.129	0.178	0.119	0.085	0.174	0.182	0.186	0.194	0.193	0.192	0.149	0.181	0.161		
United States	0.058	0.056	0.064	0.058	0.065	0.063	0.063	0.059	0.060	0.061	0.070	0.073	0.058	0.057	0.058		

Table 30 Energy Intensity of the Iron and Steel Industry (excluding electricity)

toe / ton

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Australia	0.350	0.302	0.345	0.293	0.265	0.283	0.248	0.293	0.269	0.261	0.278	0.295	0.283	0.241	0.241		
Canada	0.323	0.311	0.306	0.280	0.272	0.284	0.274	0.275	0.278	0.269	0.254	0.270	0.266	0.257	0.265		
Chile	0.534	0.541	0.551	0.470	0.490	0.475	0.481	0.482	0.463	0.472	0.469	0.468	0.443	0.420	0.402		
China	1.456	1.361	1.334	1.305	1.308	1.227	1.222	1.217	1.149	1.147	1.122	0.561	0.536	0.851	0.886		
Hong Kong, China	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
Indonesia	0.429	0.252	0.228	0.841	0.717	0.362	0.292	0.256	0.243	0.235	0.166	0.195	0.173	0.480	0.447		
Japan	0.195	0.181	0.166	0.155	0.154	0.154	0.160	0.149	0.151	0.155	0.152	0.157	0.160	0.162	0.163	0.160	0.166
Korea						0.169	0.151	0.145	0.149	0.149	0.156	0.159	0.158	0.151	0.155	0.144	0.147
Malaysia	0.096	0.127	0.093	0.026	0.041	0.046	0.043	0.033	0.021	0.038	0.048	0.062	0.047	0.086	0.086		
New Zealand	0.389	0.367	0.343	0.375	0.288	0.327	0.441	0.419	0.448	0.469	0.468	0.434	0.470	0.406	0.429		
Philippines	1.706	1.144	2.510	1.773	1.456	1.159	1.041	1.172	1.101	0.675	0.651	0.583	0.730	0.637	0.709		
Singapore	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
Chinese Taipei	0.367	0.355	0.424	0.408	0.383	0.427	0.434	0.455	0.426	0.394	0.358	0.323	0.334	0.334	0.363		
Thailand	25.784	14.158	14.908	18.873	13.116	13.922	11.476	10.521	11.003	12.745	13.174	13.146	11.096	12.269	10.052		
United States	0.245	0.219	0.214	0.190	0.178	0.177	0.171	0.129	0.125	0.116	0.133	0.128	0.063	0.072	0.089		

Table 31 Iron and Steel CO_2 Emissions

Thousand tonnes

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Australia	9,707	8,369	8,136	6,105	6,126	6,682	5,989	6,363	6,313	6,510	6,792	6,708	7,215	6,992	7,473	7,149	7,226
Canada	17,334	15,469	12,349	12,244	13,735	14,014	12,956	13,523	13,934	13,703	10,076	11,471	12,031	11,898	11,658	12,521	11,623
Chile	1,379	1,277	1,005	1,111	1,299	1,247	1,303	1,354	1,599	1,416	1,390	1,469	1,751	1,753	1,624	1,705	1,851
China	210,390	189,020	193,482	203,979	221,760	223,800	247,727	262,902	267,199	275,966	290,996	222,904	241,787	287,194	300,714	342,638	332,519
Indonesia	496	500	504	2,081	2,084	1,280	1,297	1,351	1,289	1,551	1,509	1,880	1,588	4,779	4,614	4,831	5,117
Japan	80,882	69,648	61,366	56,302	60,627	60,642	58,773	54,191	59,048	61,524	61,773	63,344	57,502	58,964	58,214	59,419	58,988
Korea	7,670	10,155	8,726	8,624	9,030	8,566	8,189	9,101	10,759	12,363	13,534	15,509	16,551	18,689	19,422	19,771	21,358
Malaysia	80	106	77	36	57	72	77	88	77	152	209	276	289	484	493	518	591
Mexico	6,380	6,772	6,305	7,924	7,752	13,066	11,474	12,574	12,746	15,550	12,367	11,509	11,041	11,515	12,838	14,328	15,367
New Zealand	335	297	319	323	292	265	501	680	995	1,261	1,327	1,377	1,414	1,378	1,305	1,460	1,381
Peru	263	227	209	173	137	201	217	213	239	196	148	299	267	467	197	161	168
Philippines	2,033	1,358	1,704	1,478	1,243	943	851	964	1,101	1,242	1,316	1,280	1,210	1,323	1,506	1,719	1,722
Russia											94,957	68,591	66,954	60,258	51,745	58,251	58,998
Chinese Taipei	4,614	4,169	6,717	7,812	7,232	8,300	9,181	9,640	13,706	13,787	13,454	13,760	13,553	15,130	15,928	15,891	16,175
Thailand	143	135	78	115	272	251	302	316	361	377	449	473	721	818	776	739	1,075
United States	95,170	93,281	56,525	58,047	59,266	56,317	50,262	41,390	45,033	40,849	47,170	40,552	20,914	25,396	32,118	67,837	69,625
TOTAL	436,876	400,783	357,502	366,354	390,912	395,646	409,099	414,650	434,399	446,447	557,467	461,402	454,788	507,038	520,625	608,938	603,784

Table 32 Iron and Steel Energy Saving Potentials

Per cent; 1988-96

	1988	1989	1990	1991	1992	1993	1994	1995	1996
Australia	-0.505	-3.583	4.380	8.492	3.882	-6.641	-8.375	-8.793	-5.947
Canada	25.756	21.385	23.096	22.060	21.304	21.332	26.723	26.342	21.614
Chile	36.448	38.730	38.309	38.404	33.976	30.152	27.740	34.083	29.983
China	76.690	76.864	80.826	72.386	72.379	75.207	76.299	77.670	75.297
Hong Kong, China	28.391	82.901	82.714	82.808	82.202				
Indonesia	77.409	76.648	66.947	71.857	68.215	88.567	87.710	87.463	88.195
Japan	-23.378	-19.502	-18.780	-16.466	-12.028	-12.497	-10.056	-11.173	-6.045
Korea	-36.268	-41.054	-33.150	-36.248	-36.025	-36.522	-10.779	-13.693	-9.227
Malaysia	-364.246	-158.031	-98.376	-55.497	-82.924	4.542	9.093	22.251	13.435
Mexico	66.202	73.748	63.730	67.253	62.603	62.848	64.982	63.210	63.660
New Zealand	80.370	78.670	76.308	74.197	74.736	74.028	77.508	75.060	75.498
Peru	-10.353	-52.596	-2.098	-4.928	9.042	30.340	-68.627	-137.098	-157.268
Philippines	95.724	93.040	92.652	85.389	87.863	86.105	83.758	77.980	75.766
Russia					29.320	48.167	49.871	49.943	52.445
Singapore	21.442	26.691	31.234	28.805	27.583	17.763	54.888	58.630	60.536
Chinese Taipei	46.213	43.243	44.740	42.945	47.072	45.803	49.452	49.736	48.141
Thailand	86.227	86.193	86.845	86.535	86.318	88.049	83.954	77.571	81.505
United States	-30.062	-37.417	-17.578	-17.345	-96.499	-80.812	-59.352	21.826	25.389

APPENDIX E

CEMENT PRODUCTION AND ENERGY CONSUMPTION DATA

Table 33 Cement Production

Thousand tonnes

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Australia	5,560	6,006	5,211	4,836	5,463	5,887	5,928	5,880	6,620	6,999	7,068	6,108	6,108	6,500	7,019	7,400
Brunei Darussalam																
Canada	11,000	10,669	8,370	8,219	9,827	10,869	10,704	12,608	12,264	12,115	11,543	9,927	9,601	10,168	11,437	11,933
Chile	1,566	1,850	1,146	1,260	1,400	1,425	1,437	1,618	1,883	2,007	2,069	2,231	2,654	3,020	2,995	3,275
China	80,000	82,897	95,200	108,250	123,024	145,956	166,060	186,252	210,140	210,390	211,800	253,789	308,862	367,933	421,423	476,533
Hong Kong, China	1,279	1,489	1,517	1,320	1,723	1,847	1,835	2,240	2,226	2,190	2,141	1,808	1,677	1,643	1,712	1,927
Indonesia	5,831	6,844	6,748	8,102	8,813	9,805	11,322	12,444	13,218	15,637	16,298	17,068	19,229	19,430	21,957	23,266
Japan	87,957	84,828	84,225	85,090	82,716	76,714	73,453	72,705	79,122	81,889	87,000	92,573	93,239	94,130	97,431	96,292
Korea	15,573	15,600	17,912	22,664	21,829	21,948	24,734	27,592	29,854	31,367	33,964	38,778	43,323	49,680	54,845	57,843
Malaysia	2,349	2,833	3,500	3,610	4,414	4,158	4,026	3,204	3,828	4,774	5,871	7,324	8,213	8,917	10,102	11,088
Mexico	16,260	17,844	19,153	17,243	18,784	21,347	21,257	23,244	22,897	23,651	23,854	25,100	26,884	27,600	29,808	24,400
New Zealand	828	888	1,066	956	1,010	970	906	880	812	751	684	665	741	847	922	950
Papua New Guinea																
Peru	2,770	2,606	2,487	1,966	1,947	1,757	2,207	2,584	2,514	2,105	2,185	2,137	2,164	2,443	3,177	3,792
Philippines	4,516	4,008	4,393	4,559	3,662	3,080	3,280	4,276	5,353	5,873	6,632	6,913	6,667	7,961	9,571	10,554
Russia	75,800					79,100			84,000	84,500	83,000	77,500	61,700	49,900	37,200	36,400
Singapore	1,831	2,093	2,695	3,153	2,900	1,992	1,805	1,527	1,595	1,706	1,852	1,866	2,075	2,979	3,063	3,000
Chinese Taipei	14,062	14,359	12,520	13,903	13,347	13,563	13,956	14,929	16,832	17,876	18,397	19,296	21,384	24,429	23,243	22,406
Thailand	5,302	6,263	6,557	7,204	8,195	7,912	7,940	9,852	11,675	15,364	18,044	18,759	22,391	26,373	31,070	33,650
United States	68,243	65,055	57,476	63,885	70,490	70,666	71,475	70,941	69,734	70,026	69,954	65,481	69,585	73,807	77,946	76,906
Viet Nam	641	633	800	907	1,297	1,503	1,526	1,665	1,760	1,800	2,545	3,000	3,400	4,800	4,700	5,200
APEC	401,368	326,765	330,976	357,127	380,841	480,499	423,851	454,441	576,327	591,020	604,901	650,323	709,897	782,560	849,621	906,815
Non-APEC	488,298	565,631	556,425	561,261	563,574	479,658	588,618	594,579	530,802	552,952	543,035	505,316	528,915	500,947	520,230	535,740
WORLD	889,666	892,396	887,401	918,388	944,415	960,157	1,012,469	1,049,020	1,107,129	1,143,972	1,147,936	1,155,639	1,238,812	1,283,507	1,369,851	1,442,555

Source: APEC Database (Australia, Canada, Chile, China, Hong Kong, China, Indonesia, Japan, Korea, Malaysia, Mexico, New Zealand, Philippines, Chinese Taipei, Thailand, United States)
Cembureau, World Statistical Review N 18, 19 & 20 (Peru, Russia, Viet Nam)
Singapore from Cembureau, World Statistical Review N18, 19 & 20 (1993-1995) and APEC Database

Table 34 Energy Consumption in the Cement Industry

ktoe

Australia	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Fossil solids	452	513	467	403	466	461	385	380	436	414	390	341	364	418	414	365
Fossil liquids	11	10	8	7	7	9	8	7	29	19	26	33	24	27	29	23
Fossil gases	321	278	250	222	253	336	342	360	335	338	308	262	247	263	270	280
Electricity	65	72	65	60	67	72	69	70	75	76	72	67	70	73	73	74
Others																
Total	849	873	790	692	793	878	804	817	875	847	796	703	705	781	786	742
Canada																
Fossil solids	341	437	415	409	479	561	647	682	767	751	715	564	579	536	618	719
Fossil liquids	355	197	174	97	53	33	32	35	30	42	37	32	26	35	46	41
Fossil gases	484	473	297	285	327	298	226	337	284	296	327	274	238	233	257	313
Electricity	130	128	114	110	116	122	121	139	141	145	140	115	130	122	145	154
Others	3	1	1	3	7	9	14	13	12	24	37	17	28	52	106	90
Total	1,314	1,235	1,001	904	983	1,023	1,040	1,206	1,234	1,258	1,256	1,003	1,001	978	1,171	1,317
Chile																
Fossil solids	118	132	71	74	76	73	81	88	112	120	129	118	164	148	113	118
Fossil liquids	2	4	3	5	4	4	4	4	4	5	7	6	7	9	8	7
Fossil gases																
Electricity	18	20	12	14	15	16	16	18	21	22	23	25	29	32	34	35
Others																
Total	138	156	86	93	95	93	101	110	137	147	159	149	201	190	155	161

Table 35 Energy Consumption in the Cement Industry (cont)

ktoe

Japan	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Fossil solids		5,555	5,543	4,604	4,822	4,504	4,070	4,015	4,514	4,703	4,966	5,316	5,300	5,033	5,151	5,144
Fossil liquids		1,207	645	1,582	1,020	726	825	757	633	697	719	697	765	1,007	1,055	1,023
Fossil gases		0.02	0.06	0	0	0.05	0	0.05	0.03	0	0	4.36	5.72	5.57	4.92	4.58
Electricity		887	836	818	778	706	680	672	719	749	781	824	839	826	851	835
Others		16	9	8	8	8	5	5	3	3	3	4	4	4	4	5
Total		7,665	7,034	7,012	6,627	5,944	5,580	5,449	5,870	6,153	6,470	6,846	6,914	6,875	7,066	7,011
Korea																
Fossil solids		994	1,637	1,913	1,664	1,628	1,769	1,976	2,140	2,226	2,344	2,797	2,900	3,417	3,525	3,717
Fossil liquids		1,240	707	614	700	734	758	813	926	1,056	1,235	1,350	1,527	1,568	1,673	1,589
Fossil gases					0	3	8	16	23	36	53	50	60	71	86	108
Electricity		227	251	286	289	301	330	364	412	440	484	563	616	682	753	802
Others																
Total		2,461	2,595	2,812	2,654	2,665	2,865	3,170	3,501	3,758	4,116	4,760	5,102	5,739	6,036	6,216
Mexico																
Fossil solids																
Fossil liquids	1,387	1,535	1,648	1,458	1,575	1,766	1,687	1,867	1,698	1,784	1,807	1,890	1,949	1,940	1,959	1,666
Fossil gases	225	249	267	236	255	286	273	165	239	144	249	213	319	281	251	238
Electricity	185	205	220	195	211	238	198	215	256	236	224	279	286	294	331	256
Others																
Total	1,797	1,990	2,136	1,889	2,040	2,291	2,158	2,247	2,193	2,164	2,279	2,383	2,554	2,516	2,542	2,161

Table 36 Energy Consumption in the Cement Industry (cont)

ktoe

Philippines	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Fossil solids	82	80	94	239	405	329	306	346	487	308	422	533	432	549	635	683
Fossil liquids	485	438	460	306	46	17	23	57	79	230	152	70	168	158	245	279
Fossil gases																
Electricity	66	79	71	31	50	47	47	49	44	45	50	54	64	74	95	99
Others																
Total	633	597	625	576	501	393	376	452	610	583	624	657	664	781	975	1,061
Thailand																
Fossil solids		31	158	145	186	304	348	467	568	762	939	1,024	1,161	1,836	2,296	2,857
Fossil liquids		743	601	522	399	401	387	470	472	674	710	682	997	962	848	740
Fossil gases				32	194	178	87	118	60	75	151	210	280	329	309	383
Electricity		78	82	89	97	101	107	118	156	191	222	240	194	290	377	429
Others																
Total		852	841	788	876	984	929	1,173	1,256	1,702	2,022	2,156	2,632	3,417	3,830	4,409
United States																
Fossil solids	6,410	6,518	5,784	6,120	6,860	6,096	5,911	5,935	5,575	5,588	5,420	5,271	5,122	5,749	6,355	6,230
Fossil liquids	610	322	303	204	110	112	104	157	142	181	279	211	143	652	537	764
Fossil gases	1,434	1,030	623	342	334	251	286	283	273	244	246	561	876	557	542	892
Electricity	900	871	781	836	910	820	897	877	855	860	866	870	873	860	934	938
Others																
Total	9,354	8,741	7,491	7,502	8,213	7,280	7,198	7,252	6,845	6,873	6,811	6,913	7,014	7,818	8,368	8,823

Source: Survey (Australia, Korea, Chile, Thailand and Philippines), INEDIS database (Canada, Mexico and United States), MITI (Japan). Due to lack of data, 1991 for United States was interpolated.

Table 37 Total Energy Consumption in the Cement Industry

ktoe

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Australia	849	873	790	692	793	878	804	817	875	847	796	703	705	781	786	742
Canada	1,314	1,235	1,001	904	983	1,023	1,040	1,206	1,234	1,258	1,256	1,003	1,001	978	1,171	1,317
Chile	138	156	86	93	95	93	101	110	137	147	159	149	201	190	155	161
Japan		7,665	7,034	7,012	6,627	5,944	5,580	5,449	5,870	6,153	6,470	6,846	6,914	6,875	7,066	7,011
Korea		2,461	2,595	2,812	2,654	2,665	2,865	3,170	3,501	3,758	4,116	4,760	5,102	5,739	6,036	6,216
Mexico	1,797	1,990	2,136	1,889	2,040	2,291	2,158	2,247	2,193	2,164	2,279	2,383	2,554	2,516	2,542	2,161
Philippines	633	597	625	576	501	393	376	452	610	583	624	657	664	781	975	1,061
Thailand		852	841	788	876	984	929	1,173	1,256	1,702	2,022	2,156	2,632	3,417	3,830	4,409
United States	9,354	8,741	7,491	7,502	8,213	7,280	7,198	7,252	6,845	6,873	6,811	6,913	7,014	7,818	8,368	8,823
TOTAL		24,570	22,598	22,267	22,782	21,551	21,051	21,875	22,521	23,485	24,534	25,570	26,787	29,095	30,929	31,901

Table 38 Energy Source Mix in the Cement Industry

ktoe

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Coal	7,404	14,260	14,170	13,906	14,958	13,957	13,517	13,889	14,599	14,872	15,325	15,964	16,022	17,687	19,106	19,833
Petroleum	2,850	5,696	4,549	4,795	3,913	3,802	3,828	4,166	4,015	4,688	4,971	4,973	5,606	6,357	6,399	6,131
Electricity	1,364	2,568	2,432	2,438	2,533	2,423	2,464	2,522	2,678	2,764	2,863	3,037	3,100	3,254	3,593	3,623
Other	2,467	2,046	1,447	1,128	1,378	1,369	1,242	1,298	1,229	1,161	1,374	1,596	2,058	1,796	1,830	2,314
Total	14,084	24,570	22,598	22,267	22,782	21,551	21,051	21,875	22,521	23,485	24,534	25,570	26,787	29,095	30,929	31,901

Table 39 Energy Intensity in the Cement Industry

toe/tonne of cement

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Australia	0.1527	0.1454	0.1516	0.1431	0.1452	0.1491	0.1356	0.1389	0.1322	0.1210	0.1126	0.1151	0.1154	0.1202	0.1120	0.1003
Canada	0.1194	0.1158	0.1196	0.1099	0.1000	0.0941	0.0971	0.0956	0.1006	0.1039	0.1088	0.1011	0.1043	0.0962	0.1024	0.1104
Chile	0.0880	0.0844	0.0749	0.0740	0.0677	0.0650	0.0705	0.0677	0.0728	0.0734	0.0771	0.0670	0.0756	0.0628	0.0519	0.0492
Japan		0.0904	0.0835	0.0824	0.0801	0.0775	0.0760	0.0749	0.0742	0.0751	0.0744	0.0739	0.0742	0.0730	0.0725	0.0728
Korea		0.1578	0.1449	0.1241	0.1216	0.1214	0.1158	0.1149	0.1173	0.1198	0.1212	0.1227	0.1178	0.1155	0.1100	0.1075
Mexico	0.1105	0.1115	0.1115	0.1095	0.1086	0.1073	0.1015	0.0967	0.0958	0.0915	0.0956	0.0949	0.0950	0.0911	0.0853	0.0886
Philippines	0.1402	0.1490	0.1423	0.1263	0.1368	0.1276	0.1146	0.1057	0.1140	0.0993	0.0941	0.0950	0.0996	0.0981	0.1019	0.1005
Thailand		0.1360	0.1283	0.1094	0.1069	0.1244	0.1170	0.1191	0.1076	0.1108	0.1121	0.1149	0.1175	0.1296	0.1233	0.1310
United States	0.1371	0.1344	0.1303	0.1174	0.1165	0.1030	0.1007	0.1022	0.0982	0.0981	0.0974	0.1056	0.1008	0.1059	0.1074	0.1147

Table 40 Electricity Intensity in the Cement Industry

toe/tonne of cement

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Australia	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.011	0.011	0.010	0.011	0.011	0.011	0.010	0.010
Canada	0.012	0.012	0.014	0.013	0.012	0.011	0.011	0.011	0.011	0.012	0.012	0.012	0.013	0.012	0.013	0.013
Chile	0.011	0.011	0.010	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
Japan		0.010	0.010	0.010	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
Korea		0.015	0.014	0.013	0.013	0.014	0.013	0.013	0.014	0.014	0.014	0.015	0.014	0.014	0.014	0.014
Mexico	0.011	0.012	0.012	0.011	0.011	0.011	0.009	0.009	0.011	0.010	0.009	0.011	0.011	0.011	0.011	0.011
Philippines	0.015	0.020	0.016	0.007	0.014	0.015	0.014	0.011	0.008	0.008	0.008	0.008	0.010	0.009	0.010	0.009
Thailand		0.012	0.013	0.012	0.012	0.013	0.013	0.012	0.013	0.012	0.012	0.013	0.009	0.011	0.012	0.013
United States	0.013	0.013	0.014	0.013	0.013	0.012	0.013	0.012	0.012	0.012	0.012	0.013	0.013	0.012	0.012	0.012

Table 41 Energy Intensity of the Cement Industry (excluding electricity)

toe/tonne of cement

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Australia	0.141	0.133	0.139	0.131	0.133	0.137	0.124	0.127	0.121	0.110	0.102	0.104	0.104	0.109	0.102	0.090
Canada	0.108	0.104	0.106	0.097	0.088	0.083	0.086	0.085	0.089	0.092	0.097	0.089	0.091	0.084	0.090	0.097
Chile	0.077	0.074	0.065	0.063	0.057	0.054	0.059	0.057	0.062	0.062	0.066	0.056	0.065	0.052	0.041	0.038
Japan		0.080	0.074	0.073	0.071	0.068	0.067	0.066	0.065	0.066	0.065	0.065	0.065	0.064	0.064	0.064
Korea		0.143	0.131	0.111	0.108	0.108	0.103	0.102	0.103	0.106	0.107	0.108	0.104	0.102	0.096	0.094
Mexico	0.099	0.100	0.100	0.098	0.097	0.096	0.092	0.087	0.085	0.082	0.086	0.084	0.084	0.080	0.074	0.078
Philippines	0.126	0.129	0.126	0.120	0.123	0.112	0.100	0.094	0.106	0.092	0.087	0.087	0.090	0.089	0.092	0.091
Thailand		0.124	0.116	0.097	0.095	0.112	0.104	0.107	0.094	0.098	0.100	0.102	0.109	0.119	0.111	0.118
United States	0.124	0.121	0.117	0.104	0.104	0.091	0.088	0.090	0.086	0.086	0.085	0.092	0.088	0.094	0.095	0.103

Table 42 Cement CO_2 Emissions

Thousand tonnes

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Australia	2,586	2,723	2,469	2,145	2,469	2,651	2,360	2,380	2,611	2,500	2,355	2,074	2,102	2,363	2,370	2,181
Canada	3,592	3,456	2,886	2,594	2,838	3,034	3,202	3,609	3,808	3,808	3,722	2,986	2,944	2,784	3,200	3,719
Chile	476	537	292	309	312	302	335	361	457	493	534	488	675	616	474	492
Japan		25,773	23,993	23,150	22,285	20,120	18,700	18,272	19,872	20,820	21,931	23,263	23,410	23,095	23,710	23,583
Korea		7,766	8,674	9,484	8,765	8,728	9,377	10,388	11,401	12,173	13,234	15,380	16,355	18,564	19,347	19,906
Mexico	531	587	630	558	602	676	645	389	565	340	587	504	752	663	593	562
Philippines	1,819	1,667	1,790	1,891	1,750	1,358	1,286	1,549	2,177	1,931	2,144	2,332	2,232	2,666	3,276	3,571
Thailand		2,412	2,478	2,259	2,425	2,862	2,779	3,580	3,850	5,278	6,271	6,661	8,341	11,028	12,456	14,525
United States	30,710	29,297	25,366	25,731	28,358	25,142	24,460	24,712	23,216	23,317	22,957	22,900	22,843	26,147	28,161	29,188
Total		74,218	68,579	68,122	69,803	64,872	63,144	65,241	67,957	70,660	73,734	76,588	79,654	87,928	93,587	97,728

Table 43 Cement Energy Saving Potentials

Per cent

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Australia	52.6	50.2	52.3	49.5	50.2	51.5	46.7	47.9	45.3	40.2	35.8	37.2	37.3	39.8	35.4	27.9
Canada	39.4	37.5	39.5	34.2	27.7	23.2	25.6	24.4	28.1	30.4	33.5	28.4	30.7	24.8	29.4	34.5
Japan		20.0	13.4	12.2	9.7	6.7	4.8	3.5	2.5	3.7	2.7	2.2	2.5	1.0	0.3	0.7
Korea		54.2	50.1	41.7	40.5	40.4	37.6	37.0	38.3	39.6	40.3	41.1	38.6	37.4	34.3	32.7
Mexico	34.6	35.1	35.1	34.0	33.4	32.6	28.8	25.2	24.5	21.0	24.3	23.8	23.9	20.6	15.2	18.3
Philippines	48.4	51.4	49.2	42.8	47.1	43.3	36.9	31.6	36.5	27.1	23.1	23.9	27.4	26.3	29.0	28.1
Thailand		46.8	43.6	33.9	32.3	41.8	38.2	39.3	32.8	34.7	35.5	37.1	38.5	44.2	41.3	44.8
United States	47.2	46.2	44.5	38.4	37.9	29.8	28.2	29.3	26.3	26.3	25.7	31.5	28.3	31.7	32.6	37.0

APPENDIX F

PULP AND PAPER PRODUCTION AND ENERGY CONSUMPTION DATA

Table 44 Pulp and Paper Production

Thousand tonnes

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Australia	2,184	2,056	2,201	2,069	2,387	2,430	2,692	2,642	2,905	3,015	3,040	3,035	3,049				
Canada	33,333	32,888	29,415	32,574	34,564	34,867	36,949	39,058	40,418	40,291	39,301	39,891	39,251	40,431			
Chile	988	1,062	973	1,129	1,220	1,222	1,242	1,305	1,364	1,283	1,267	1,599	2,189	2,392			
China	10,540	9,710	10,329	11,338	12,912	15,477	16,569	18,811	21,331	22,633	23,746	25,537	31,713	34,430	31,450		
Japan	27,876	25,592	26,080	27,302	28,472	29,748	30,302	32,270	35,039	37,796	39,414	40,797	39,510	38,359	39,097	40,779	41,202
Korea	702,214	716,980	716,138	777,544	181,847	1,321,793	1,246,108	1,707,561	1,882,878	1,981,304	2,195,844	2,389,301	2,561,065	2,891,362	3,503,383	3,708,170	1,802,463
Mexico	2,626	2,693	2,735	2,821	3,041	3,268	3,242	3,375	3,391	3,536	3,643	3,601	3,385	3,106			
New Zealand	1,502	1,561	1,763	1,744	1,756	1,915	1,781	1,752	1,913	1,994	2,121	2,146	2,014	2,204			
Philippines	505	479	360	442	432	311	375	454	454	500	593	597	595	618			
Chinese Taipei	1,756	1,848	1,849	2,020	2,254	2,368	2,921	3,153	3,374	3,479	3,748	4,140	4,262	4,088	4,138		
Thailand	418	418	392	398	369	482	482	760	780	930	1,036	1,158	1,403	1,618	1,915		
United States	102,861	103,706	98,720	106,510	112,549	110,265	116,033	121,560	124,856	125,904	128,733	129,955	133,248	133,626			
TOTAL	886,803	898,993	890,955	965,891	381,803	1,524,146	1,458,696	1,932,701	2,118,703	2,222,665	2,442,486	2,641,757	2,821,684	3,152,234	3,579,983	3,748,949	1,843,665

Source: APEC database

Table 45 Energy Consumption in the Pulp and Paper Industry

ktoe

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Australia																	
Coal	190	194	214	259	265	287	266	281	274	254	221	218	200	189	195	172	176
Petroleum	184	140	123	64	36	35	39	40	40	41	40	40	28	31	35	35	35
Electricity	219	225	264	265	270	280	293	312	322	351	342	349	354	372	366	367	370
Others	429	440	460	432	474	473	715	727	741	779	739	716	712	760	868	883	680
Total	1,022	998	1,060	1,020	1,045	1,076	1,313	1,359	1,377	1,426	1,343	1,324	1,294	1,351	1,464	1,457	1,262
Canada																	
Coal	212	141	196	167	162	144	79	65	71	84	94	82	45	44	46	84	48
Petroleum	3,305	2,966	2,696	2,253	2,101	1,846	1,923	1,853	1,794	2,180	2,048	1,942	1,673	1,619	1,475	1,335	1,401
Electricity	3,112	2,910	2,741	3,043	3,790	4,150	4,332	4,575	4,530	4,159	4,197	4,327	4,274	4,414	4,577	4,788	4,709
Others	7,261	6,839	6,680	7,369	7,431	8,011	8,263	8,706	8,731	8,596	8,364	8,748	9,037	9,044	10,131	10,924	9,437
Total	13,890	12,857	12,312	12,833	13,485	14,151	14,598	15,199	15,126	15,018	14,703	15,098	15,029	15,121	16,231	17,130	15,594
Chile																	
Coal	3	4	3	3	3	3	3	3	3	4	4	9	7	1	1	3	1
Petroleum	102	85	62	70	70	69	67	52	60	64	68	133	150	133	150	145	153
Electricity	76	73	69	83	87	88	88	80	96	91	104	133	179	183	182	204	215
Others	445	411	417	511	551	536	512	532	514	433	494	700	794	438	429	444	437
Total	626	573	551	666	711	696	669	667	674	591	670	975	1131	755	762	795	806
China																	
Coal	3,841	3,554	3,886	4,227	4,648	6,136	6,614	7,105	7,547	7,820	7,618	7,347	8,019	9,259	9,047	9,835	9,600
Petroleum	367	299	272	265	263	302	282	246	223	232	231	400	416	292	259	358	425
Electricity	484	499	533	585	613	696	775	882	951	984	1,030	1,093	1,202	1,381	1,469	1,722	1,700
Others	17	17	59	25	17	53	54	31	29	31	29	795	903	804	976	936	1,095
Total	4,708	4,368	4,749	5,102	5,540	7,186	7,724	8,264	8,751	9,067	8,908	9,633	10,540	11,736	11,752	12,852	12,819

Table 46 Energy Consumption in the Pulp and Paper Industry (cont)

ktoe

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Hong Kong, China																	
Coal																	
Petroleum																	
Electricity	9	10	10														
Others																	
Total	9	10	10														
Japan																	
Coal	90	202	249	390	422	472	568	796	906	1,014	1,089	1,010	984	1,008	1,141	1,307	1,289
Petroleum	2,302	1,946	2,969	2,756	2,705	2,519	2,509	2,729	3,204	3,108	2,870	2,453	2,298	2,558	2,628	2,695	2,781
Electricity	1,989	1,881	2,016	2,069	2,124	2,175	2,209	2,327	2,522	2,685	2,829	2,869	2,799	2,761	2,826	2,906	2,964
Others			2,116	2,154	2,278	2,332	2,222	2,286	2,364	2,483	2,569	2,913	3,024	2,950	2,880	3,004	3,072
Total	4,382	4,029	7,351	7,369	7,529	7,497	7,510	8,138	8,996	9,290	9,358	9,245	9,105	9,277	9,476	9,913	10,106
Korea																	
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Petroleum	0	343	325	352	414	414	400	432	497	642	777	857	984	1,071	1,191	1,215	1,320
Electricity	132	137	137	153	162	176	205	231	264	297	333	364	401	439	569	600	698
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	132	480	462	504	576	589	605	662	761	939	1,110	1,221	1,385	1,510	1,760	1,814	2,018
Mexico																	
Coal						0	0	0	0	0	0	0	0	0	0	0	0
Petroleum						553	560	580	580	673	801	498	486	475	490	447	618
Electricity						126	130	135	129	184	221	197	204	282	291	268	286
Others						431	399	413	395	417	341	427	582	454	470	435	460
Total						1,110	1,089	1,129	1,105	1,274	1,363	1,122	1,272	1,211	1,251	1,150	1,364

Table 47 Energy Consumption in the Pulp and Paper Industry (cont)

ktoe

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
New Zealand																	
Coal	41	41	38	56	50	48	46	35	35			0	0	0	0	0	0
Petroleum	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0
Electricity	0	0	0	0	0	0	0	0	0			184	208	222	134	114	125
Others	3	76	89	108	118	115	0	0	0			0	0	0	0	0	0
Total	45	117	127	164	168	163	46	35	35			184	208	222	134	114	125
Philippines																	
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Petroleum	204	110	192	196	144	119	129	157	164	180	182	173	176	193	229	275	272
Electricity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Others	3	76	89	108	118	115	0	0	0	0	0	0	0	0	0	0	0
Total	204	110	192	196	144	119	129	157	164	180	182	173	176	193	229	275	272
Russia																	
Coal											0	0	0	0	0	0	0
Petroleum											0	0	0	620	612	0	0
Electricity											1,714	1,609	1,483	0	0	1,656	1,608
Others											380	380	380	812	381	8,363	8,244
Total											2,094	1,989	1,863	1,432	993	10,019	9,852
Chinese Taipei																	
Coal	65	71	74	49	72	89	93	134	171	197	258	333	399	411	449	411	493
Petroleum	504	437	388	390	410	364	415	435	439	448	438	462	464	434	463	499	508
Electricity	131	133	136	141	152	159	183	200	217	218	220	230	218	208	219	225	215
Others																	13
Total	700	642	598	580	634	611	691	769	827	863	916	1,025	1,082	1,053	1,130	1,136	1,228

Table 48 Energy Consumption in the Pulp and Paper Industry (cont)

ktoe

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Thailand																	
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Petroleum	100	109	90	97	80	103	114	104	101	93	81	91	132	149	144	161	204
Electricity	0	0	0	0	0	0	28	47	52	59	68	72	84	55	95	108	104
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	100	109	90	97	80	103	142	151	153	152	149	163	216	205	238	269	308
United States																	
Coal	4,958	5,149	5,276	5,688	6,387	6,679	7,038	6,907	7,181	7,131	7,155	7,013	96	2,920	2,396	1,994	1,837
Petroleum	8,724	6,684	6,360													4,562	4,537
Electricity	5,103	5,375	5,989	6,282	8,727	8,643	8,829	9,158	9,539	9,655	10,858	11,074	11,060	11,205	11,490	12,179	11,982
Others	0	0	0	0	0	0	0	0	0	0	0	0	523	3,928	3,438	20,204	20,979
Total	18,786	17,208	17,625	11,971	15,114	15,322	15,866	16,065	16,720	16,786	18,013	18,087	11,680	18,053	17,325	38,939	39,335

Source: IEA database

Table 49 Total Energy Consumption in the Pulp and Paper Industry

ktoe

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Australia	1,022	998	1,060	1,020	1,045	1,076	1,313	1,359	1,377	1,426	1,343	1,324	1,294	1,351	1,464	1,457	1,262
Canada	13,890	12,857	12,312	12,833	13,485	14,151	14,598	15,199	15,126	15,018	14,703	15,098	15,029	15,121	16,231	17,130	15,594
Chile	626	573	551	666	711	696	669	667	674	591	670	975	1,131	755	762	795	806
China	4,708	4,368	4,749	5,102	5,540	7,186	7,724	8,264	8,751	9,067	8,908	9,633	10,540	11,736	11,752	12,852	12,819
Hong Kong, China	9	10	10														
Japan	4,382	4,029	7,351	7,369	7,529	7,497	7,510	8,138	8,996	9,290	9,358	9,245	9,105	9,277	9,476	9,913	10,106
Korea	132	480	462	504	576	589	605	662	761	939	1,110	1,221	1,385	1,510	1,760	1,814	2,018
Mexico	0	0	0	0	0	1,110	1,089	1,129	1,105	1,274	1,363	1,122	1,272	1,211	1,251	1,150	1,364
New Zealand	45	117	127	164	168	163	46	35	35			184	208	222	134	114	125
Philippines	204	110	192	196	144	119	129	157	164	180	182	173	176	193	229	275	272
Russia											2,094	1,989	1,863	1,432	993	10,019	9,852
Chinese Taipei	700	642	598	580	634	611	691	769	827	863	916	1,025	1,082	1,053	1,130	1,136	1,228
Thailand	100	109	90	97	80	103	142	151	153	152	149	163	216	205	238	269	308
United States	18,786	17,208	17,625	11,971	15,114	15,322	15,866	16,065	16,720	16,786	18,013	18,087	11,680	18,053	17,325	38,939	39,335
TOTAL	44,604	41,500	45,128	40,501	45,026	48,622	50,381	52,595	54,689	55,586	58,807	60,239	54,980	62,119	62,744	95,864	95,090

Table 50 Energy Source Mix in the Pulp and Paper Industry

ktoe

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Coal	9,402	9,357	9,935	10,839	12,010	13,856	14,707	15,325	16,189	16,505	16,440	16,011	9,751	13,832	13,275	13,806	13,443
Petroleum	15,792	13,118	13,478	6,442	6,223	6,323	6,438	6,629	7,103	7,660	7,535	7,048	6,807	7,574	7,676	11,728	12,255
Electricity	11,256	11,243	11,895	12,622	15,924	16,491	17,073	17,947	18,622	18,683	21,916	22,501	22,466	21,523	22,219	25,137	24,976
Others	8,155	7,782	9,820	10,599	10,869	11,951	12,164	12,694	12,775	12,738	12,916	14,679	15,956	19,190	19,573	45,193	44,416
TOTAL	44,605	41,500	45,128	40,502	45,026	48,621	50,382	52,595	54,689	55,586	58,807	60,239	54,980	62,119	62,743	95,864	95,090

Table 51 Energy Intensity of the Pulp and Paper Industry

toe/tonne

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Australia	0.47	0.49	0.48	0.49	0.44	0.44	0.49	0.51	0.47	0.47	0.44	0.44	0.42				
Canada	0.42	0.39	0.42	0.39	0.39	0.41	0.4	0.39	0.37	0.37	0.37	0.38	0.38	0.37			
Chile	0.63	0.54	0.57	0.59	0.58	0.57	0.54	0.51	0.49	0.46	0.53	0.61	0.52	0.32			
China	0.45	0.45	0.46	0.45	0.43	0.46	0.47	0.44	0.41	0.4	0.38	0.38	0.33	0.34	0.37		
Japan	0.16	0.16	0.28	0.27	0.26	0.25	0.25	0.25	0.26	0.25	0.24	0.23	0.23	0.24	0.24	0.24	0.25
Mexico						0.34	0.34	0.33	0.33	0.36	0.37	0.31	0.38	0.39			
New Zealand	0.03	0.07	0.07	0.09	0.10	0.09	0.03	0.02	0.02			0.09	0.10	0.10			
Philippines	0.4	0.23	0.53	0.44	0.33	0.38	0.34	0.35	0.36	0.36	0.31	0.29	0.3	0.31			
Chinese Taipei	0.4	0.35	0.32	0.29	0.28	0.26	0.24	0.24	0.25	0.25	0.24	0.25	0.25	0.26	0.27		
Thailand	0.24	0.26	0.23	0.24	0.22	0.21	0.29	0.2	0.2	0.16	0.14	0.14	0.15	0.13	0.12		
United States	0.18	0.17	0.18	0.11	0.13	0.14	0.14	0.13	0.13	0.13	0.14	0.14	0.09	0.14			

Table 52 Electricity Intensity of the Pulp and Paper Industry

toe/tonne

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Australia	0.10	0.11	0.12	0.13	0.11	0.12	0.11	0.12	0.11	0.12	0.11	0.11	0.12				
Canada	0.09	0.09	0.09	0.09	0.11	0.12	0.12	0.12	0.11	0.1	0.11	0.11	0.11	0.11			
Chile	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.07	0.07	0.08	0.08	0.08	0.08			
China	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.05		
Japan	0.07	0.07	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Mexico						0.04	0.04	0.04	0.04	0.05	0.06	0.05	0.06	0.09			
New Zealand												0.09	0.10	0.10			
Chinese Taipei	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05		
Thailand							0.06	0.06	0.07	0.06	0.07	0.06	0.06	0.03	0.05		
United States	0.05	0.05	0.06	0.06	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.08	0.08			

Table 53 Energy Intensity of the Pulp and Paper Industry (excluding electricity)

toe / tonne

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Australia	0.37	0.38	0.36	0.36	0.32	0.33	0.38	0.4	0.36	0.36	0.33	0.32	0.31				
Canada	0.32	0.3	0.33	0.3	0.28	0.29	0.28	0.27	0.26	0.27	0.27	0.27	0.27	0.26			
Chile	0.56	0.47	0.5	0.52	0.51	0.5	0.47	0.45	0.42	0.39	0.45	0.53	0.43	0.24			
China	0.40	0.40	0.41	0.40	0.38	0.42	0.42	0.39	0.37	0.36	0.33	0.33	0.29	0.30	0.33		
Japan	0.09	0.08	0.20	0.19	0.19	0.18	0.17	0.18	0.18	0.17	0.17	0.16	0.16	0.17	0.17	0.17	0.17
Mexico						0.30	0.30	0.29	0.29	0.31	0.31	0.26	0.32	0.30			
New Zealand	0.03	0.07	0.07	0.09	0.1	0.09	0.03	0.02	0.02			0.00	0.00	0.00			
Chinese Taipei	0.32	0.28	0.25	0.22	0.21	0.19	0.17	0.18	0.18	0.19	0.19	0.19	0.20	0.21	0.22		
Thailand	0.24	0.26	0.23	0.24	0.22	0.21	0.24	0.14	0.13	0.1	0.08	0.08	0.09	0.09	0.08		
United States	0.13	0.11	0.12	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.00	0.05			

Table 54 Pulp and Paper CO_2 Emissions (from Coal and Oil)

Thousand tonnes

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Australia	1,322	1,200	1,229	1,223	1,163	1,251	1,178	1,239	1,211	1,138	1,004	992	882	845	882	793	809
Canada	11,023	9,698	9,082	7,603	7,117	6,255	6,236	5,966	5,809	7,048	6,681	6,304	5,332	5,160	4,729	4,445	4,504
Chile	327	277	203	225	228	224	218	174	198	213	224	446	492	415	466	456	477
China	16,389	15,040	16,276	17,613	19,276	25,308	27,146	28,986	30,675	31,785	30,979	30,420	33,143	37,688	36,747	40,181	39,452
Hong Kong, China																	
Japan	7,450	6,796	10,137	10,038	10,010	9,633	9,987	11,568	13,467	13,601	13,169	11,568	10,988	11,885	12,629	13,496	13,688
Korea		1,057	1,000	1,083	1,274	1,274	1,232	1,329	1,531	1,978	2,392	2,639	3,031	3,298	3,668	3,742	4,065
Mexico						1,702	1,725	1,788	1,788	2,072	2,466	1,533	1,495	1,463	1,510	1,375	1,903
New Zealand	163	164	151	222	198	189	181	137	137								
Philippines	629	340	591	603	443	366	396	485	505	553	560	533	543	595	704	846	837
Russia														1,908	1,885		
Chinese Taipei	1,811	1,630	1,489	1,396	1,550	1,474	1,648	1,871	2,033	2,164	2,374	2,747	3,016	2,970	3,208	3,173	3,522
Thailand	308	335	279	299	246	317	350	321	312	285	250	279	407	460	442	497	629
United States	46,572	41,045	40,550	22,601	25,378	26,536	27,962	27,443	28,532	28,334	28,428	27,863		11,600	9,519	21,973	21,273
Grand Total	85,996	77,581	80,988	62,906	66,883	74,530	78,260	81,305	86,198	89,172	88,527	85,325	59,328	78,286	76,389	90,977	91,159

Table 55 Pulp and Paper Energy Savings Potentials

Per cent; 1986-94

	1986	1987	1988	1989	1990	1991	1992	1993	1994
USA	-51.893	-57.313	-55.232	-55.855	-49.027	-49.357	-136.888	-54.220	
Canada	57.023	56.714	55.308	55.500	55.371	55.634	56.115	54.149	
Japan	22.428	23.777	24.791	21.504	18.394	14.090	15.105	19.163	18.943
Australia	66.964	68.216	65.511	66.892	64.749	63.219	62.179		
China	69.832	68.046	65.203	64.219	61.834	62.276	58.064	59.159	62.144
Mexico	49.261	48.988	48.951	53.775	55.594	46.321	54.651	57.243	
Thailand	45.110	19.032	17.735	-2.443	-8.827	-11.865	-3.232	-29.692	-35.944