國立交通大學

經營管理研究所

博 士 論 文

No.114

APEC 經濟體之總要素環境能源效率

Total-Factor Environmental-Energy Efficiency of APEC Economies

研 究 生：高志宏

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國 立 交 通 大 學
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中文摘要

能源係人類生活中的重要元素。隨著經濟的持續發展，能源消耗亦大量增加，但能源卻有其供給上限。同時，能源的生產及消費所產生的廢氣對環境產生極大的衝擊。因此，使用能源以促進經濟發展，並兼顧環境保護的議題日漸重要，並為能源政策中重要的一環。在新燃料及替代能源具可行性及經濟性以前，為維持經濟發展需要，在制定環境能源政策上，提昇能源效率及降低二氧化碳(CO_2)排放量成為兩大主軸。尤其是發展中及工業化國家，更注重這兩方面的議題。

過去能源學者如Patterson (1996)及Wilson et al. (1994)曾建議能源效率應以總要素概念進行衡量，但過去文獻仍均採用部分要素指標進行環境能源效率之衡量及比較。本文嘗試使用資料包絡分析法，建構總要素資源投入減量指標，再發展出總要素環境能源指標，以探討環境能源政策中，有關節能效率及CO_2減量議題，並以APEC經濟體為例進行探討。透過建構出的總要素環境能源指標與實際投入量的比較，分別就能源及CO_2，以分析各經濟體的節能目標及CO_2減量目標。本文亦就環境能源效率與經濟發展及產業結構之關聯進行分析，同時審

視APEC中主要經濟體的能源效率政策，以提供各經濟體於制定提昇能源效率及降低CO_2排放量的環境能源政策上的政策建議及方案構想。

本研究分析 1991 年至 2000 年間亞太經濟合作(APEC)中 17 個經濟體的環境能源效率。名目變數均已轉換為以 1995 年為基準年的購買力(PPP)實質變數。本研究主要發現如下：(1)中國的環境能源效率最低，並在能源消耗及CO_2減量上，具有最大可減少量及比率（約 50%）。(2)香港、菲律賓及美國是APEC中最具有環境能源效率的三個經濟體，可為其他經濟體在環境能源政策上仿傚及學習的標竿。(3)APEC經濟體的總體及個別環境經濟效率都在逐年提昇中。(4)人均節能目標與人均GDP間有倒U型的關係存在。(5)人均 CO_2減量目標與人均GDP間存有環境顧志耐曲線的關係。(6)環境能源效率與服務業對GDP的貢獻比重呈正相關。工業對GDP的貢獻比重愈高，能源使用效率愈差。

發展中及新興工業國家不僅可持續投入資源以維持經濟發展，更可透過節能及CO_2減量以兼顧永續發展。經由本文的研究分析，無效率的APEC經濟體在制定政策計畫時，可向有效率的經濟體已施行的政策經驗借鏡，且不會妨礙國家的經濟發展。透過APEC的跨國際合作，可減少成本並增加新政策成功的機會。

關鍵詞： 資料包絡分析法、環境能源政策、總要素能源效率、總要素節能目標、總要素二氧化碳減量目標、產業結構

Total-Factor Environmental-Energy Efficiency of APEC Economies

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ABSTRACT

Energy is one of the most important basic elements for human's living from time immemorial. Perto-fossil fuels are limited while energy consumption and economic development are unconstrained. Meanwhile, energy production and consumption have undesirable environmental repercussions. The effects of economic growth using energy on natural and environmental resources have become a central question with the rising concern over environmental protection. Before new and alternative fuels become available, improving energy efficiency and reducing CO_2 emissions are two necessities for an economy to design national environmental-energy policy while remaining its economic development possibilities.

Although some energy scholars, such as Patterson (1996) and Wilson et al. (1994), suggested using total factor indicator to evaluate energy efficiency, the existing literature all uses partial-factor indicators to analyze environmental-energy efficiency. This study tries to use the data envelopment analysis (DEA) approach for constructing a total-factor framework which is then applied to study APEC economies. Input-reducing targets are extracted from the total-factor framework. Environmental-energy efficiency indicators are also derived from the same total-factor framework. The potential energy savings and CO_2 abatement also result from the environmental-energy efficiency indicators. This study also overview the energy efficiency polices in selected APEC economies for providing policy and program ideas for reducing consumption and emission growth.

Seventeen APEC economies during 1991 to 2000 are analyzed. All nominal variables are transformed into real variables by the purchasing power parity (PPP) at the 1995 price level. The DEA approach is used to construct environmental-energy efficiency indicators for APEC economies without reducing their maximum potential gross domestic productions (GDPs) in each year. The production function with inputs including labor and capital as well as energy and CO_2, respectively, is analyzed, while GDP is the single output. The major findings are as follows: (1) China has the worst environmental-energy efficiency and has the largest potential energy savings and CO_2 abatement almost half of its current amount. (2) Hong Kong, the Philippines, and the United States have the highest environmental-energy efficiency. (3) The environmental-energy efficiency generally increases for APEC economies. (4) An inverted U-shape relation exists between per capita potential energy savings and per capita GDP. (5) An Environmental Kuznets Curve (EKC) relation exists between per capita CO_2 abatement target and per capita GDP. (6) The higher value-added percentage of GDP by the service sector has more efficient environmental-energy efficiency. The higher value-added percentage of GDP by the industry sector has more inefficient energy consumption.

Keywords: Data envelopment analysis (DEA), Environmental-energy policy, Total-factor energy-saving target (EST), Total-factor energy-saving target ratio (ESTR), Total-factor CO_2 abatement target (CAT), Industrial structure

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回顧四年，一路走來，有掙扎，有自責，有痛苦，但也有歡笑，然至這一切都不比上此刻的心情如此深刻，也許這正反映著這所有學習過程中的一切情緒。

今日得償獲得博士學位，首要感謝胡均立老師於就學及論文寫作期間給予的指導及協助，他亦師亦友的教學態度及溫文謙和的處事態度，讓我印象深刻。從他身上學習到的，不僅止於學問上的知識，更包括了論文的寫作能力及對待自己成品的嚴謹態度，也讓我看到身為人師的典範及立身於社會的責任及勇氣。

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拿到博士學位，並不是一個結束，而是一個新的開始：開始一個新的人生歷程及處習態度。

高志宏　謹致

中華民國 95 年 8 月 8 日

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List of Abbreviations

CAT	CO_2 abatement target
CATR	CO_2 abatement target ratio
CO_2	Carbon dioxide
CRS	Constant returns to scale
DEA	Data envelopment analysis
EKC	Environmental Kuznets curve
EST	Energy-saving target
ESTR	Energy-saving target ratio
GDP	Gross domestic product
GHG	Greenhouse gases
IRT	Input-reducing target
IRTR	Input-reducing target ratio
Mt-C	Millions tons of carbon
Mtoe	Millions of tons of oil equivalent
OECD	Organization for Economic Cooperation and Development
OTE	Overall technical efficiency
PTE	Pure technical efficiency
SE	Scale efficiency
t-C	Tons of carbon
TFCE	Total-factor CO_2 abatement efficiency
TFEE	Total-factor energy efficiency
TFIE	Total-factor input efficiency
toe	Tons of oil equivalent
VRS	Variable returns to scale

Chapter 1 Introduction

1.1 Research motivation

Energy is one of the most important basic elements for human's living from time immemorial. In the last two centuries, thanks to scientific progress, the energy constraint has progressively loosened to improve greatly the energy efficiency from petro-fossil fuels including coal, oil, and gas. The revolution has sparked unprecedented economic development. However, perto-fossil fuels are limited while energy consumption and economic development are unconstrained. Meanwhile, energy production and consumption have undeniable environmental repercussions. The effects of economic growth using energy on natural and environmental resources have become a central question with the rising concern over environment preservation. "Sustainable development" becomes an important policy target for every country. Ever since the Kyoto Protocol became effective in February 2005, the production and consumption of fossil fuels has been a focal point of energy policy in many economies including developed and developing ones. The energy system plays a central role in the interrelated economic, social, and environmental aims of sustainable human development (WCED, 1987).

For achieving sustainable development, energy policy relies on three main aspects (Jean-Baptiste and Ducroux, 2003):

1. Energy conservation: improved energy efficiency and energy saving.
2. Carbon waste management: reducing the emissions of greenhouse gases (GHG).
3. Evolution of the energy mix: replacement of high carbon fuels (coal, oil) by lower carbon content hydrogenated fuels (natural gas), and greater reliance on non-carbon dioxide (non-CO_2) emitting energies like hydropower, nuclear, wind, biomass, and solar.

Before new and substitute fuels become available, improving energy saving and reducing CO_2 emissions are two musts in order to make economic growth possible and achieve sustainable development. Despite the continuing policy interest and the very many reports and books written on the topic of targets on saving energy saving and reducing CO_2 emissions, little attention has been given to set the "real" target considering the effects of complements or substitutes with other factors.

The commonly used indicator of energy inefficiency is the energy intensity as a direct ratio of the energy input to GDP. However, there has been widespread criticism of using energy intensity for measuring energy efficiency (Patterson, 1996). Energy is the prime source of value, because other factors of production such as labor and capital cannot do without energy (Ghali and El-Sakka, 2004). The use of the energy (in)efficiency indicator in conjunction with labor and capital can provide useful insights into whether or not energy inputs act as complements or substitutes to other inputs (Patterson, 1996). At the same situation, according to the Kyoto Protocol, the targets to reduce GHG emissions are the certain percent from 1990 level. Those targets result from negotiation and compromise instead of a rational model or a scientific approach. Many people worry that the extremely reducing emissions will limit economic growth.

Given the limited availability of economically viable alternative energy sources, reducing total domestic energy use and total CO_2 emissions without reducing economic growth is important issues for economies all over the world. Considering environmental-energy policies, energy saving target (EST) and CO_2 abatement target (CAT) are hence important for all economies. Therefore, effective and rational indicators of EST and CAT resulting from a scientific model considering other factors should be further studied. According to these indicators, energy policy makers can measure and evaluate the real energy efficiency and CO_2 intensity and really coordinate the development of energy, environment, and economy for economies.

Asia-Pacific Economic Cooperation (APEC) economies include the fastest economies in the world and have attracted the most foreign capital, technology, as well as managerial know-how during the past 20 years. Fast-developing economies definitely add pressure to petro-fossil fuels' depletion and CO_2 abatement. In the period from 1980 to 2000, primary energy supply average 2.2% growth per annum, in contrast with 3.5% growth in real GDP over the same period. CO_2 emissions from fuel combustion grew by 2.0% per annum from 1992 to 2000 (APEC, 2002). Growth in energy consumption, particularly in industrializing Asia, is being driven by rising incomes and higher standards of living. Income and energy use levels in economies such as China and Indonesia are still very low compared to the APEC average. Therefore, energy consumption growth in Asia, excluding Japan, will continue at a brisk pace for many years to come. In recent years, APEC has been promoting energy efficiency as a way of reducing or minimizing energy consumption without sacrificing quality of life in the Asia-Pacific region (APERC, 2001). Therefore, finding efficient ESTs and CATs s without reducing the potential maximum economic outputs has become a very important issue for APEC economies.

1.2 Research purpose

The main interest of this study is to address the issues related to the analysis of energy efficiency and CO_2 intensity and the potential application and strengths of DEA in assessing the targets of energy saving and CO_2 abatement for APEC economies. This study can provide additional suggestions for energy and environment policies of APEC economies.

The first purpose of this study is to establish a common methodology for constructing input-reducing efficiency indicators based on DEA approach to analyze APEC economies. Through the DEA model, we can provide the relative comparison base for the input usage efficiencies of APEC economies considering different inputs. The result can provide the real 'best practices' among APEC economies.

The second purpose is to construct environmental-energy efficiency indicators for the whole economy of APEC member economies based in the above methodology. Through the results of DEA, we can construct total-factor environmental-energy efficiency indicators of APEC economies. The environmental-energy efficiency indicators are more efficient than the traditional partial-factor indicators.

The third purpose develops economic energy savings and CO_2 abatement potentials in APEC economies for environmental-energy policies. We can calculate the EST from the results of DEA for every APEC economy. The EST can present the possible energy savings without reducing the maximum potential economic outputs and provide some suggestions about the energy policy for APEC economies, and CAT means the target of CO_2 abatement without reducing real economic growth.

The forth purpose is to identify and produce an overview of successful energy efficiency policies and programs in APEC economies. According the best practice, EST, and CAT resulted from DEA approach, the policy-makers in the inefficient APEC economy can learn and transfer the experts and technologies from efficient economies to improve environmental-energy efficiency.

The fifth purpose concerns the relation among environmental-energy efficiency, income level, and industry structure. Environmental-energy efficiency is influenced by industrialization and economic income level. This study use panel data approach to analyze the environmental-energy efficiency to compare with income level and the industry structure, respectively. The results will provide policy suggestions for the policy-makers of APEC economies to evaluate and identify their policies and programs according their income level, and to improve their environmental-energy efficiency by adjusting their industry structure.

1.3 Organization of the dissertation

This dissertation is organized as follows and shown as Figure 1: Chapter 1 presents the motives and purposes of the study, and introduces the structure of this study. Chapter 2 discusses the issues of environmental-energy policies among APEC economies and prior literatures related this study. Chapter 3 proposes a research design that includes the explanation how to construct the total-factor model based on DEA to construct the input-reducing efficiency. Environmental-energy efficiency indicators, including EST and CAT, are then calculated. Summary statistics of the empirical data also are shown in this chapter. Chapter 4 presents and discusses the empirical results. Finally, Chapter 5 concludes this dissertation.

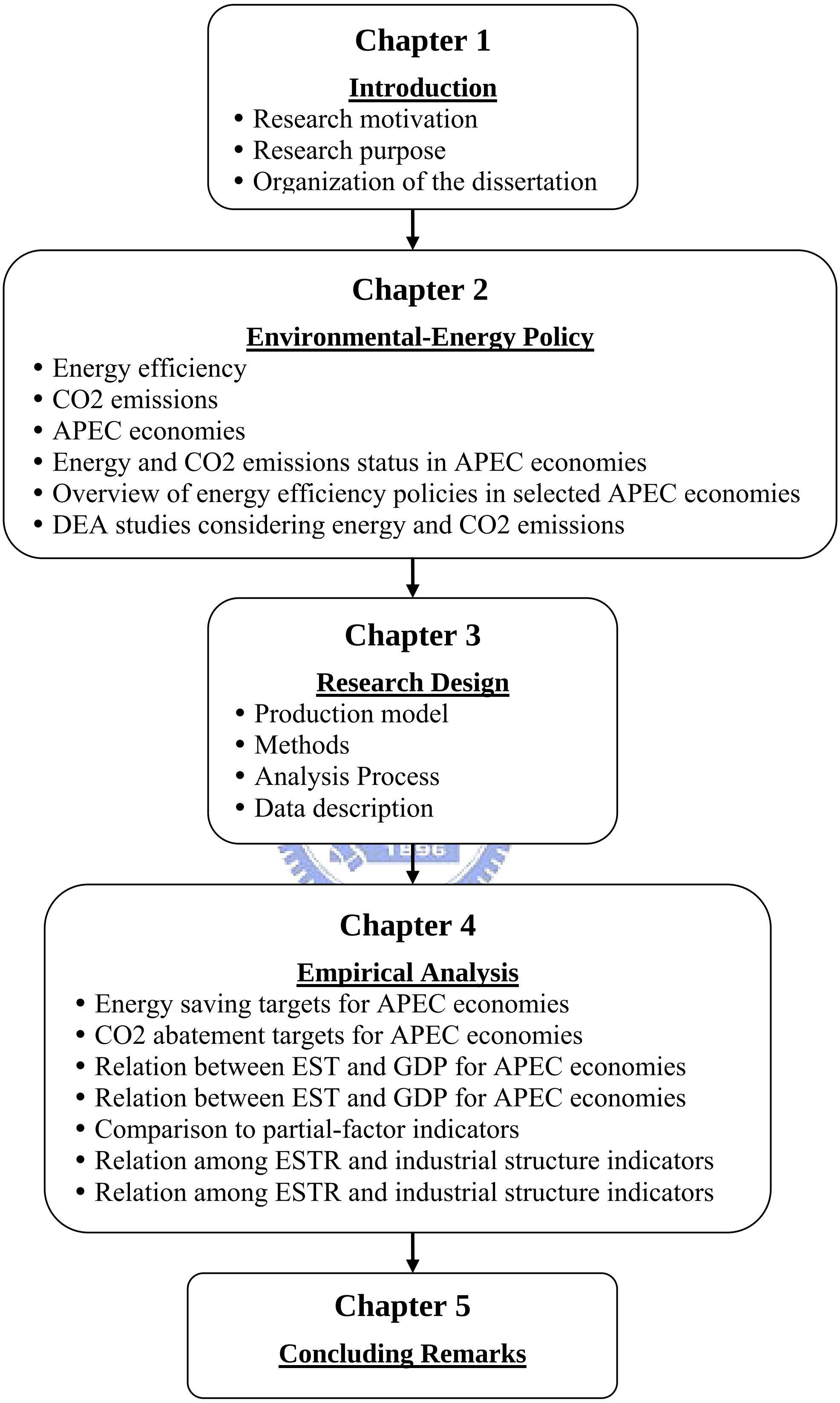


Figure 1 Research flow chart

Chapter 2 Environmental-Energy Policy

In recent decades, the concerns of environmental pollution and natural resource consumption have become more important in parallel to rapid world economic growth. Energy is required in all production process and fossil fuels have been a key energy carrier since the Industrial Revolution. Combustion of fossil fuels causes emissions of CO_2, a substance that is associated with global warming (Lindmark, 2004). There are existed several possibilities to reduce the CO_2 emissions of an economy, the most habitual ones from macroeconomic perspective being: (i) reduction of economic output (GDP), (ii) reduction of the energy intensity of the economic production or (iii) reduction of the CO_2 intensity of the energy production (Kaivo-oja and Luukkanen, 2004). The first option is usually not interesting for the policymakers. So the key question in this study is how energy efficiency can be developed and how many CO_2 emissions can be reduced without reducing economic output.

2.1 Energy efficiency

Worldwide energy consumption has risen 30% in the last 25 years. Industrialized economies consume about four times more than the world average. As economic growth is being pursued in economies such as China, India, and Brazil, the energy consumption is expected to increase further (Lopes et al., 2005). Fast-developing economies and fast-growing energy consumption definitely add pressure to petro-fossil fuels' depletion. Meanwhile, energy is a key issue in the considerations of the World Summit on Sustainable Development and the Johannesburg Summit 2002 brochure notes that: "Governments, business and communities need to improve energy efficiency while expanding access to energy sources around the world. Most importantly, the energy sources employed in all regions must be economically viable, socially acceptable and environmentally sound."

Given the limited availability of economically viable alternative energy sources, reducing total domestic energy use without reducing economic growth is an important issue for economies all over the world (de Nooij et al., 2003). Therefore, before new and substitute fuels become available, improving energy efficiency and energy saving is a must in order to make economic growth possible. However, many people worry that drastic savings in energy will hamper economic growth. Therefore, finding efficient energy saving target (EST) without reducing the potential maximum economic growth has become a very important issue.

Ever since the Kyoto Protocol became effective in February 2005, reducing the consumption of fossil fuels has been a focal point of environmental policy in many economies including developed and developing ones (de Nooij et al., 2003). The energy system plays a central role in the interrelated economic, social, and environmental aims of sustainable human development (WCED, 1987). Energy issues must be integrated with environmental management to achieve sustainable development, especially for fast-developing economies. Energy efficiency improvement is the key to sustainable energy management. For example, European Union estimates that realizing 10% to 20% of efficiency potential in the European use of electricity would save 10 to 20 billion European Currency Unit (ECU) annually in term of fossil fuels use. In Malaysia, it is expected that aggressive deployment of energy efficiency could save about US$1.38 billion by 2015 (Keong, 2005). The economic energy efficiency potentials of various industries range from 2% to 18% in the United States in 2010, 5% to 40% in China in 2010, and 2.2% to 28.5% in Thailand 2005 (WEC et al., 2000). Hu and Wang (forthcoming) also indicate that China can improve its energy efficiency in various regions without reducing its potential economic growth. These studies also show that developing economies have more energy efficiency potentials than developed ones.

Patterson (1996) indicates that the importance of energy efficiency as a policy objective is linked to commercial, industrial competitiveness and energy security benefits, as well as increasingly to environmental benefits such as reducing CO_2 emissions. Energy efficiency is a generic term, and there is no one unequivocal quantitative measure of ‘energy efficiency’. In general, energy efficiency refers to using less energy to produce the same amount of services or useful outputs. On the other hand, since energy consumption is responsible for roughly 90% of CO_2 emissions, energy efficiency indicators can also be used for environmental monitoring. 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. Energy efficiency improvements are an important tool for mitigating GHG emissions (APERC, 2001).

2.2 CO_2 emissions

Energy consumption in economic sectors is directly linked with CO_2 emissions. Expanding economic activities impose the greenhouse effect at local and global levels. However, the relation between economic growth and environmental degradation has been widely debated since the late 1960s (Lindmark, 2004). One line of argumentation has stressed that economic growth leads to degradation of the environment, a view that was brought forward in the Limits to Growth study (Meadows et al., 1972, 1992). As a reaction to these conclusions, economists have argued in favor of growth as a precondition for an improved environment (for instance, Beckerman, 1975).

Since the 1992 Rio summit, a new clean production paradigm, defined by environmental programs of the United Nations and Organization for Economic Cooperation and Development (OECD), is becoming widespread. This new paradigm augments the old reactive one, based on assimilation capacity, critical loads, and control – end of the pipe – solutions, taking into account new principles that add an additional parameter to the production/consumption system: the explicit consideration of environmental protection at all stages. This new clean production strategies approach is based on the principles of precaution, prevention, and integration, i.e. the effects of hazard displacement (Hirschhorn et al., 1993). The principle of prevention states that future technology developments should reduce potential pollution emissions and thus, the risk of environmental damage at source (Zofío and Prieto, 2001).

The issue of global warming is becoming a major and unavoidable element of world energy policy. The United Nations Convention on Climate Change marked the first step towards an international determination to limit releases of GHG. In December 1997, 39 developed economies signed the Kyoto Protocol to curb the emissions of GHG including CO_2, methane, nitrous oxide, hydro-fluorocarbons, per-fluorocarbons, and sulphur hexafluoride. The largest contributor to the greenhouse effect is CO_2 emissions. In 1995, it accounted for about 82% of total GHG emissions from developed economies whereas methane was 12% and nitrous oxide about 4% (UNEP, 1999). The emissions of the other three remaining gases are less than 2%. Therefore, reducing CO_2 emissions has been a focal point of energy and environmental policy in many economies. As rising atmospheric concern about global warming and dependence on fossil fuels grows, the search for reducing carbon dioxide emissions becomes a matter of widespread attention.

Considering the present 85% share of the world energy supplied by fossil fuels, and knowing the time needed for new energy systems to penetrate to their market potential, capturing and sequestering CO_2 appears as an efficient response to the CO_2 problem. Moreover, in the long term, CO_2 sequestration will allow us to keep on exploiting the large coal and natural gas reserves that represents a substantial share of the world available energy sources (Jean-Baptiste and Ducroux, 2003).

Although there was general agreement about the need to control emissions, lots of problems arise when fixing reduction commitments. The main problem is to establish the targets of emissions limitations for different economies. While rich economies fear the dangers to economic growth of limiting their emissions, poor economies argue the great inequality in the distribution of CO_2 emissions across economies in current and past emissions for not limiting their development possibilities with mitigation policies. The different relative responsibilities of the inhabitants of different economies and groups of economies and the problems generated by this inequality constitute fundamental features to be taken into account in the negotiations among economies on the actions for mitigating the emissions of GHG.

As the consideration of economic growth and climate policy, the USA proposal was to establish heterogeneous targets of emissions limitations while the EU proposal was to establish as large a homogeneous reduction as possible at least for the USA, Japan, and the EU for the Kyoto Protocol (Bengochea-Morancho et al., 2001). Finally, the Kyoto Protocol (1997) set a specific timetable for each economy under the Convention on Climate Change, with a view to reducing their overall emissions of such gases by at least 5 percent below 1990 levels in the commitment period 2008 to 2012. The European Union, United States, Canada, and Japan could reduce their emissions relative to 1990 levels by 8%, 7%, 6%, and 6%, respectively. Only three economies (Island, Australia, and Norway) are allowed to increase their emissions relative to 1990 levels by 10%, 8%, and 1%, respectively. Russia, Ukraine, and New Zealand may keep their emissions at the 1990 level. The rest of the industrialized economies are required to reduce their emissions 6% to 8% from 1990 levels in the 2008 to 2012 period. Especially, the developing economies were not given any specific reduction commitments in the Kyoto Protocol.

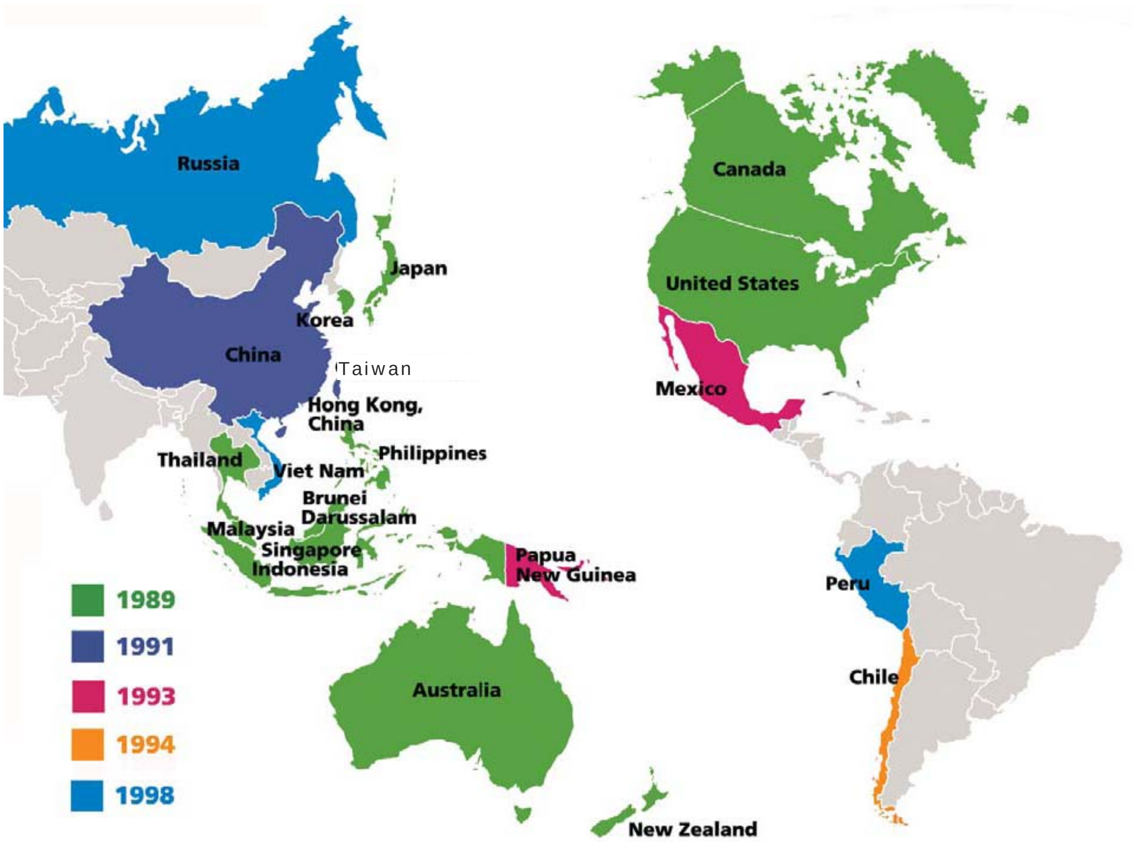
However, the reduction is compared to the levels of 1990, which is the base year for the Kyoto Protocol, during the first commitment period 2008 to 2012. The targets somewhat come from negotiation and compromise. The targets might mislead the country's policy and limit the economic growth and the ability of competition. That maybe is the reason that the USA do not want to ratify the Protocol until some of the lesser-developed economies (particularly China, India, and Brazil) agree to curb their emissions.

The inequality in the distribution of CO_2 emissions across economies is one of the most relevant issues for the design of global climate policies. While rich economies fear the dangers to economic growth of limiting their emissions, poor economies argue the great inequality in current and past emissions for not limiting their development possibilities with mitigation policies. The different relative responsibilities of the inhabitants of different economies and groups of economies and the problems generated by this inequality constitute fundamental features to be taken into account in the negotiations among economies on the actions for mitigating the emissions of GHG.

2.3 APEC economies

Asia-Pacific Economic Cooperation (APEC) was established in 1989 to further enhance economic growth and prosperity for the region and to strengthen the Asia-Pacific community. APEC is the premier forum for facilitating economic growth, cooperation, trade and investment in the Asia-Pacific region. APEC is the only inter governmental grouping in the world operating on the basis of non-binding commitments, open dialogue and equal respect for the views of all participants. Unlike the WTO or other multilateral trade bodies, APEC has no treaty obligations required of its participants. Decisions made within APEC are reached by consensus and commitments are undertaken on a voluntary basis. APEC has 21 members - referred to as 'member economies' - which account for approximately 40% of the world's population, approximately 56% of world GDP and about 48% of world trade. It also proudly represents the most economically dynamic region in the world having generated nearly 70% of global economic growth in its first 10 years.

APEC's 21 member economies as seen in Figure 2 are: Australia, Brunei Darussalam, Canada, Chile, People's Republic of China, Hong Kong, China, Indonesia, Japan, Republic of Korea, Malaysia, Mexico, New Zealand, Papua New Guinea, Peru, The Republic of the Philippines, The Russian Federation, Singapore, Taiwan, Thailand, United States of America, and Viet Nam.



Note: (1) The color represents the participation year of the economy. (2) Source: APEC Secretariat, 2005.

Figure 2 APEC member economies

APEC member economies work together in order to sustain this economic growth through a commitment to open trade, investment, and economic reform. By progressively reducing tariffs and other barriers to trade, APEC member economies have become more efficient and exports have expanded dramatically. A highlight of APEC's achievements in the first 10 years:

- Exports increased by 113% to over US$2.5 trillion.
- Foreign direct investment grew by 210% overall, and by 475% in lower income APEC economies.
- Real gross national product grew by about a third overall, and by 74% in lower income APEC economies.
- Gross domestic product per person in lower income APEC economies grew by 61%.

APEC works in three broad areas to meet the Bogor Goals of free and open trade and investment in the Asia-Pacific by 2010 for developed economies and 2020 for developing economies. Known as APEC's ‘Three Pillars,” APEC focuses on three key areas:

- Trade and Investment Liberalization
- Business Facilitation
- Economic and Technical Cooperation

APEC operates as a cooperative, multilateral economic and trade forum. Member economies take individual and collective actions to open their markets and promote economic growth. These actions are discussed at a series of meetings of Senior Officials, Ministers and finally, by the Leaders of APEC's 21 Member economies. APEC policy direction is provided by the 21 APEC Economic Leaders. Strategic recommendations, provided by APEC Ministers and the APEC Business Advisory Council are considered by APEC Economic Leaders as part of this process. APEC structure is shown in Figure 3.

The Energy Working Group (EWG) is one of 11 Working Groups operating under the APEC umbrella, bringing together twenty-one economies from the APEC region who currently account for around 60% of world energy demand. EWG, launched in 1990, seeks to maximize the energy sector's contribution to the region's economic and social well-being, while mitigating the environmental effects of energy supply and use. The EWG provides a multilateral forum for member economies to cooperate on energy-related issues. The APEC region overall is a net energy importer. Energy imports to APEC economies are projected to increase by approximately 92%, as indigenous (or ‘within economy’) supply fails to keep pace with expanding energy demand driven by economic growth, industrialization and urbanization (APEC, 2006).

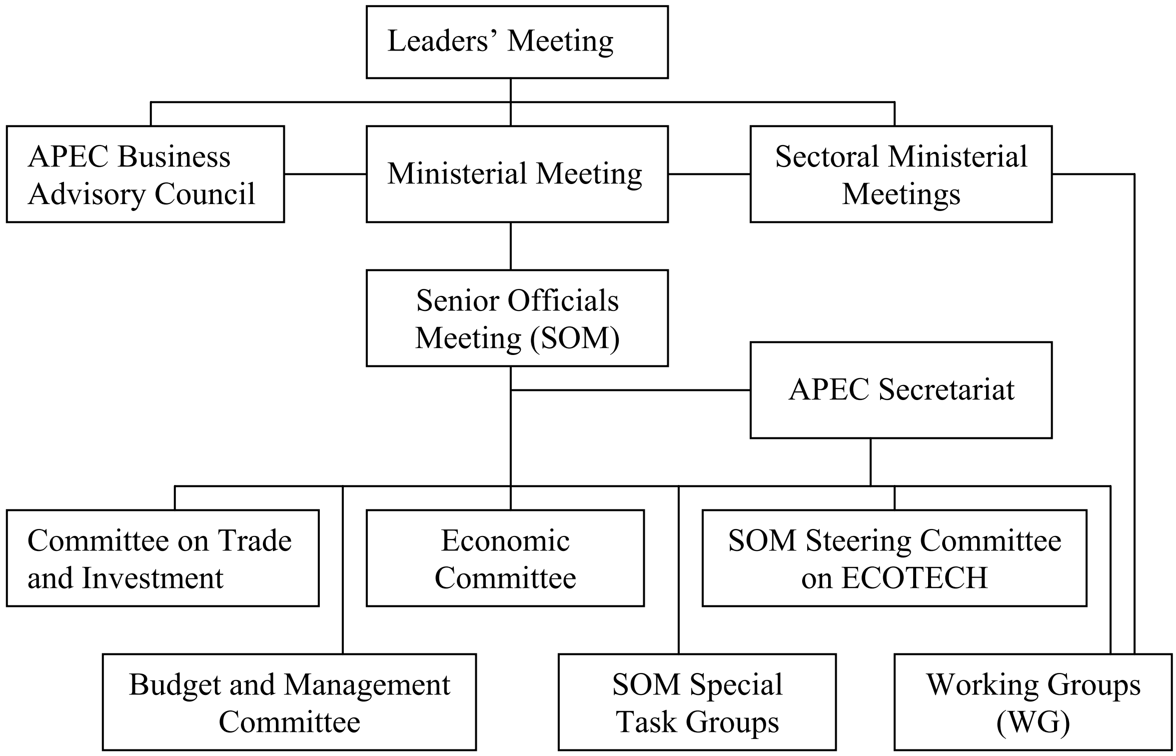


Figure 3 Organizational structure of APEC

The major EWG initiatives relate to energy security and energy for sustainable development. With respect to sustainable development, 'Energy for Sustainable Development: The Contribution and Role of the APEC Energy Working Group' as a Type 2 Partnership Initiative is agreed by APEC Energy Ministers at their 6th meeting. The Initiative demonstrated to a global audience how voluntary regional partnerships can be effectively utilized to achieve sustainable development objectives. Energy for Sustainable Development highlights the four main elements of the EWG's approach to furthering sustainable development objectives:

- Strengthening the security and reliability of affordable energy to all within our APEC community;
- Promoting clean and efficient technologies, and the efficient use of energy to achieve both economic gains and environmental enhancement;
- Achieving environmental improvement of energy production, use and mineral extraction within our APEC community, and

- Harnessing all expertise available to the EWG to give effect to the above objectives.

Improving energy efficiency and CO_2 abatement is the key target for APEC economies to work together and share the knowledge and technology.

2.4 Energy consumption and CO_2 emissions status in APEC economies

The causes of rapid Asian economic growth and its sustainability have generated considerable debates since the early 1990s (e.g., World Bank, 1993; Krugman, 1994; Kim and Lau, 1994, 1995; Young, 1994, 1995; Chen, 1997; Drysdale and Huang, 1997; Krüger et al., 2000; Chang and Luh, 2000; Iwami, 2004). Many economies have adopted environmental-energy policies and measures, but systematic information is only available for OECD economies. There is hence a significant need to improve environmental-energy policy collaboration among APEC economies and disseminate successful practices.

Asia-Pacific Economic Cooperation (APEC) economies include the fastest economies in the world and have attracted the most foreign capital, technology, as well as managerial know-how during the past 20 years. Fast-developing economies definitely add pressure to petro-fossil fuels' depletion and CO_2 abatement. According to the statistics from APEC (2002), the level of primary energy supply in 2000 of 4,665 Mtoe was a rebound after the third year of a financial and economic crisis in Asia, which saw primary energy supply declining in 1998 for the first time in 17 years. In the period from 1980 to 2000, primary energy supply averaged 2.2% growth per annum, in contrast with 3.5% growth in real GDP over the same period. As a result, elasticity of demand was calculated at 0.63 for this period. For the period 1980 to 2000, coal supply rose by and average of 2.4% per annum to reach 1,278Mtoe in 2000. Oil supply rose by an average of 1.4% per annum to reach 1,894 Mtoe in 2000. Gas supply increased 2.0% per annum to reach 893 Mtoe. The supply of hydro, nuclear, etc. grew by 5.2% per annum to reach 479 Mtoe.

Final energy consumption in the APEC region grew by 1.7% per annum from 2,386 Mtoe in 1980 to 3,335 Mtoe in 2000. This growth rate for 20 years was lower than that of primary energy supply. It indicates that net energy consumption growth in the transformation sector surpassed the final energy consumption sector. In terms of changes in final energy consumption by sector, though the consumption in the industrial sector grew slowly (1.1% from 1980 to 2000), the total of 1,339 Mtoe was the largest for all sectors in 2000. The industry sector share of the total was 40.1%, the transportation sector share 30.1%, and the residential/commercial sector share 24.5% in 2000. By energy source, oil supply grew by 1.7% per annum from 1,210 Mtoe in 1980 to 1,685 Mtoe in 2000. Electricity supply with 624 Mtoe in 2000 marks the eighteenth straight year of increase from 1982. Coal supply dropped to 361 Mtoe in 2000, the fourth year in a row of decline.

Developing economies with high demand growth are contributing significantly to increases in CO_2 emissions, and use of energy is a major source of CO_2 emissions in most of APEC economies. CO_2 emissions in the APEC region from fuel combustion grew by 2.0% per annum from 2,874 Mt-C in 1992 to 3,362 Mt-C in 2000. As a result, CO_2 emissions per total primary energy supply, per real GDP, and per population became 0.72 t-C/toe, 173.5 t-C/US Million-dollar (in 1995 price), and 1.46 t-C/person in 2000 respectively.

Currently, specialized journals, technological fairs, multi-nationals' global marketing strategies, etc. guarantee that new innovations are readily available to all economies (Zofío and Prieto, 2001). The international trade agreements among APEC force economies to be more competitive and the pressure of Kyoto Protocol requires updated technologies, improves input usage efficiency, and reduces CO_2 emissions. Facing the growth of economy, energy consumption, and CO_2 emissions, finding efficient ESTs and CATs for APEC economies without reducing the potential maximum economic growth has become very important issues. The energy efficiency and targets of energy saving and CO_2 abatement among APEC economies are needed further to study. Focusing on the international association as a partnership in sharing technology and resources, we apply the DEA approach using multiple inputs in order to analyze the total-factor environmental-energy efficiency in APEC economies. This analysis computes the possible energy savings and CO_2 abatements without reducing the maximum potential economic outputs for APEC economies.

2.5 Overview of energy efficiency policies in selected APEC economies

APEC economies, especially those undergoing rapid economic development, face serious energy policy challenges as they attempt to build and maintain the energy supply infrastructures needed to ensure national wealth creation and social well-being. Energy policy must strike a balance in terms of common - but sometimes conflicting - over-arching goals of economic growth, security of supply, and environmental integrity. The main drives of energy efficiency policy are political or industrial, or a combination of both. In political policy, as each economy understands its obligations in efforts to protect the global and local environment, it attempts appropriate measures to reduce its emissions of GHG. Regarding industrial policy, many governments are promoting innovative ideas and equipment to enhance energy efficiency. Many have begun using financial incentives such as rebates to ensure a greater impact in their economies.

Subsidies or incentives offered by government to involve key players in emission reduction efforts have also generated energy efficiency gains, such as through industries opting for more fuel-efficient or technologically improved equipment. Perhaps the end-use sectors which yield high gains or derive the greatest energy efficiency savings are the industrial, power generation, transport, and commercial sectors, because of a desire – for political reasons – to meet global environmental concerns.

Many economies have adopted energy efficiency policies. The good practice they have accumulated provided valuable lessons for other economies. The following is an overview of the status of energy efficiency policies in Australia, Canada, New Zealand, Japan, and the United States. Also included is a review of energy efficiency programs in Chile, China, Hong Kong, China, South Korea, Mexico, the Philippines, and Taiwan (APERC, 2001, 2002).

2.5.1 Energy efficiency policies in developed APEC economies

2.5.1.1 The industrial sector

Table 1 summarizes the efforts by each economy in its industrial sector. It is apparent that most of the economies have ongoing energy audit programs with continuous information dissemination systems using training and distribution of brochures, media and so on. Some have industries carrying out demand-side management in order to conserve energy and maximize output. Most have concerns about environmental safeguards.

Table 1 Energy efficiency policies in the industrial sector, developed APEC economies

Program Type	Australia	Canada	New Zealand	Japan	United States
Energy audits	×	×	×	×	×
Information dissemination	×	×	×	×	×
Demand side management	×	×	×	×	×
Environmental concerns	×	×	×	×	×
Industrial concerns	×	×	×	×	×
Financial incentives				×	
Regulatory requirements				×	
Innovative incentives				×	
Possible drivers	Industrial and Political	Industrial and Political	Industrial and Political	Industrial and Political	Industrial and Political
Duration results expected	Long term	Long term	Long term	Long term	Long term

Note: Source: IEA (2001).

The table shows Japan is promoting energy savings by offering financial incentives or tax rebates. Furthermore, technological advances made by Japan (and other economies) may be transferred to developing economies that need to save energy by retrofitting more cost-effective equipment.

Australia and New Zealand follow closely in energy savings achievements. The United States is continuing many of its programs despite its reluctance to ratify the Kyoto Protocol. The international community should maintain cooperation to reduce GHG emission levels, because safeguarding the global environment is largely the responsibility of industrial nations, which produced a major part of the accumulated GHG emissions in past industrial development.

2.5.1.2 The residential and commercial sector

Table 2 summarizes the efforts by each economy in its residential and commercial sector. It is apparent from the table that most of the economies have building codes or standards for residential and commercial buildings. Energy labeling of consumer goods and household appliances may become common practice in the immediate future if mandatory standards are agreed by economies. There are also ongoing programs to continuously disseminate information.

Table 2 Energy efficiency policies in the residential and commercial sector, developed APEC economies

Program Type	Australia	Canada	New Zealand	Japan	United States
Energy audits	×	-	-	-	-
Building codes/laws/standards	×	×	×	×	×
Energy labeling	×	×	×	×	×
Information dissemination	×	×	×	×	×
Environmental concerns	×	×	×	×	×
Residential/commercial concerns	×	×	×	×	×
Financial incentives			×		
Regulatory requirements					×
Possible drivers	Industrial and Political	Industrial and Political	Industrial and Political	Industrial and Political	Industrial and Political
Duration results expected	Long term	Long term	Long term	Long term	Long term

Note: Source: IEA (2001).

For Australia in the residential and commercial sector, there are no indicatives figures in terms of actual savings or savings potential to date as the programs are still being evaluated, just started or are nearly due for evaluation. For New Zealand only residential sector is considered, as commercial sector is combined with industrial sector.

2.5.1.3 The transport sector

Table 3 summarizes the efforts by each economy in its transport sector. It is apparent from the table that most of the economies have strong transport policy frameworks, public transport planning, fuel efficiency standards, and transport concerns. Some highly developed economies tend to have policies that encourage road users to favor the best vehicles – those that make less noise and cause less pollution. There is also ongoing dissemination of information by training and distribution of brochures, media and so on for transport equipment purchasers. Road infrastructure, railway lines, airports, wharves, and supporting construction tend to be developed and operated taking into account environmental issues.

Table 3 Energy efficiency policies in the transport sector, developed APEC economies

Program Type	Australia	Canada	New Zealand	Japan	United States
Transport policy framework	×	×	×	×	×
Fuel efficiency standards	×	×	×	×	×
Efficient public transport planning	×	×	×	×	×
Information dissemination	×	×	×	×	×
Environmental concerns	×	×	×	×	×
Transport concerns	×	×	×	×	×
Financial incentives					×
Possible drivers	Industrial and Political	Industrial and Political	Industrial and Political	Industrial and Political	Industrial and Political
Duration results expected	Long term	Long term	Long term	Long term	Long term

Note: Source: IEA (2001).

2.5.2 Energy efficiency policies in selected APEC non-OECD economies

2.5.2.1 Chile

Initiatives in demand-side energy efficiency is as follow, however, no quantitative evaluation is available for these programs.

- Monitoring energy efficiency indicators for energy-intensive industries: copper mining, sugar production, etc.
- Energy standards have been defined for appliances, lighting, air conditioning and thermal equipment, motors and pumps, and transformers and cables.
- Voluntary agreements on energy consumption in the copper mining sector.

2.5.2.2 China

Energy efficiency policies in China are driven by the need to ensure adequate energy supplies and improve environmental quality in the face of rapid economic growth. China's energy use, notably coal use, discharges 19 million tones of sulphur dioxide into the atmosphere annually and affects 30 percent of the economy's territory with acid rain. China's cities have some of the worst air quality in the world, with only a third of cities meeting international air quality standards. Better energy efficiency and environmental control technologies are needed to improve the situation.

As government energy efficiency budgets have declined and the private market economy has grown, China has sought ways to use the market economy to promote energy efficiency. The Energy Conservation Law of 1998 sets forth general principles and directions for energy efficiency practices. Detailed implementing regulations for the law include energy standards, an energy efficiency certification system for energy-using products, and energy management regulation for key energy consumers.

As a national policy, the Chinese government promotes new technologies usage and encourages energy efficiency improvements. In 1998, China launched a national program aimed at updating electricity end use distribution grids in both urban and rural areas. This program will reduce the amount of electricity lost through the transmission process. Energy standards for some electric appliances such as television sets, refrigerators, air conditioners, and the like, are also being introduced.

2.5.2.3 Hong Kong

Most energy efficiency programs in Hong Kong are voluntary. Labeling programs started in 1995, with the "Hong Kong Voluntary Energy Efficiency Labeling Scheme for Household Refrigeration Appliances" (revised in 1999). These voluntary labeling schemes have also been applied to washing machines (1997), air conditioners (1996, revised in 2000), compact fluorescent lamps (1998), electric clothes dryers (1999), electric storage water heaters (2000) and photocopiers (2000). In the transportation sector, subsidies are provided for electric cars (exemption from first registration tax), as well as to scrap old cars. There is also an information program on energy efficiency for cars.

Only service buildings have mandatory thermal efficiency standards. Energy audits in dwellings, commercial buildings and industry are also voluntary. The Government pays for audits in public buildings. There are also a variety of information programs on energy efficiency for commercial and residential buildings. A code of practice and guidelines for the commercial and residential buildings, set minimum efficiency standards and provide advice on best practices concerning lighting, air conditioning, electrical and lift/escalator installations. The codes of practice are implemented by means of a voluntary registration scheme. A demand-side management program for non-residential sectors started in July 2000. It provides rebates for new installations of efficient lighting. A similar program for the residential sector is being planned.

2.5.2.4 South Korea

Energy efficiency standards and a labeling program for household electrical appliances have been in place since 1992. Refrigerators, lighting products and air conditioners currently carry labels. This labeling program will be extended to gas boilers in 2001 and dishwashers and electric water heaters in 2002. Efficiency standards were set for incandescent bulb in 1997 and those for fluorescent lighting systems including ballast and lamp came into effect in 2000. By 2001, standards for appliances such as refrigerators, washing machines, air conditioners and domestic gas boilers will come into effect.

Other efficiency measures in Korea include requirements for consumption reporting and preparation of energy saving plans for industrial and commercial buildings; provision of soft loans, tax breaks and credits for energy efficient equipment and measures; and information dissemination on best practices and energy efficiency measures. Moreover, research and development (R&D), demonstration and dissemination of technologies on energy and mineral resources, commercialization and diffusion of higher-efficiency energy appliances and climate change mitigation efforts are also being pursued in Korea.

2.5.2.5 Mexico

Mexico has several national energy efficiency programs such as the Electricity Sector Savings Program (PAESE) and the Daylight Time Savings Program. Several efficiency measures are mandatory, such as (a) thermal efficiency standards for new dwellings and service buildings; and (b) labels and standards for refrigerators, washing machines and air conditioners. Other measures include soft loans for major end use sectors, technical assistance and information programs on best practice. Incentive and market transformation programs provide economic incentives to users that acquire and install high efficiency equipment. These programs have been geared to residential lighting and the productive sectors. Supply-side programs include the promotion of cogeneration and renewable energy.

2.5.2.6 The Philippines

In the Philippines, there are specific energy efficiency programs for each of the energy-consuming sectors. Programs in place for the industrial sector include energy audits, special financing for energy conservation projects, power patrol and energy certification of industrial fans and blowers. System loss reduction, heat rate improvement of power plants and demand-side management are some of the programs available to the electricity sector. Programs for the residential and commercial sector are energy efficiency labeling of appliances such as room air-conditioners and refrigerators and freezers, and lamp ballast efficiency standards. The Power Patrol Programme provides information on energy efficient practices to all sectors and has been in operation since 1993. A similar program for the transport sector, the Road Transport Patrol was started in 1998. In addition, vehicle efficiency standards and testing protocols for motor vehicles are currently in place in the Philippines.

2.5.2.7 Taiwan

The government in Taiwan has set goals to improve total energy efficiency by 1.2 percent per year from 1997 to 2010 and 1.0 percent per year from 2010 to 2020. The plan is expected to save about 18 Mtoe by 2010, and 39 Mtoe by 2020 (ADEME and APERC, 2000). To achieve these goals, Taiwan has implemented a "Comprehensive Plan for the Conservation of Energy and the Promotion of Energy Efficiency." If energy utilization by an energy consumer reaches a certain level, the owner of the facilities must report energy utilization levels to the government, establish an energy audit system, and submit a conservation plan with energy targets. Taiwan has mandatory performance standards for all energy using equipment, including motor vehicles. It also has energy conservation standards for new buildings. To encourage investment in high-efficiency equipment and facilities, the government offers accelerated depreciation, investment tax credits and low-interest loans.

Taiwan also promotes voluntary action through public information campaigns, compiling teaching materials for schools and sponsoring training programs on energy conservation. The government offers technical conservation services such as energy audits, advisory services, technology transfer and voluntary commitments with industry. See Table 4 for a summary of energy efficiency programs in Taiwan.

Table 4 Summary of energy efficiency policies in Taiwan

Program Type	Industrial	Transportation	Commercial	Residential
Energy controls	×		×	
Fiscal/financial incentives	×		×	
Voluntary commitments	×			
Product efficiency standards	×	×	×	×
Information	×	×	×	×

Note: Source: ADEME and APERC (2000).

2.5.3 Remarks on energy efficiency policies in selected APEC economies

Good public policies on energy efficiency are vital for our livelihood because they promote technology progress, save the usage of petro-fossil fuels, and serve as an environment protection measure. Sound policies also encourage achieving better standards and a better quality of life.

Energy policies overviewed here can be divided into eight broad categories (APERC, 2002):

1. Labels and standards,

2. Energy audits,

3. Demand side management (DSM),

4. Voluntary agreements,

5. Financial incentives (subsides, soft loans),

6. Fiscal incentives (accelerated depreciation, tax rebates),

7. Environmental incentives (carbon tax, Clean Development Mechanism framework),

8. Information programs ('best practice', training).

2.6 DEA studies considering energy and CO_2 emissions

The DEA approach was originally intended for use in microeconomic environments to measure the performance of schools, hospitals, and the like, and it is also ideally suited to macroeconomic performance analysis. DEA can evaluate the efficiency of converting multiple into multiple outputs. Furthermore, DEA is also a theory-based, transparent, and reproducible computational procedure. In comparison to the traditional approaches such as ratio analysis and regression analysis, DEA has gained several more advantages. These characteristics include (Lewin et al., 1982):

- capable of deriving a single aggregate measure of the *relative* efficiencies of units in terms of their utilization of input factors to produce desired outputs;
- able to handle non-commensurate multiple outputs and multiple input factors;
- able to adjust for factors outside the control of the unit being evaluated;
- not dependent on a set of a *priori* weights or prices for the inputs or the outputs;
- able to handle qualitative factors such as 'extent of information processing available', presence of certain state statues, etc.;
- able to provide insights on the possibilities for increasing outputs and/or conserving inputs for the inefficient unit to become efficient;
- able to maintain equity in performance assessment.

Seiford and Thrall (1990) reviewed the various advantages of non-parametric approaches (including DEA) over parametric approaches. Among these advantages there are the robustness of the linear programming methods used to solve DEA problems and the new insights and additional information it provides with respect to conventional econometric methods. Charnes et al. (1985) also noted that a variable, neither an economic resource nor a product but an attribute of the environment or the production process, can be included easily in a DEA-based production model.

One major advantage is that DEA has emerged as the leading method for efficiency evaluation in terms of both the number of research papers published and the number of applications to real world problems. Considering other factors' complement and substitution, DEA using multiple inputs containing capital, labor, and energy consumption is an appropriate approach to analyze the total-factor energy efficiency. However, few studies apply DEA to compare productivity and efficiency by considering energy use and CO_2 emissions across economies.

Edvardsen and Førsund (2003) and Jamasb and Pollitt (2003) analyzed the benchmarking of the electricity industry in Europe and Northern Europe. The main purpose of these two studies is to find the firm and plant level's efficiency and productivity. Boyd and Pang (2000) used plant level data to examine the relation between productivity and energy efficiency for two segments of the glass industry. Productivity is measured by DEA with electricity, fuel, and capital as the input while cumulative output represented in million US dollars. All coefficients of the regression models that link productivity to energy efficiency are significant.

Haynes et al. (1994) applied DEA model and regarded the pollution generated as the only inputs of the production processes to the measurement of environmental performance. Tyteca (1996) reviewed the literature on environmental performance indicators. In this paper he calls for an index that simultaneously accounts for resources used, good outputs produced and pollutants or undesirable outputs emitted. He ultimately recommends using DEA approaches to evaluate environmental performance. Tyteca (1997) used four alternative DEA models developed from Tyteca (1996) to define standardized, aggregate environmental performance indicators for firms. Results are obtained with data from U.S. fossil fuel-fired electric utilities accounted for desirable output (electricity generation), undesirable outputs (sulphur dioxide, nitrogen oxide, and CO_2), and resources used as input (installed capacity, coal, oil, gas, and labor). Färe et al. (2004) followed Tyteca's model and used DEA to construct an alternative environmental performance index focusing on pollution. They developed a revised DEA approach to evaluate the environment efficiency considering pollution. Since their major objective is to find a method considering undesirable outputs, they used output-oriented DEA models. Then they applied their model to a sample of 17 OECD economies for 1990 with desirable output (real GDP), undesirable outputs (CO_2, nitrogen oxide, and sulphur dioxide) and inputs (energy consumption, capital stock, and labor).

Lovell et al. (1995) studied the macroeconomic performance of 19 OECD economies by taking four services- real GDP, a low rate of inflation, a low rate of unemployment, and a favorable trade balance- into analysis. When two environment disamenities (carbon and nitrogen emissions) were included into the service list, the rankings changed while the relative scores of the European economies decline. According to the above literature, energy efficiency indicator and environmental indicators did seem to have crucial effect on a nation's relative performance.

Most existing economic analyses of energy saving and air pollution abatement focus on benefit evaluation, possible impacts on economic activities, or strategies to achieve them. To the best our knowledge, the topic of efficient target rations seems to receive little attention by the existing literature. However, for developing economies such as APEC economies, finding out efficient and feasible energy-saving target and pollution abatement target are definitely crucial for sustainable development. A special feature of this across economies study herein is that the data (for 1990s) are based on a sample of APEC economies at the economy level and the focus is on the use of energy and the abatement of CO_2 emissions.

Chapter 3 Research Design

3.1 Production model

An economy's economical growth is provided by many factors. The most discussed factors are capital and labor. However, energy can substitute capital and labor for maintaining the same level of economic output. Energy is the prime source of value, because other factors of production such as labor and capital cannot do without energy (Ghali and El-Sakka, 2004). In this study, we use the production approach to evaluate the energy efficiency. The production model includes three inputs: energy, labor, and real capital, while real GDP is the single output. The model is shown as Figure 4.

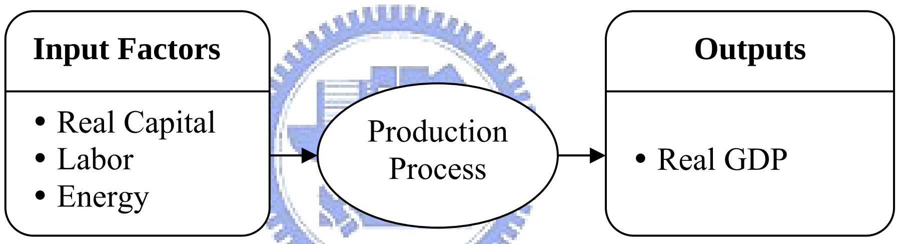


Figure 4 Production model for evaluating energy efficiency

The DEA approach has been proposed as a method for evaluating producer's performance in the presence of adverse environmental impacts. Environmental impacts are treated either as undesirable outputs (e.g., Färe et al., 1989; Zofío and Priteo, 2001; Färe et al., 2004)) or undesirable inputs (e.g., Tyteca, 1997; Lansink and Silva, 2003; Hu et al., 2005); conceptually there is no difference between the two approaches. The DEA approach allows an asymmetric treatment of desirable and undesirable inputs and outputs. A non-parametric piecewise linear technology that satisfies weak disposability of undesirable inputs (outputs) and strong disposability of desirable inputs (outputs) can be constructed without imposing a functional form on the production technology. Nonparametric efficiency measures that satisfy those requirements can be calculated as solutions to (nor-) linear programming problems. The DEA efficiency measures require data on output and input quantities rather than prices which is particularly useful when well-defined market prices for undesirable inputs or outputs do not exist (Lansink and Silva, 2003).

Energy consumption in economic sectors is directly linked with CO_2 emissions. In this study, CO_2 emissions were calculated in using the methods of Marland and Rotty (1984). Appendix shows the factors and units for calculating CO_2 emissions from fuel production and trade data (Marland et al., 2005). Energy related CO_2 emissions vary significantly across APEC economies (APERC, 2001). In this study we treat the air emissions as proxies for the cost of environmental goods used for production (Oates and Schwab, 1988; López, 1994; Smulders, 1999; de Bruyn, 2000; Hu et al., 2005), e.g., the health problem caused, the corrosion of industrial equipment due to polluted air, and other related social expenses. Since energy consumption is responsible for roughly 90 percent of CO_2 emissions (APERC, 2001) and the high correlation between energy consumption and CO_2 emissions exists, they both cannot be considered together in the DEA model. Therefore, we use CO_2 emissions instead of energy consumption for the production approach in Figure 2 to evaluate the target of CO_2 abatement. The production model then includes three inputs: CO_2 emissions, labor, and real capital. Real GDP is still the single output for every economy. Figure 5 shows the model for measuring CO_2 abatement target.

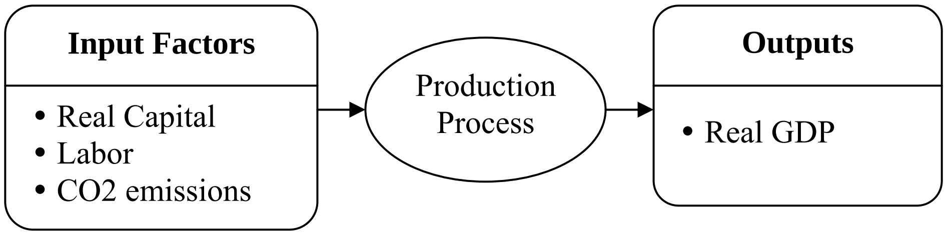


Figure 5 Production model for evaluating CO_2 abatement target

3.2 Methods

3.2.1 Partial-factor energy efficiency indicator

A number of indicators can be used to measure energy efficiency according to existing literatures. These fall into four main groups. These four groups are all partial factor energy efficiency indicator. They all only compare single output to single input to identify the efficiency. However, they do not consider other factors which influence the output. They are introduced respectively as following (Patterson, 1996).

1. Thermodynamic indicators

These are energy efficiency indicators that rely entirely on measurements derived from the science of thermodynamics. Some of these indicators are simple ratios and some are more sophisticated measures that relate actual energy usage to an ideal process.

$$E_{\Delta H} = \frac{\Delta H_{out}}{\Delta H_{in}}, \tag{1}$$

where $E_{\Delta H}$ = Enthalpy efficiency;

ΔH_{out} = Sum of the useful energy output of a process;

ΔH_{in} = Sum of all of the energy inputs into a process.

One attraction of using thermodynamic quantities for measuring energy efficiency is that they are calculated in terms of 'state functions' of the process. Sioshansi (1986) and Schurr (1984) use these measures in macro-level energy efficiency studies. However, a criticism of thermodynamic indicators of energy efficiency is that they do not adequately encapsulate the end use service required by consumers in the output measurement.

2. Physical-thermodynamics Indicator

These are hybrid indicators where the energy input is still measured in thermodynamic units, but the output is measured in physical units. These physical units attempt to measure the service delivery of the process – for example in terms of tones of product or passenger miles:

$$E_{PT} = \frac{Output(e.g.\ vehiclekilometers)}{Energy\ input(\Delta H_{in})}, \tag{2}$$

where E_{PT} = Energy efficiency in physical-thermodynamic term.

ΔH_{in} = Sum of all of the energy inputs into a process.

One advantage of using these physical measures is that they can be objectively measured. Collins (1992) uses the energy input/passenger kilometers as the energy efficiency indicator for passenger transport. The measurement of energy efficiency in terms of physical-thermodynamic indicators has the so-called joint production or partitioning problem. This refers to the difficulty in allocating one energy input to several outputs.

3. Economic-thermodynamic Indicators

These are also hybrid indicators where the service delivery (output) of the process is measured in terms of market prices ($). The energy input, as with the thermodynamic and physical-thermodynamic indicators, is measured in terms of conventional thermodynamic units. The most commonly used aggregate measure of a nation's 'energy efficiency' in these indicators is named energy productivity ratio:

$$Energy\ productivityratio = \frac{GDP}{Energy\ input}. \tag{3}$$

The Joint Economic Committee of the Congress of the United States (1981) proposed a commonly used indicator of energy inefficiency --- the energy intensity as a direct ratio of the energy input to GDP. The energy intensity is the inverse of energy productivity ratio which simply evaluates energy efficiency by observing how much GDP is produced when how much of energy is input. These indicators can be applied to various levels of aggregation of economic activity – product, sectoral or national levels. Although the energy:GDP ratio is the most commonly used aggregate measure of a nation's 'energy efficiency', there has been widespread criticism of the use of this indicator for this purpose. The uncritical use of the energy productivity ratio can lead to misleading conclusions. For example, the energy productivity ratio may decrease solely because energy is substituting for labor.

An alternative approach is labeled CO_2 intensity, using GDP as a denominator and CO_2 emissions as a numerator. It has the same problem as the indicator of energy intensity, such as it does not measure the underlying technical efficiency.

4. Economic Indicator

These indicators measure changes in energy efficiency purely in terms of market values ($). That is, both the energy input and service delivery (output) are enumerated in monetary terms.

$$E_E = \frac{GDP}{Cost\ of\ energy\ consumption}, \tag{4}$$

where E_E = Energy efficiency in economic term.

Turvey and Norbay (1965) and Berndt (1978) use this indicator to calculate the energy efficiency. However, it is argued on axiomatic grounds that a pure economic indicator of energy efficiency is not truly an energy efficiency indicator. Rather, it is an economic efficiency indicator because it is fully enumerated in economic value ($) terms, and therefore it should be immediately dismissed as a candidate measure of energy efficiency.

5. Remarks on partial-factor energy efficiency indicator

Energy efficiency is now a central focus of many national energy policies and at the forefront of the debate on energy sustainability issues. If energy efficiency policy objectives are going to be properly set, theoretically sound approach of energy efficiency need to be developed. Thermodynamic indicators of energy efficiency are very limited at the macro-level. Physical-thermodynamic indicators are only allow for the comparison of the efficiency of processes which requite the same end use service and hence are restrictive as general measures of energy efficiency. Economic indicators are economic efficiency indicators rather than energy efficiency indicators. Economic-thermodynamic indicators, such the energy:GDP ratio, are more useful macro-level policy analysis (Patterson, 1996).

Although Economic-thermodynamic indicators in terms of simple ratios provide important and useful information for evaluating energy efficiency, there has been widespread criticism of using energy intensity for measuring energy efficiency (Patterson, 1996). The main problem with energy/GDP, as pointed out by Wilson et al. (1994), is that it does not measure the underlying technical energy efficiency, which can lead to misleading conclusions. For example, the energy intensity may decrease solely because energy is substituted for labor, rather than any underlying deterioration in the technical energy efficiency. The use of the energy efficiency indicator in conjunction with labor and capital can provide useful insights into whether or not energy inputs act as complements or substitutes to other inputs (Patterson, 1996).

3.2.1 Total-factor energy efficiency indicator

1. Methodology of data envelopment analysis

Data envelopment analysis (DEA) finds the efficient outputs and inputs in a total-factor framework. This technique makes use of information available in considering factors simultaneously. It is a non-parametric method that uses linear programming methods to construct a non-parametric piecewise frontier over the data for an efficiency measurement. DEA does not need to specify either the production functional form or weights on different inputs and outputs.

Efficiency is defined by the difference in the 'best practice' production frontier, as measured by DEA. The 'best practice' in the frontier is the benchmark to calculate the projected and possible energy saving for those not on the frontier. By comparing the relative practice of various inputs and output in different economies, we can identify the main amount (target) for energy saving and CO_2 abatement likely to be found. Thus, the performance of the economies that have the 'best practices' can serve as a benchmark to evaluate a particular economy's energy consumption and CO_2 emissions. A similar approach to construct abatement ratios from the total-factor framework can be found in Hu (forthcoming) and Hu and Wang (forthcoming).

This paper uses DEA to find out the input targets for each APEC economy by comparing with the annual efficiency frontier constituted by all the APEC economies in each year. There is an efficiency frontier for each APEC economy in each year constituted by data of all APEC economies in that year. Since it is an input-reducing focus, this paper uses input-orientated measures following Farrell's (1957) original ideas. In order to pursue overall technical efficiency with energy inputs, our study adopts the constant returns to scale (CRS) DEA model (Charnes et al., 1978).

Our measure of relative efficiency is based on non-parametric techniques (Färe et al., 1994). Let us first define some mathematical notations: There are K inputs and M outputs for each of N objects. For the ith object these are represented by the column vectors x_i and y_i, respectively. The $K \times N$ input matrix X and the $M \times N$ output matrix Y represent the data for all N objects. The input set $L(y_i)$ for the ith object is defined as $L(y_i) = \{x_i\colon y_i \geq f(x_i)\}$. The efficiency score θ equals the value of the distance function, $D(y_i, x_i) = \min \{\lambda\colon x_i\lambda \in L(y_i)\}$ (Shephard, 1970). The set $L(y_i)$ can be numerically computed by linear programming using observed data. The input-oriented CRS DEA model then solves the following linear programming problem for object i in each year:

$$D(y_i, x_i) = \text{Min}_{\theta, \lambda} \ \theta$$

$$\text{subject to} \quad -y_i + Y\lambda \geq 0,$$

$$\theta x_i - X\lambda \geq 0,$$

$$\lambda \geq 0, \tag{5}$$

where θ is a scalar and λ is a $N\times1$ vector of constants.

The value of θ is the efficiency score for the ith object, with $0 \leq \theta \leq 1$. The value of unity indicates a point on the frontier that is hence a technically efficient object, according to Farrell's (1957) definition. The frontier is a piece-wise linear isoquant, determined by the observed data points of the same year, i.e., all the objects in this study of the same year. The object that constructs the frontier is the 'best practice' among those observed objects in that year. The weight vector λ serves to form a convex combination of observed inputs and outputs.

Figure 6 illustrates the efficiency measurement: Each point on Figure 6 represents a combination of inputs that all produce the same output level. Objects C and D are on the frontier and they cannot maintain the given output level by further reducing their inputs. Objects A and B are hence inefficient objects.

Equation (5) is known as the constant returns to scale (CRS) DEA model (Charnes et al., 1978). This model finds the overall technical efficiency (OTE) of each object. The variable returns to scale (VRS) DEA model (Banker et al., 1984) is further extended with adding following convexity constraint:

$$N1'\lambda \geq 0,$$

where $N1'$ is a $N\times1$ vector of ones.

The VRS DEA model decomposes the OTE into pure technical efficiency (PTE) and scale efficiency (SE). That is, OTE = PTE × SE. In order to pursue OTE with energy or CO_2 emissions, this study adopts the CRS DEA model.

Furthermore, both output-oriented and input-oriented CRS DEA models generate exactly the same efficiency scores, target inputs, and target outputs. However, results of a VRS DEA model can be drastically changed by shifting output orientation to input orientation.

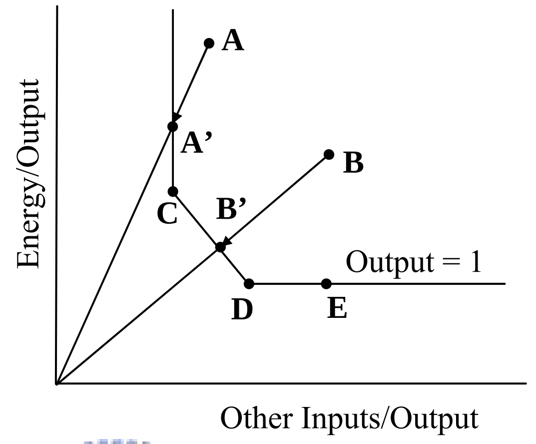


Figure 6 DEA representation of 'best practice', target, radial adjustment, and input slacks

2. Slack and radial adjustment

An important issue in efficiency studies is the credibility of the assumption that all production processes can actually reach the best practice production frontier (Zofío and Prieto, 2001). In the present study, when measuring energy efficiency and CO_2 abatement, it is assumed that all economies have access to the best practice. This assumption seems to be adequate since only APEC economies are considered. Currently, specialized journals, technological fairs, multi-nationals' global marketing strategies, etc. guarantee that new innovations are readily available to all economies (Zofío and Prieto, 2001). The international trade agreements among APEC force economies to be more competitive and the pressure of Kyoto Protocol requires updated technologies and improves input usage efficiency.

The $f(x_i)$ set in the frontier is the 'best practice' production among the observed economies. The inefficient object (economy) could reduce inputs by the amount indicated by the arrow and still remain in the input set $L(y_i)$ (Boyd and Pang, 2000). For the ith object, the distance (amount) of it to the projected point on the frontier by radial reduction without reducing the output level, $(1-\theta)x_i$, is called 'radial adjustment'. We can illustrate this from Figure 6. Point B is the actual input set and point B' is the ideal or best practice input set for object B by reducing the radial adjustment BB'.

More over, the mostly seen piecewise-linear form of the non-parametric frontier causes the second stage to shift from the projected point to a point at the practical minimum level of the inputs on the frontier. When the frontier runs parallel to the axes, this could be a problem. In Figure 6, point A' is the best practice for object A by reducing the redial adjustment AA'. However, the input level at point A' could be further reduced to input level at point C so as to maintain the same output level. The reduced amount is called 'slack' (by the amount CA'). The best practice for object A is point C, instead of point A', by reducing the radial adjustment AA' and slack CA'.

The summation of slack and radial adjustment for inputs is called the amount of total adjustment ('target') that could be reduced without decreasing output levels. That is, it is the total amount for any individual input which should be reduced by an object or an economy so as to reach its optimal production efficiency. With respect to any specified input, the above summation is called Input-reducing Target (IRT). The formulas are as follows:

$$\text{IRT}_{k\,(i,\,t)} = \text{Slack Adjustment}_{k(i,\,t)} + \text{Radial Adjustment}_{k\,(i,\,t)}, \quad (6)$$

where it is in the ith object and the tth year for kth input.

An inefficient object (economy) can save or reduce IRT in kth input, such as energy or CO_2 emissions, without reducing the real economic growth. The adjustments require both a promotion of technology level and an improvement of production process so that OTE is optimized. The total reducing amount is then removed and the output level maintains in the same level when an object or an economy operates at the efficient position on frontier of production.

Point E in Figure 6 indicates that object E has been operating on the frontier of production efficiency. The object E has already reached at the target input level of specified (energy) inputs in production. It can be observed that no amount of total adjustments exists for energy. There is only slack amount of the "other inputs' (capital or labor) needs further adjustment, which is DE. After reducing the amount of total adjustment in the other inputs except for energy input, the production efficiency of object E then has the practical minimum input for all inputs, including capital, labor, and energy, on the frontier.

The CRS model may suggest the slack and radial adjustments of any individual input for all objects to be efficient and the amount of target input can either be calculated accordingly. DEA calculation then decides this 'amount of total adjustments' for each object for production efficiency analysis.

3. Efficient input-reducing target ratio (IRTR)

Efficiency is generally defined in terms of the ratio with which best practice compares with actual operation. The indicator of a specified input efficiency therefore should be the ratios of the aggregate IRT from Equation (6) to the actual input amount. The amount of total adjustments in that input is regarded as the inefficient portion of actual input amount. For example, based on the target of energy obtained from DEA, we can calculate the IRTR for energy consumption considering other factors simultaneously. The target inputs of an object in a year are found by comparing its actual inputs to the efficiency frontier in that year. The formula is as below:

$$\text{IRTR}_{k(i,t)} = \frac{\text{Input-Reducing Target}_{k(i,t)}}{\text{Actual Input}_{k_{(i,t)}}} = \frac{\text{IRT}_{k(i,t)}}{\text{Actual Input}_{k_{(i,t)}}}, \qquad (7)$$

where it is in the ith economy and the tth year for the kth input.

As Equation (7) shows, the IRTR represents each economy's inefficiency level of energy consumption. Since the actual practice can be improved to the best practice, the actual input amount is always larger than or equal to the ideal input amount, the minimal value of IRT is zero. Therefore, the value of IRTR is between zero and unity. The total-factor input efficiency (TFIE) index for specified input originally proposed by Hu and Wang (forthcoming) has the following relation with IRTR_k:

$$\text{TFIE}_{k\,(i,\,t)} = 1 - \text{IRTR}_{k\,(i,\,t)}, \tag{8}$$

where it is in the ith economy and the tth year for the kth input.

A zero IRTR value indicates an object on the frontier with the best total-factor kth input efficiency up to one among the observed economies. A zero IRTR means that no redundant or over-consumed kth input use exists (the amount of target zero) in this economy. An inefficient economy with the value of IRTR larger than zero means otherwise that the kth input should and could be saved or reduced at the same economic growth level. A higher IRTR implies higher kth input inefficiency and a higher input-reducing amount.

3.2.3 Wilcoxon signed rank test

The Wilcoxon signed rank test is a non-parametric alternative to the paired Student's t-test. It should be used whenever the assumptions that underlie the t-test cannot be satisfied. The test is named for Frank Wilcoxon (1892–1965) who proposed this, and the rank-sum test, in 1945. Wilcoxon signed rank test is generally more powerful than the sign test for making inferences about the population median difference (η_D). In practice, and especially in experimental settings, the population of differences between matched pairs frequently will be symmetrical, or approximately so. In the case of experiments where matched subjects are each assigned randomly to two different treatments, a symmetrical distribution is to be expected when the two treatments have no differential effects, because each subject has an equal chance of being assigned to either treatment (Neter et al., 1988). The null hypothesis (H_0) is that the difference ($D_i = x_i - y_i$) between the members of each pair (x_i, y_i) has a median value of zero. To be complete, x and y need to have identical distributions. One assumption is that the distribution of the difference (d) between the values within each pair (x_i, y_i) must be symmetrical, and the median difference must be identical to the mean difference. Another assumption is as members of a pair are assumed to have identical distributions, and their differences (under H_0) should always have a symmetrical distribution. The latter assumption is not very restrictive.

Wilcoxon signed rank test is used for between ordinal and interval scale (also called an ordered metric scale). The test statistic for Wilcoxon test is calculated as follows:

1. Obtain the absolute differences $|D_i|$ and rank them.
2. To each rank, attach a plus sign or a minus sign according to whether D_i is positive or negative, respectively.
3. Sum the signed ranks, and denote the sum by T.

If a difference D_i should happen to equal zero, discard it and reduced the sample size accordingly. When absolute differences are tied, they are assigned the average value of the corresponding ranks. When a random sample of n differences is selected from a symmetrical population of differences with $\eta_D = 0$, the sampling distribution of T has the mean and variance as follows:

$$E\{T\} = 0 \text{ and } \sigma^2\{T\} = \frac{n(n+1)(2n+1)}{6}, \tag{9}$$

when n is 10 or more, the sampling distribution of T is approximately normal. The standardized test statistic of Wilcoxon signed rank test is:

$$Z^* = \frac{T - 0}{\sigma\{T\}}, \tag{10}$$

where $\sigma\{T\}$ is given by Equation (9) and α risk is controlled at $\eta_D = 0$. When $\eta_D = 0$, Z^* follows approximately a standard normal distribution.

3.2.4 Analysis of panel data

Panel data, also called pooling cross-section and time series data or longitudinal data, needs special estimation techniques. To make the presentation easier to understand, we choose the simple linear regression model with just use one independent variable. The extension to the general case of many independent variables is straightforward. The modified general model is (Ramanathan, 2002):

$$Y_{it} = \alpha_{it} + \beta_{it} X_{it} + u_{it}, \tag{11}$$

where $i = 1, 2, \ldots, G$, represent the G cross-sectional groups and $t = 1, 2, \ldots, n$, represent time.

Because there are only Gn observations to estimate $2Gn$ the parameters, we need to impose some restrictions to reduce the number of unknown parameters. A popular approach to estimating models using models using panel is using dummy variables for each of the cross-section units called the fixed effects model. To illustrate, if $G = 3$, then we define three dummy variables for these three groups: D_{1t} which takes the value 1 when $i = 1$ and for all the time periods, and 0 otherwise; D_{2t} which takes the value 1 when $i = 2$ and for all the time periods, and 0 otherwise; D_{3t} which takes the value 1 when $i = 3$ and for all the time periods, and 0 otherwise. The modified model is (for $i = 1, 2, 3$)

$$Y_{it} = \lambda_1 D_{1t} + \lambda_2 D_{2t} + \lambda_3 D_{3t} + \beta_1 X_{it} + u_i, \tag{12}$$

In essence, we are assuming that the error variances in the equations are the same across the same across equations. If this is so, pooling gives more efficient estimates of the parameters because of the considerably increased number of observations.

The fixed effects model treated the dummy variable coefficients as fixed but unknown. In the random effects model (commonly known as the error component model), they are treated as random drawings from a common population with a fixed mean (call it θ). The modification is as follows:

$$Y_{it} = \alpha_i + \beta_1 X_{it} + u_{it} \text{ and } \alpha_i = \theta + \varepsilon_i, \tag{13}$$

or

$$Y_{it} = \theta + \beta_1 X_{it} + (u_{it} + \varepsilon_i) = \theta + \beta_1 X_{it} + v_{it}, \tag{14}$$

where θ is the fixed mean effect and ε_i is an unobservable time-invariant random effect, specific to the ith cross-section group, assumed to be independent of other ε's with a zero mean and constant variance. The combined error term v_{it} has two components (hence the name error component model), the group specific error (ε_i) and the overall error u_{it}.

The various error terms are assumed to satisfy the following conditions:

$$E(u_{it}) = E(\varepsilon_i) = 0,\ Var(\varepsilon_i) = \sigma_\varepsilon^2,\ Var(u_{it}) = \sigma_u^2,\ \mathrm{Cov}(\varepsilon_i, \varepsilon_j) = 0 \text{ for } i \neq j,$$

$$\mathrm{Cov}(u_{it}, \varepsilon_j) = 0, \text{ for all } i, j, \text{ and } t, \text{ and } \mathrm{Cov}(u_{it}, u_{js}) = 0, \text{ for } i \neq j \text{ and } t \neq s.$$

The following results are easy to show:

$$Var(v_{it}) = \sigma_u^2 + \sigma_\varepsilon^2 \text{ and } \mathrm{Cov}(v_{it}, v_{js}) = \sigma_\varepsilon^2, \text{ for } t \neq s.$$

3.2.5 Hausman test

Given a model and data in which fixed effects estimation would be appropriate, a Hausman test tests whether random effects estimation would be almost as good. In a fixed-effects kind of case, the Hausman test is a test of H_0: random effects would be consistent and efficient, versus H_1: random effects would be inconsistent. (Note that fixed effects would certainly be consistent.) The result of the test is a vector of dimension k (dim (b)) which will be distributed chi-square (k). So if the Hausman test statistic is large, one must use fixed effect estimation. If the statistic is small, one may get away with random effects estimation. The statistic of Hausman test is as follows (Hausman and Tayor, 1982).

Given two estimators, $\widehat{\beta_0}$ and $\widehat{\beta_1}$, where under the null hypothesis both estimators are consistent but only $\widehat{\beta_0}$ is asymptotically efficient and under the alternative hypothesis only $\widehat{\beta_1}$ is consistent, the statistic, *m*, is:

$$m = \hat{q}'(\hat{V}_1 - \hat{V}_0) - \hat{q},$$

where $\hat{V}_1$ and $\hat{V}_0$ represent consistent estimates of the asymptotic covariance matrices of $\widehat{\beta_1}$ and $\widehat{\beta_0}$, and $q = \widehat{\beta_1} - \widehat{\beta_0}$. The *m*-statistic is then distributed χ^2 with *k* degrees of freedom, where *k* is the rank of the matrix $(\hat{V}_1 - \hat{V}_0)$.

3.3 Analysis process

The growth of an economy's output depends on capital formation as well as efficiency and productivity improvement. Labor and capital are two major inputs in production. When measuring an economy's overall output, gross domestic product (GDP) is commonly used. While GDP (income) preferred to increase more, consumption of energy is preferred by an economy to be less and efficient. The question between change of GDP and consumption of energy is in an output and input relation: First, the increasing of GDP would be closely related to input consumption of energy directly because these resources are generally key input for production. In reverse, the supply of energy in an economy is at certain level and impossibly supply unlimited for GDP growth. An important point emerges upon this relation: How the energy is consumed in an economy and is the consumption efficient? The GDP growth goal and energy consumption level should be put together in order to set energy policy appropriately, the improvement and concerns to efficiency of energy consumption are key subjects to study and understand.

With respect to CO_2 emissions for an economy, while GDP (income) is desirable, emissions (pollutions) are undesirable. The change in income and pollutions is a two-way relation: First, increasing income deteriorates the environmental condition directly, because pollutions are generally by-products of a production process and are costly to dispose. Conversely, the growth of income is accompanied by the public increasing the demand for better environmental quality through driving forces such as control measures, technological progress, and the structure change of consumption. Desirable GDP and undesirable pollutions should be both taken into account in order to correct a nation's output. This concept is called 'green GDP.' Green GDP is derived from GDP through a deduction of negative environmental and social impacts.

As mentioned above, many studies criticize the commonly-used indicator of energy inefficiency - the energy intensity as a direct ratio of the energy input to GDP for measuring energy efficiency (e.g., Patterson, 1996; Renshaw, 1981). The ratio is only a partial-factor energy efficiency indicator since energy input is the only input-considered factor. Another argument is that this partial-factor ratio is inappropriate to analyze the impact of changing energy use over time (APERC, 2002). We compute the energy efficiency by a total-factor framework including labor and capital inputs. A total-factor efficiency indicator can provide more information and a more realistic comparative base to examine the de facto situation across economies. We then calculate IRT, IRTR, and TFIE through Equation (6) to (8) from the results of the CRS DEA model for energy input. The IRT, IRTR, and TFIE for energy are called energy-saving target (EST), energy-saving target ratio (ESTR), and total-factor energy efficiency (TFEE), respectively. We use the software DEAP 2.1, kindly provided by Coelli (1996), to solve the linear programming problems as specified in Equation (5) for computing the target inputs and outputs of each economy in each year.

An inefficient economy can reduce or save EST in energy use without reducing the real economic growth. ESTR represents each economy's inefficiency level of energy consumption. Since the minimal value of EST is zero, the value of ESTR is between zero and unit. A zero ESTR value indicates an economy on the frontier with the best total-factor energy efficiency up to one among the observed economies and means that no redundant or over-consumed energy use exists (the amount of target zero) in this economy. An inefficient economy with the value of ESTR larger than zero means otherwise that the energy should and could be saved at the same economic growth level. A higher ESTR implies higher energy inefficiency and a higher energy-saving amount.

With respect to CO_2 emissions, we use CO_2 emissions instead of energy consumption into the same framework including capital and labor inputs to calculate IRT, IRTR, and TFIE through Equation (6) to (8) for CO_2 abatement. The IRT, IRTR, and TFIE for energy are called CO_2 abatement target (CAT), CO_2 abatement target ration (CATR), and total-factor CO_2 abatement efficiency (TFCE), respectively. CAT represents that an inefficient economy can reduce the amount of CAT in CO_2 emissions in the same real economic growth. Each economy's inefficiency level of energy consumption is CATR. The greater CATR whose value is between zero and unit is, the more inefficiency and amount of CO_2 abatement are. A zero CATR value indicates an economy on the frontier with the best total-factor CO_2 abatement efficiency up to one among the observed economies. An inefficient economy with the value of CATR larger than zero means otherwise should and could reduce CO_2 emissions without reducing economic growth level.

Then we use Wilcoxon signed rank test to compare the total-factor indicator, which is constructed in this study, with the traditional partial-factor indicator.

Following the rising income, the center of weight in production and consumption shifts from primary to secondary and then to tertiary industry. In the process of a shift from primary to secondary industry with larger energy consumption, environment condition deteriorate, while the shift from secondary to tertiary industry causes alleviation of the negative impact on the environment with higher energy efficiency and less energy waste. With higher income, citizens become more aware of environmental quality and induce their governments to introduce stricter regulations. Moreover, the investments necessary for environmental protection are only feasible with the financial resources made available by a certain level of income. Industrialization causes wastes of toxic chemical substances and heavy metals, on the one hand, and leads to larger energy consumption that results in increased emissions of air-pollutants and GHG, on the other hand. For finding out the relation between input-reducing target and income level and the relation between industrial structure and input-reducing efficiency, this study use panel data regression models to analyze. The results will show the relation among input reducing, income level, and industrial structure in APEC economies.

3.4 Data description

The analytical measures described in the preceding section are applied to a dataset of 17 APEC economies for the period 1991-2000. The APEC economies include Australia, Canada, Chile, China, Hong Kong, Indonesia, Japan, South Korea, Malaysia, Mexico, New Zealand, Peru, the Philippines, Singapore, Taiwan, Thailand, and the United States. Brunei Darussalam, Papua New Guinea, Russia, and Vietnam in APEC are not included due to a lack of data. Then 15 economies among the above 17 APEC economies are selected to do the panel data analysis, except South Korea and Singapore, since there is a limitation of data. The data of value-added percents of GDP by industry and service sectors for every economy are taken from *World Development Indicators* (World Bank, 2005).

To solve the data comparability problem, there are only two practical alternatives: the average rates of exchange and the purchasing power parity (PPP) as measured by OECD (Edvardsen and Førsund, 2003). Usually GDP measurements are commensurate with the exchange rate method. It is often argued in the literature that the PPP method of equivalent GDP should be used to obtain valid cross-national comparisons (Reister, 1987). This study chooses the PPP method to measure GDP.

There are three inputs and one output factor analyzed in this study. As for energy, the three inputs are capital stock, labor employment, and energy consumption. With respect to CO_2 emissions, the three inputs are capital stock, labor employment, and CO_2 emissions. The single output is all selected as real growth, gross domestic production (GDP) using purchasing power parties. It is expressed in 1995 US dollars. The data of GDP using purchasing power parties and the total energy consumption are from *Energy Balances of OECD Economies* (IEA, 2002a) and *Energy Balances of Non-OECD Economies* (IEA, 2002b). The data of CO_2 emissions comes from Marland et al. (2005).

The data of labor and capital stock come from the *Penn World Tables* (Heston et al., 2002). Multiplying capital stock per worker by labor retrieves the capital stock. However, for China, Indonesia, Malaysia, and Singapore, the data on capital stock per worker are not available. They are calculated using the perpetual inventory method:

$$K_t = I_t + (1-\delta)K_{t-1}, \tag{15}$$

where I_t denotes gross investment, which is estimated by first multiplying the real investment share by real GDP, at time t; and δ is the depreciation rate.

The choice of the rate of depreciation is problematic due to the difference between the developed economies and the developing ones. The perception is that developed economies can afford to update their equipment and apply new technology. Thus, the rate of depreciation of those economies may be greater than that of the developing ones. However, due to their backwardness and hence the leapfrogging effects, some developing economies may actually be able to adopt new technology faster than developed economies. Unless detailed data at the sector or firm level are available, it is difficult to derive a precise rate of depreciation (Wu, 2004). While the potential impact of the choice of the rate of depreciation is noted, due to data constraints this paper applies a unified rate of depreciation of 5%.

The units of real GDP, real capital, labor, energy consumption, and CO_2 emissions are billions of US$, billions of US$, 10,000 people, millions tons of oil equivalent (Mtoe), and millions tons of carbon (Mt-C), respectively. Table 5 lists the average annual amounts and growth rates of real GDP, labor, real capital, energy consumption, and CO_2 emissions for 17 APEC economies. The United States, China, and Japan are the first three having real GDP, labor, real capital, energy consumption, and CO_2 emissions among APEC economies. China has the highest growth rate of real GDP (9.2%). However, the growth rates of energy consumption and CO_2 emission, 1.1% and 0.9% respectively, in China are far less than average of those, 4.1% and 3.4%, among APEC economies. Singapore with the second highest economic growth rate only has the modest growth rates of energy consumption and CO_2 emissions with the second highest growth rate of labor. The East Asian economies, with the exception of Japan, Indonesia, and the Philippines, indeed achieved high economic growth in the 1990s. In those economies, high economic growth rates matched the rapid expansion of capital stocks. On the other hand, the average labor growth was rather modest and quite even across all APEC economies. Energy consumption and CO_2 emissions growth rates also exhibited a similar pattern with real GDP growth rates. As Table 5 shows, the Southeast Asian economies, except Singapore, have the highest average annual growth rates in energy consumption and CO_2 emissions. Among APEC economies, Hong Kong, the only one economy with negative growth rate of labor but the highest growth rate of real capital, has the highest average energy consumption growth rate (9.4%), Malaysia has the highest average CO_2 emissions growth rate (7.1%), and Mexico has both the lowest growth rate (0.2%) in energy consumption and CO_2 emissions. We also can find that the energy consumption and CO_2 emissions has very high correlation. That means that an economy consuming more energy emits more CO_2.

Table 6 shows the percentages in total energy consumption and CO_2 emissions of APEC economies. The United States is the largest energy-consuming and CO_2-

emitting economy with almost half of the total energy consumption. For the other half of energy consumption, China, Japan, and Canada consume respectively around 20%, 11%, and 7% of the total energy consumption during the research period. The other 13 economies use only less than 13% of total energy consumption. The United States, China, and Japan, the largest three CO_2-emitting economies, have about eighty percentages of the total CO_2 emissions. During the ten years, the percentage in total energy consumption and CO_2 emissions does not change drastically among APEC economies.

Table 5 Average annual amounts and growth rates of real GDP, real capital, labor, and energy consumption (1991-2000)

Economies	Real GDP		Real Capital		Labor		Energy Consumption		CO_2 Emissions	
	Billions US$	%	Billions US$	%	10,000 people	%	Mtoe	%	Mt-C	%
Australia	402.83	3.7	688.69	8.2	892.84	1.4	64.71	2.2	83.33	2.9
Canada	707.86	2.9	1287.13	7.9	1500.7	1.2	126.45	1.9	121.54	1.8
Chile	112.04	5.8	155.5	13.3	551.45	2.0	11.2	5.6	13.11	5.9
China	3394.72	9.2	4122.14	14.7	73080.42	0.9	561.2	1.1	802.85	0.9
Hong Kong, China	138.49	3.2	226.59	15.5	329.07	-0.2	10.77	9.4	8.85	2.5
Indonesia	541.37	3.3	1033.7	7	7763.12	1.9	50.88	6.1	56.36	3.5
Japan	3079.92	1.1	7183.32	7.9	7963.75	0.3	326.69	1.4	309.39	0.8
South Korea	620.89	5.2	1304.9	12.7	1904.38	1.2	105.29	6.1	98.4	4.9
Malaysia	154.71	6.1	263.4	16.6	739.56	2.5	22.14	7.2	29.06	7.1
Mexico	723.02	3.1	958.6	9.6	3169.47	1.8	94.15	0.2	101.48	0.2
New Zealand	64.27	2.8	107.59	7.6	172.7	1.4	11.87	3.2	7.81	3.0
Peru	102.7	3.8	144.6	8.8	1005.13	4.3	7.59	3.6	6.77	3.2
Philippines	255.98	2.9	226.56	9.7	2791.67	2.5	14.57	6.2	17.34	5.5
Singapore	69.89	7.0	274.78	7.8	179.55	3.2	8.74	4.2	14.75	2.4
Taiwan	324.35	5.4	518.57	8.3	934.49	0.9	41.98	4.4	48.21	5.9
Thailand	341.43	3.5	748.04	13.6	3143.27	0.9	35.27	6.3	46.98	5.7
United States	7758.29	3.3	11191.59	10.1	13395.57	1.3	1400.83	1.4	1446.39	1.9
Average	1105.46	4.2	7030.42	1.6	1709.34	10.5	170.25	4.1	188.98	3.4

Notes: (1) Statistics in the 'GDP,' 'Capital,' 'Labor,' 'Energy,' and 'CO_2 Emissions' columns are mean percentage rates of growth. (2) The base year for real GDP and real capital is 1995. (3) Source: *Penn World Tables*, *IEA Statistics 2002 Edition*, Marland et al. (2005).

A correlation matrix is given in Table 7 that shows a high correlation exists between input and output factors selected for this analysis among APEC economies. As shown in Table 7, all inputs have positive correlation coefficients with the output. That is, all inputs satisfy the isotonicity property with the output. Labor employment, capital stock, energy consumption, and CO_2 emissions do actually correlate to GDP performance in this analysis model. The correlation coefficients between energy input and GDP output and CO_2 emissions and GDP are calculated as 0.98 and 0.97, respectively, which are statistical significant. The relation reveals that the more energy is consumed, the more GDP is generated. The more GDP is generated, the more CO_2 is emitted. However, energy efficiency and CO_2 abatement efficiency need to be analyzed in this study in order to learn individual efficiency scores for all APEC economies.

Table 6 Percentage in total energy consumption and CO_2 emissions of APEC economies in 1991, 1995, and 2000

	1991		1995		2000	
	Energy Consumption	CO_2 Emissions	Energy Consumption	CO_2 Emissions	Energy Consumption	CO_2 Emissions
Australia	2.18	2.52	2.16	2.48	2.26	2.78
Canada	6.01	3.96	5.93	3.75	6.09	3.93
Chile	0.31	0.32	0.38	0.37	0.45	0.48
China	18.95	24.19	19.83	26.81	17.68	22.15
Hong Kong, China	0.27	0.26	0.33	0.25	0.55	0.28
Indonesia	1.39	1.55	1.67	1.56	2.11	1.81
Japan	11.45	10.49	11.08	9.53	10.97	9.48
South Korea	2.69	2.55	3.63	3.13	4.09	3.42
Malaysia	0.55	0.65	0.74	1.00	0.93	1.08
Mexico	3.47	3.56	3.23	3.08	2.96	3.04
New Zealand	0.38	0.24	0.40	0.23	0.44	0.26
Peru	0.24	0.2	0.26	0.21	0.28	0.23
Philippines	0.36	0.44	0.50	0.53	0.56	0.62
Singapore	0.26	0.43	0.29	0.39	0.33	0.45
Taiwan	1.24	1.15	1.39	1.46	1.59	1.70
Thailand	0.86	1.11	1.25	1.52	1.33	1.61
United States	49.39	46.37	46.92	43.70	47.40	46.67

Note: The unit is percentage.

Table 7 Correlation Coefficients between inputs and the output for APEC economies

	Real Capital Stock	Labor	Energy Consumption	CO_2 Emission
Real GDP	0.95	0.46	0.98	0.97

Chapter 4 Empirical Analysis

4.1 Energy-saving targets for APEC economies

Each economy's ESTR is also calculated. Table 8 reports the summary of ESTR based on Equation (7) for each economy. Table 9 shows EST for each APEC economies. Table 10 presents the per capita EST for each economy. Several interesting observations are summarized as follows.

Table 8 Summary of ESTR for each APEC economy (1991-2000)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Australia	10.81	10.73	12.69	14.61	13.18	10.76	8.45	5.12	4.25	6.45
Canada	22.63	25.34	26.16	26.49	26.84	28.74	29.59	29.01	29.48	30.42
Chile	47.12	38.38	37.63	3.97	0.00	0.00	0.07	0.00	2.72	2.42
China	82.75	79.53	75.42	69.97	66.89	64.99	59.14	56.12	49.95	48.95
Hong Kong, China	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indonesia	46.04	40.01	37.50	31.02	28.59	29.86	29.31	35.22	37.67	39.65
Japan	1.83	3.22	10.13	16.60	17.21	16.49	17.03	10.62	10.05	1.41
South Korea	30.99	31.44	36.71	31.81	28.53	28.02	27.62	27.87	23.90	21.13
Malaysia	59.11	52.74	51.61	15.26	16.25	16.37	17.95	24.49	23.13	22.35
Mexico	59.49	52.13	51.52	3.97	7.61	3.44	0.31	0.00	0.00	0.00
New Zealand	20.56	22.90	31.55	15.36	12.85	12.60	13.05	15.07	15.17	21.86
Peru	31.19	15.28	23.49	13.23	13.41	16.41	12.06	7.94	12.21	9.47
Philippines	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Singapore	21.76	20.23	18.54	19.31	17.39	16.10	14.72	11.62	8.07	3.84
Taiwan	27.21	25.38	42.61	16.67	9.39	5.02	0.74	0.00	0.00	0.00
Thailand	40.14	33.70	33.50	30.80	33.33	37.15	38.82	33.87	31.81	27.29
United States	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	29.51	26.53	28.77	18.18	17.15	16.82	15.81	15.11	14.61	13.84

Note: (1) The unit is percentage. (2) Scores with a gray background are those reached at the best efficiency with zero score.

1. The ESTR score generally decreases for the APEC economies during the period considered. As seen in Table 8, the APEC economies, except Canada and New Zealand, have become more efficient in energy efficiency and energy-saving efficiency over time. In the late 1990s, they improved their energy efficiency

and were closer to the frontier than in the beginning. We separate the samples into developed and developing groups: developed economies included Australia, Canada, Hong Kong, Japan, New Zealand, Singapore, and the United Sates. The other economies belong to the developing group. Since developed economies could afford to update equipment and apply new technologies, they have lower ESTR scores than those in the developing group.

2. The ESTR scores of all the Asian economies but four (Hong Kong, Japan, Singapore, and Taiwan) are higher than the average scores during the research period. Neither any of the Central nor the South American economies are efficient EST economies. Their ESTRs are much lower than the Asian economies under a similar growth level.

3. China has the largest EST with almost half the amount of its current usage even as it owns the highest development growth rate from 1991 to 2000. China can save around 50% of the amount of its current energy consumption by improving technology efficiency without reducing the high production level. As seen in Table 9, the EST of China in 2000 is 273.67 Mtoe by 65% of the total APEC's EST. China plays a key role in energy saving and environmental protection in the association of APEC economies. However, the ESTR score decreased from 83% in 1991 down to 50% in 2000. An improvement in energy efficiency and technical and structural changes has been identified as the main factor that caused the fall in ESTR in China (Crompton and Wu, 2005).

4. Hong Kong, the Philippines, and the United States have the 'best practice' among APEC economies and have the complete know-how of production function. They have the lowest ESTR rankings with zero over the 1990s among APEC economies. Chile, Mexico, and Taiwan significantly improved their energy efficiency in the last 7 years of the 1990s. Mexico and Taiwan possess an ESTR value of zero in the latter three years of the research period. Chile's ESTR scores are at zero from 1995 to 1996 and 1998, but then increase slightly

in the last 2 years. These economies can share their know-how with others to improve energy efficiency in the international association by trade agreement.

Table 9 Energy-saving target for each APEC economy (1991-2000)

	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Australia	6.24	6.25	7.68	9.05	8.46	7.13	5.72	3.54	2.97	4.62
Canada	36.02	41.15	43.59	45.69	47.26	52.54	54.76	52.41	55.05	58.55
Chile	3.92	3.55	3.72	0.41	0.00	0.00	0.01	0.00	0.38	0.35
China	415.11	412.20	404.59	396.01	393.91	405.19	343.43	327.29	276.80	273.67
Hong Kong, China	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indonesia	16.95	15.58	16.21	14.35	14.17	16.43	16.58	19.59	22.63	26.45
Japan	5.56	9.90	31.26	52.97	56.62	55.37	57.82	35.61	34.38	4.89
South Korea	22.06	25.62	32.81	31.64	30.75	32.52	34.12	31.14	29.40	27.30
Malaysia	8.66	8.58	9.17	2.91	3.55	3.91	4.67	6.26	6.23	6.55
Mexico	54.60	48.96	48.42	3.84	7.30	3.24	0.29	0.00	0.00	0.00
New Zealand	2.08	2.38	3.36	1.73	1.52	1.55	1.63	1.90	2.02	3.02
Peru	1.94	0.94	1.52	0.91	1.03	1.34	0.99	0.65	1.10	0.84
Philippines	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Singapore	1.49	1.34	1.35	1.56	1.51	1.51	1.48	1.17	0.82	0.40
Taiwan	8.91	8.89	15.79	6.65	3.89	2.18	0.33	0.00	0.00	0.00
Thailand	9.16	8.56	9.66	10.06	12.40	15.54	16.40	13.07	13.02	11.52
United States	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	34.87	34.94	37.01	33.99	34.26	35.20	31.66	28.98	26.16	24.60

Note: (1) The unit is millions of tons of oil equivalent (Mtoe). (2) Scores with a gray background are those reached at the best efficiency with zero score.

5. Canada and New Zealand are the two exceptions among APEC economies with decreasing total-factor energy efficiency when energy input is considered. Canada's ESTR score is 0.23 in 1991 and adds up to 0.30 in 2000. New Zealand improved its energy efficiency in the middle of the observed period. However, her ESTR score increased to 0.22 in 2000, which was higher than that in 1991. The same pattern applies to per capita EST in Table 10. These two developed economies have to face the situation seriously in order to be a part of the APEC economies.

Table 10 Per capita energy-saving targets for each APEC economies (1991-2000)

	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Australia	0.36	0.36	0.44	0.51	0.47	0.39	0.31	0.19	0.16	0.24
Canada	1.29	1.45	1.52	1.57	1.61	1.77	1.83	1.73	1.81	1.90
Chile	0.29	0.26	0.27	0.03	0.00	0.00	0.00	0.00	0.03	0.02
China	0.36	0.35	0.34	0.33	0.33	0.33	0.28	0.26	0.22	0.22
Hong Kong, China	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indonesia	0.09	0.08	0.09	0.08	0.07	0.08	0.08	0.10	0.11	0.13
Japan	0.04	0.08	0.25	0.41	0.45	0.44	0.46	0.28	0.27	0.04
South Korea	0.51	0.59	0.74	0.71	0.68	0.71	0.74	0.67	0.63	0.58
Malaysia	0.46	0.45	0.47	0.14	0.17	0.19	0.22	0.28	0.27	0.28
Mexico	0.64	0.57	0.55	0.04	0.08	0.03	0.00	0.00	0.00	0.00
New Zealand	0.60	0.68	0.95	0.48	0.42	0.52	0.43	0.50	0.53	0.79
Peru	0.09	0.04	0.07	0.04	0.04	0.06	0.04	0.03	0.04	0.03
Philippines	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Singapore	0.48	0.42	0.41	0.46	0.43	0.41	0.39	0.30	0.21	0.10
Taiwan	0.43	0.43	0.76	0.32	0.18	0.10	0.02	0.00	0.00	0.00
Thailand	0.16	0.15	0.17	0.17	0.21	0.26	0.28	0.22	0.22	0.19
United States	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	0.34	0.35	0.41	0.31	0.30	0.31	0.30	0.27	0.27	0.27

Note: The unit is tons of oil equivalent (toe) per person.

6. Chile, Malaysia, Mexico, and Taiwan enjoy a jump in ESTR from 1993 to 1994. The increment range is from 26% to 38%. There are two opposite reasons for this situation. One is that these three economies improved their productivity and efficiency, pushing them closer to the frontier. The opposite one is that other economies' efficiency turned lower and hence pushed these economies up to the efficiency frontier. The result may be caused by a combination of these two reasons. However, the distance between the frontier and these three economies (i.e., EST) was shortened and held for the rest of the period.

7. As Table 10 shows, Canada has the highest per capita EST by 1.9 tons of oil equivalent (toe). Canada has to intensively promote its energy efficiency in the agricultural, manufacturing, residential, commercial, and transportation sectors. However, Canada is an outlier. Its per capita EST is too high compared with

other economies. People in South Korea and New Zealand also have to save more energy than other economies for their high per capita total-factor EST.

4.2 CO_2 abatement targets for APEC economies

Each economy's CATR is also calculated. Table 11 reports the summary of ESTR based on Equation (7) for each economy. Table 12 shows the percentage of total APEC's CAT. Table 13 presents the per capita CAT for each economy. Several interesting observations are summarized as follows.

Table 11 Summary of CATR for each APEC economy (1991-2000)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Australia	15.06	16.49	15.93	17.01	14.65	13.24	11.16	10.64	13.05	16.56
Canada	5.73	9.11	10.63	11.19	12.61	13.67	13.79	8.38	7.23	10.06
Chile	44.58	35.89	30.72	4.12	0.49	0.98	1.47	0.57	7.54	6.22
China	83.67	80.52	79.07	76.66	74.43	73.46	67.28	63.13	59.39	54.24
Hong Kong, China	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indonesia	44.07	41.82	41.45	40.41	29.73	37.01	36.02	33.85	30.16	35.46
Japan	0.00	4.07	9.95	18.75	19.15	18.83	18.92	12.73	12.73	19.80
South Korea	38.91	41.29	43.27	42.13	39.46	39.10	38.09	36.70	32.91	32.69
Malaysia	62.50	59.52	62.18	15.89	21.89	20.03	21.79	25.66	25.49	31.16
Mexico	60.00	58.23	53.19	8.09	11.87	7.89	3.42	1.09	4.00	3.44
New Zealand	8.13	14.38	15.23	15.08	9.26	7.93	6.66	1.57	2.96	7.38
Peru	13.91	9.46	16.17	8.30	2.30	3.40	0.51	0.00	0.00	1.45
Philippines	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Singapore	34.07	34.02	31.39	31.80	24.08	23.84	24.36	23.27	21.11	21.98
Taiwan	22.21	26.15	46.83	15.26	9.31	5.25	1.63	0.00	0.00	0.00
Thailand	48.52	43.91	44.14	39.79	38.11	38.99	40.87	41.74	40.33	40.45
United States	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	28.31	27.93	29.42	20.26	18.08	17.86	16.82	15.26	15.11	16.52

Note: (1) The unit is percentage. (2) Scores with a gray background are those reached at the best efficiency with zero score.

1. The CATR score generally decreases for the APEC economies during the period considered, but the CATR score increases slightly in 2000. As Table 11 shows, except Australia, Canada, and Japan, the APEC economies have become more efficient in CO_2 abatement and CO_2-reducing efficiency over time. In the late

1990s, they improved their energy efficiency and were closer to the frontier than in the beginning.

2. The developed group includes Australia, Canada, Hong Kong, Japan, New Zealand, Singapore, and the United Sates. The other economies belong to the developing group. Since developed economies could afford to update equipment and apply new technologies, they have lower CATR scores than those in the developing group.

3. The CATR scores of all the Asian economies but four (Hong Kong, the Philippines, and Taiwan) are higher than the average scores during the research period. Neither any of the Central nor the South American economies are efficient CAT economies. However, their CATRs are much lower than the Asian economies under a similar growth level.

4. China has the largest CAT with more than half amount of its current usage even as it owns the highest development growth rate from 1991 to 2000. China can reduce around 54% of the amount of its current CO_2 emissions by improving the technology of capture and geological storage of CO_2 without reducing the high production level. As Table 12 shows, the CAT of China in 2000 is 409.7 t-C per person by 68% of the total APEC's CAT. China plays a key role in CO_2 abatement and environmental protection in the association of APEC economies. However, the CATR score decreased from 84% in 1991 down to 54% in 2000.

5. Southeast Asian Economies and South Korea, except for the Philippines, lie on the second high CATR score group. Thailand can reduce around 40% of the amount of its current CO_2 emissions in 2000 without reducing the high production level. South Korea, Indonesia, and Malaysia car reduce more than 30% of it current CO_2 emissions. Even for Singapore, its CATR score is 21.98% which is higher than average. Those economies have to take the responsibility for the global warming and environmental degradation.

Table 12 CO_2 abatement target for each APEC economy (1991-2000)

	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Australia	10.78	12.27	12.17	13.42	11.84	11.38	9.64	9.57	12.27	15.72
Canada	6.45	10.43	12.59	12.69	15.39	16.86	18.17	10.07	9.05	13.48
Chile	4.09	3.44	2.99	0.46	0.06	0.14	0.23	0.09	1.29	1.01
China	575.30	580.83	601.32	618.94	649.60	669.57	603.87	535.31	455.49	409.70
Hong Kong, China	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indonesia	19.39	20.92	22.57	22.34	15.12	25.45	24.83	18.10	16.87	21.92
Japan	0.00	12.29	29.31	57.85	59.43	60.00	60.34	39.19	39.75	63.98
South Korea	28.15	32.70	37.48	39.42	40.24	43.53	44.06	36.41	35.35	38.13
Malaysia	11.54	12.07	15.34	4.02	7.11	6.68	7.69	8.09	8.30	11.43
Mexico	60.75	62.85	53.63	8.57	11.89	7.90	3.23	1.09	4.03	3.56
New Zealand	0.55	1.02	1.05	1.08	0.68	0.66	0.58	0.13	0.26	0.67
Peru	0.79	0.54	1.07	0.54	0.15	0.22	0.04	0.00	0.00	0.11
Philippines	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Singapore	4.14	4.20	4.56	5.57	3.08	3.49	4.25	3.57	3.22	3.39
Taiwan	7.27	10.47	20.21	6.81	4.44	2.63	0.87	0.00	0.00	0.00
Thailand	15.37	15.19	17.16	17.17	18.86	21.55	23.41	21.21	21.66	22.24
United States	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	43.80	45.84	48.91	47.58	49.29	51.18	47.13	40.17	35.74	35.61

Note: (1) The unit is millions tons of carbon (Mt-C). (2) Scores with a gray background are those reached at the best efficiency with zero score.

6. Hong Kong, the Philippines, and the United States have the 'best practice' among APEC economies and have the complete know-how of production function. They have the lowest CATR rankings with zero over the 1990s among APEC economies. Peru and Taiwan significantly improved their CO_2 abatement efficiency in the last three years of the 1990s. Taiwan possesses a CATR value of zero in the latter part of the research period. Peru's CATR scores are at zero in 1998 and 1999, but then increase slightly in the last year. These economies can share their know-how with others to improve CO_2 abatement efficiency in the international association by trade agreement.

7. As Table 11 shows, Australia, Canada, and Japan are the three exceptions among APEC economies with decreasing total-factor CO_2 abatement efficiency when CO_2 input is considered. They improved their CO_2 abatement efficiency in the

middle of the observed period. However, their CATR scores increased in 2000 and were higher than that in 1991. These three developed economies have to face the situation seriously in order to be a part of the APEC economies. Australia and Canada reject the Kyoto Protocol (the New Scientist website, 2005; Vedantam, 2005). The decreasing CATR can represent their position and tell the truth what are they really concern to reject the Kyoto Protocol.

8. Japan was on the frontier in 1991, and then the CO_2 abatement efficiency decreased with CATR score which is 19.80% higher than the average score in 2000. Its per capita CO_2 abatement target is 0.5 t-C per person in 2000 as seen in Table 13. The result may explain why that Japan needs to trade CO_2 emissions with China in order to achieving its commitment with the Kyoto Protocol.

Table 13 Per capita CO_2 abatement targets for each APEC economies (1991-2000)

	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Australia	0.62	0.70	0.69	0.75	0.66	0.62	0.52	0.51	0.65	0.82
Canada	0.23	0.37	0.44	0.44	0.52	0.57	0.61	0.33	0.30	0.44
Chile	0.31	0.25	0.22	0.03	0.00	0.01	0.02	0.01	0.09	0.07
China	0.50	0.50	0.51	0.52	0.54	0.55	0.49	0.43	0.36	0.32
Hong Kong, China	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indonesia	0.11	0.11	0.12	0.12	0.08	0.13	0.12	0.09	0.08	0.10
Japan	0.00	0.10	0.24	0.45	0.47	0.48	0.48	0.31	0.31	0.50
South Korea	0.65	0.75	0.85	0.88	0.89	0.96	0.96	0.78	0.75	0.81
Malaysia	0.62	0.63	0.78	0.20	0.35	0.32	0.35	0.36	0.37	0.49
Mexico	0.72	0.73	0.61	0.10	0.13	0.09	0.03	0.01	0.04	0.04
New Zealand	0.16	0.29	0.30	0.30	0.19	0.18	0.15	0.03	0.07	0.17
Peru	0.04	0.02	0.05	0.02	0.01	0.01	0.00	0.00	0.00	0.00
Philippines	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Singapore	1.33	1.31	1.38	1.64	0.88	0.94	1.12	0.92	0.81	0.85
Taiwan	0.35	0.50	0.97	0.32	0.21	0.12	0.04	0.00	0.00	0.00
Thailand	0.27	0.27	0.30	0.29	0.32	0.37	0.39	0.35	0.36	0.37
United States	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	0.35	0.38	0.44	0.36	0.31	0.31	0.31	0.24	0.25	0.29

Note: The unit is tons of carbon (t-C) per person.

9. The United States is the other economy rejecting the Kyoto Protocol. As the result of this study, the United States is the 'best practice' of CO_2 abatement. If the reduction of CO_2 emission wants to upgrade, government and industry have to invest a lot of cost and research the new technology. Otherwise, the reduction of CO_2 emissions may hamper the United States' economic growth. Under the consideration of real output, the United States has to refuse to approval the Kyoto Protocol.

4.3 Relation between EST and GDP for APEC economies

We use the Hausman test and then reject the random-effects model at a 5% level (CHISQ = 5.05, *p*-value = .08). Table 14 presents the relation of per capita EST and per capita GDP for APEC economies. We find that an inverted U-shape relation exists. The inverted U-shape relation is established between the per capita EST, increases with per capita income at low levels of income, and then decreases once a threshold level of per capita income level is reached. According to this relation, a developing economy should pay more attention to energy-saving issues than developed and less-developing economies.

Table 14 Relation between per capita energy-saving target and per capita GDP for APEC economies (random-effects panel data model estimation)

Variable	Coefficient	*t*-statistic	*p*-value
per capita GDP	220.01	4.184	<0.001***
(per capita GDP)^2	-7.63	-4.404	<0.001***
Constant	-198.69	-.626	0.531
R^2		0.104	

Note: ***represents significance at the 0.01 level.

4.4 Relation between CAT and GDP for APEC economies

The Hausman test shows that the random-effects model at a 5% level is not rejected (CHISQ = 0.03, *p*-value = .98). Table 15 presents the relation of per capita

CAT and per capita GDP. It shows a similar scenario to the environmental Kuznets curve (EKC). An inverted U-type relationship, commonly referred as the environmental Kuznets curve, as seen in Figure 7, has been established between the environmental degradation increases with income at low levels of income and then decreases once a threshold level of per capita income level is reached (Grossman and Krueger 1995). The inverted U-shape relation is established between the per capita CAT, increases with per capita income at low levels of income, and then decreases once a threshold level of per capita income level is reached. Although CO_2 emissions, generally speaking, increase along with economic development, and accordingly income level, they might turn to a decline after a certain threshold as the hypothesis of EKC argues. According to this relation, a developing economy should pay more attention to CO_2 abatement issues than developed and less-developing economies.

Table 15 Relation between per capita CO_2 abatement target and per capita GDP for APEC economies (random-effects panel data model estimation)

Variable	Coefficient	*t*-statistic	*p*-value
per capita GDP	66.93	5.691	<0.001***
(per capita GDP)^2	-2.09	-5.368	<0.001***
Constant	-41.32	-.579	0.563
R^2		0.157	

Note: ***represents significance at the 0.01 level.

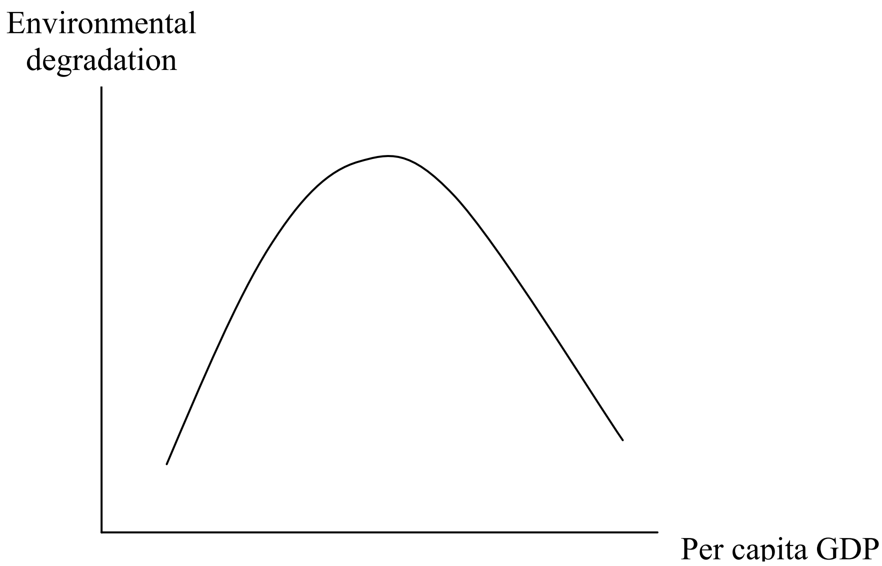


Figure 7 Environmental Kuznets curve

4.5 Comparison to partial-factor indicators

4.4.1 Comparison to partial-factor energy efficiency

Table 16 shows that the partial-factor energy efficiency, energy intensities, of all economies except China and Hong Kong are steady with small changes. Peru and the Philippines are the two most efficient economies, and Canada is the worst. China improved its energy efficiency, but Hong Kong's efficiency was decreasing at the same time. We compare the total-factor ESTR to energy intensity as the inverse of partial-factor energy efficiency by applying the Wilcoxon signed rank test. The result of Wilcoxon signed rank test ($W_+ = 96$, $W_- = 74$, $Z = -2.716$, p-value < 0.01) between the energy intensity and ESTR is significant at the 5% level, showing that the total-factor energy efficiency has significantly different rank patterns with the partial-factor energy efficiency. In addition, the relation between energy intensity and per capita GDP does not have a significant pattern as with the inverted U-shape relation between per capita ESTR and per capita GDP. This shows a significant substitution effect of other inputs such as labor and capital on the energy input to produce the GDP. The energy efficiency could be over-estimated or under-estimated if energy consumption is taken as a single input in the production. A certain portion of GDP output is produced not only by energy input, but also by labor and capital. This study hence applies a total-factor framework, with which the total-factor ESTR is established.

Table 16 Energy intensity for each APEC economies (1991-2000)

	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Australia	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.15	0.15	0.15
Canada	0.26	0.26	0.26	0.26	0.25	0.26	0.25	0.24	0.24	0.23
Chile	0.11	0.10	0.10	0.10	0.10	0.10	0.11	0.10	0.11	0.10
China	0.25	0.23	0.21	0.19	0.18	0.18	0.15	0.14	0.12	0.12
Hong Kong, China	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.09	0.09	0.11
Indonesia	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.11	0.11
Japan	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11
South Korea	0.15	0.16	0.17	0.17	0.17	0.17	0.18	0.17	0.17	0.16
Malaysia	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.15	0.15	0.15
Mexico	0.14	0.14	0.14	0.14	0.15	0.14	0.13	0.12	0.11	0.11
New Zealand	0.18	0.19	0.18	0.18	0.18	0.18	0.18	0.19	0.19	0.19
Peru	0.08	0.07	0.08	0.07	0.07	0.08	0.07	0.07	0.08	0.07
Philippines	0.04	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Singapore	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.12	0.11
Taiwan	0.13	0.13	0.13	0.14	0.13	0.13	0.13	0.13	0.12	0.12
Thailand	0.09	0.09	0.09	0.10	0.10	0.11	0.11	0.11	0.11	0.11
United States	0.20	0.19	0.19	0.19	0.19	0.19	0.18	0.17	0.17	0.16
Average	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13

Note: The unit is toe/US$1000 purchasing power parity, at 1995 international prices.

4.4.2 Comparison to partial-factor CO_2 intensity

Table 17 shows that the partial-factor CO_2 intensities, of all economies except China and Singapore are steady with small changes. Hong Kong, Peru, and the Philippines are the three most efficient economies, and Australia is the worst. China improved its CO_2 intensity, but Chile's CO_2 intensity was increasing slightly at the same time. By applying Wilcoxon signed-rank test to compare the total-factor CATR to CO_2 intensity, the result ($W_+ = 87$, $W_- = 83$, $Z = -2.129$, p-value = 0.03) is significant at the 5% level and shows that the total-factor CATR has significantly different rank patterns with the partial-factor CO_2 intensity. In addition, the relation between CO_2 intensity and per capita GDP does not have a significant pattern as with the inverted U-shape relation between per capita CATR and per capita GDP. This shows a significant substitution effect of other inputs such as labor and capital on the energy input to produce the GDP. The CO_2 abatement efficiency could be over-estimated or under-estimated if CO_2 emission is taken as a single factor to measure. This study hence applies a total-factor framework, with which the total-factor IRTR is established.

Table 17 CO_2 intensity for each APEC economies (1991-2000)

	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Australia	0.21	0.21	0.21	0.21	0.21	0.21	0.20	0.20	0.20	0.20
Canada	0.18	0.19	0.19	0.17	0.18	0.18	0.18	0.16	0.16	0.16
Chile	0.12	0.11	0.11	0.11	0.11	0.12	0.13	0.13	0.13	0.12
China	0.35	0.32	0.30	0.28	0.27	0.26	0.24	0.21	0.18	0.16
Hong Kong, China	0.07	0.07	0.08	0.06	0.06	0.05	0.05	0.07	0.08	0.06
Indonesia	0.11	0.11	0.11	0.11	0.09	0.11	0.11	0.10	0.10	0.11
Japan	0.11	0.11	0.10	0.11	0.11	0.11	0.10	0.10	0.10	0.10
South Korea	0.18	0.19	0.20	0.20	0.20	0.20	0.20	0.18	0.18	0.18
Malaysia	0.17	0.18	0.20	0.18	0.21	0.20	0.20	0.19	0.18	0.19
Mexico	0.17	0.17	0.16	0.16	0.16	0.15	0.14	0.14	0.13	0.13
New Zealand	0.13	0.13	0.12	0.12	0.12	0.13	0.13	0.12	0.12	0.13
Peru	0.07	0.07	0.08	0.07	0.07	0.06	0.06	0.06	0.07	0.07
Philippines	0.06	0.06	0.06	0.07	0.07	0.07	0.08	0.08	0.07	0.07
Singapore	0.26	0.25	0.26	0.28	0.19	0.20	0.22	0.20	0.18	0.17
Taiwan	0.13	0.15	0.16	0.15	0.15	0.15	0.15	0.15	0.14	0.14
Thailand	0.12	0.12	0.13	0.13	0.14	0.14	0.15	0.15	0.15	0.15
United States	0.20	0.20	0.20	0.20	0.19	0.19	0.19	0.18	0.18	0.18
Average	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.14	0.14	0.14

Note: The unit is toe/US$ billion purchasing power parity, at 1995 international prices.

4.6 Relation among ESTR and industrial structure indicators

We use panel data regression models to find out the relation between industrial structure and ESTR. Fifteen economies are selected, except South Korea and Singapore, since there is a limitation of data. The data of value-added percents of GDP by industry and service sectors for every economy are taken from *World*

Development Indicators (World Bank, 2005). The Hausman test does not reject the random-effects model at the 5% level (CHISQ = 0.70, *p*-value = .71). In the random-effects model's estimates shown in Table 18, ESTR has a positive relation with value-added percent of GDP by industry sector and a negative relation with that of the service industry - that is, ESTR increases with industrialization and then decreases with the rising service industries. According to this relation, a newly industrializing economy will have lower total-factor energy efficiency than agriculture-dominant and service-dominant economies. The industrial structure of an economy is hence a crucial factor for energy efficiency and thus the energy-saving ratio. An industry-dominant economy can improve its energy efficiency and save energy more efficiently and effectively via shifting the economy structure toward services.

Due to data limitation, we can only find the retail prices of oil in 1997 for 17 economies from APERC (2000). However, there is neither a significant relation found between ESTR and the retail price of oil nor one between per capita EST and the retail price of oil. This may be because energy prices alone cannot determine the total energy efficiency and energy saving of an economy. The structure of energy mixes, energy efficiency, taxation, and relative prices for all energy resources includes the factors influencing energy use and the energy saving of an economy.

Table 18 Relation among ESTR and industrial structure indicators for APEC economies (random-effects panel data model estimation)

Variable	Coefficient	*t*-statistic	*p*-value
Value-added percentage of GDP by the industry sector	0.60	2.328	0.020**
Value-added percentage of GDP by the service sector	-0.73	-3.991	<0.001***
Constant	0.41	2.291	0.022**
R^2		0.432	

Note: **represents significance at the 0.05 level; ***represents significance at the 0.01 level.

4.7 Relation among CATR and industrial structure indicators

The same dataset as 4.2.1 is used with panel data regression models to find out the relation between industrial structure and CATR. The Hausman test does not reject the random-effects model at the 5% level (CHISQ = 0.97, *p*-value = .61). In the random-effects model's estimates shown in Table 19, CATR has not a significant relation with value-added percent of GDP by industry sector, but has a significant negative relation with that of the service industry – that is, CATR does not change with industrialization but then decreases with the rising service industries. According to this relation, a service-dominant economy has higher total-factor CO_2 abatement efficiency. On the other hand, the industrial structure of an economy may not be a crucial factor for CO_2 abatement and thus the CO_2 abatement ratio.

APEC economies have followed the industrialization pattern of developed countries shifting one after another from labor-intensive to capital-intensive industries, and then recently, even to technology-intensive industries. While technology transfer itself does not necessarily cause such shifts, they are at least promoted thereby. However, we should note that technology transfer could have a double-edged effect on emissions. On the one hand, it can lead to enlarged industrial capacity, resulting in increased pollutant emissions, but on the other hand, abatement technology can be also made available to the recipient economy. Whether the net effect on emissions is positive or negative depends in part on the characteristics of the technology and on levels of public and government awareness (Iwami, 2004).

The former negative effect is related to the degree of industrialization achieved by an economy, whereas the latter positive effect is not easily measured. Because the correlation is either positive or negative, it implies that factors other than the negative effects of technology transfer are, in fact, at work. An "advantage of latecomer" would imply that economies industrializing later would complete the process in a shorter time and/or with better performances. Factors related to this issue include not only technology transfer and initiatives on the part of government and private institutions (for example, banks), but also learning from the experiences of advanced economies. The existence of the "advantage of latecomer" can explain the no significant relation between CATR and value-added percent of GDP by industry sector.

Table 19 Relation among CATR and industrial structure indicators for APEC economies (random-effects panel data model estimation)

Variable	Coefficient	*t*-statistic	*p*-value
Value-added percentage of GDP by the industry sector	0.38	1.431	0.152
Value-added percentage of GDP by the service sector	-1.09	-5.879	<0.001***
Constant	0.68	3.745	<0.001***
R^2		0.521	

Note: **represents significance at the 0.05 level; ***represents significance at the 0.01 level.

Chapter 5 Concluding Remarks

In summary, this paper employs a total-factor framework to analyze the environmental-energy efficiency of APEC economies. The IRT can be obtained by comparing the ideal input amount based on the 'best practice' of the production function and actual input. IRTR as a total-factor input-reducing efficiency indicator is constructed based on the theory of the frontier theory through DEA, which considers multiple input/output simultaneously. IRTR advises energy efficiency and IRT without scarifying real economic output for every economy. When input is the single input to produce GDP output, there might be an over-estimation or under-estimation of efficiency. The IRT and IRTR constructed in this paper are better ways to compute the input usage efficiency and also the input-reducing level.

In terms of environmental-energy policy, energy efficiency and CO_2 abatement are the main issues. In this study a set of environmental-energy efficiency indicators was constructed for macroeconomic level, highlighting the main drivers behind energy consumption and CO_2 emissions trends. The general methodology is a DEA analysis of monetary-based indicators in an economy level. Form the results of DEA approach, we calculate the efficiency indicators of energy saving and CO_2 abatement for APEC economies. The potential of energy saving and CO_2 abatement among APEC economies also are gained from the efficiency indicators. Those results provide an international comparative base for APEC member economies and a clear and identified policy direction for the policy-makers to create their environmental-energy policies according the position of their economies.

From analyzing their environment-energy efficiency in the period from 1991 to 2000, APEC economies have improved their efficiency. In particular, APEC's developed members have performed better than their developing counterparts. Hong Kong, the Philippines, and the United States are the best performers among APEC economies. Taiwan caught up in the later 1990s. In contrast, China has the worst environmental-energy efficiency with the highest percentage of total energy savings and CO_2 abatement among APEC economies. It can save half of its current energy consumption and reduce 50 percent of its CO_2 emissions while keeping the same output level. Furthermore, the environmental-energy efficiencies of the Southeast Asian economies are lower than average.

An inverted U-shape relation is found between per capita EST and per capita real income among APEC economies. Similarly to per capita EST, per capita CAT shows the EKC – an inverted U-shape relation with per capita real income level. The developed economies own a better per capita income, and so the target of environmental-energy savings is a minimum concern. The same thing does not happen to developing economies since these economies consume more energy and emit more CO_2, but at a lower efficiency. According to these findings, the condition of environmental-energy efficiency and potential savings in the Southeast Asian economies should be paid more attention. Developing economies can both pursue their urgent requirements for increased energy services and reduce their environmentally damaging emissions. They cannot exploit resources with 'no regrets' on the one hand, while wanting to reduce energy inputs and emissions in order to achieve a given outcome on the other hand. Developing economies provide more opportunities for energy savings than developed economies, offering significant scope for technology transfer and international trade in consumer products.

Sharing and transferring the knowledge, technology, and know-how from an efficient economy to an inefficient economy is costly in reality. However, those APEC economies with higher environmental-energy efficiency should help the less-efficient economies to improve their environmental-energy efficiency based on their kindness, regional cooperation, and international responsibility by promoting energy conservation and CO_2 abatement and the application of environmental-energy efficiency practices and technologies through advancing the application of demonstrated environmental-energy efficiency practices and technologies, developing and enhancing trade between

APEC economies in products and services, contributing to international efforts to reduce the adverse impacts of energy production and consumption, and improving the analytical, technical, operational and policy capacity for environmental-energy efficiency and conservation within APEC economies. The energy efficiency programs currently implemented in environmental-energy efficient APEC economies could provide an example for other economies in designing national policies. Based the data of 2000, the total energy-saving target of all APEC economies is 418.15Mtoe, taking 13.22% of their total energy consumption. The energy-saving amount will help APEC economies reduce pollution emissions and meet the principles of Kyoto Protocol.

Developing and newly-industrializing economies need not input more resources to maintain their economic growth, but can also save more energy and abate more emissions for sustainable development. Environmental-energy efficiency can be promoted without reducing maximum potential GDPs by importing new technology, improving processes, and changing the industrial structure to reduce wasteful energy use. For example, environmental-energy efficiency can be improved by shifting from energy-intensive industries (such as mining, basic metals, chemicals, and petrochemicals) to less energy-intensive manufacturing and/or service industries, even without more effective energy end-use technologies being implemented.

Even for the same sector, environmental-energy efficiency levels can be different across economies. Older power plants in many developing economies consume from 18% to 44% more fuels per kilowatt-hour of electricity produced than those in industrialized economies (Balce et al., 2001; Pearson and Fouquet, 1996). It is an interesting topic for future research to study how industry-level energy efficiency affects macro-level energy efficiency. However, this type of work needs detailed data for several industries across many economies.

Government agencies, non-profit organizations and the energy sector have to use a variety of instruments and programs to reduce energy consumption, to improve energy efficiency and to mitigate carbon emissions. The goal of environmental-energy efficiency policy is to minimize market barriers and encourage the adoption of energy efficient products and services. Market barriers can include a lack of information about energy efficient products, risk aversion to trying new products and high initial purchase prices. In developing a policy strategy for encouraging energy efficiency, it is beneficial for economies to examine the experiences of other APEC members (APERC, 2001). Through the results of this study, inefficient economies considering policy actions are able to learn valuable lessons from the policy experiences of efficient APEC economies. Greater cooperation within the APEC region may reduce the cost and improve the success rate of new policies.

A range of sound policy principles and practices are identified. It is recognized that not all are appropriate for all APEC economies, but they provide options from which member economies can select, based on their particular circumstances. These practices include environmental impact assessment, environmental and performance standards, market based instruments, monitoring and enforcement, financial and taxation policies, and informative programs. Industrial structure, energy policies, energy consumption type, and treatments from an economic base can be further included. The efficiency frontier shift is another interesting topic to study, which can be conducted by DEA-Malmquist models. As long as the balance between economic growth, energy consumption and CO_2 emissions is reached, sustainable development for APEC economies can be achieved.

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Appendix

Factors and units for calculating CO_2 emissions from fuel production

$$CO_{2i} = (P_i)(FO_i)(C_i)$$

From primary and secondary gas fuel production and trade[1]

CO_{2g} = CO_2 emissions in 10^6 metric tons of carbon

P_g = annual production or consumption in thousands of 10^{12} joules

$FO_g = 0.98 \pm 1\%$

C_g = carbon content in 10^6 tons per thousand 10^{12} joules = $0.0137 \pm 2\%$

From crude oil and natural gas liquids production in the global-total accounts[2]

CO_{2l} = CO_2 emissions in 10^6 metric tons of carbon

P_l = annual production or consumption in 10^6 tons

$FO_l = 0.918 \pm 3\%$

C_l = carbon content in tons C per ton fuel = $0.85 \pm 1\%$

From primary and secondary liquid fuel production and trade in the national accounts when non-energy liquid products are specifically subtracted[3]

CO_{2l} = CO_2 emissions in 10^6 metric tons of carbon

P_l = annual production or consumption in 10^6 tons

$FO_l = 0.985 \pm 3\%$

C_l = carbon content in tons C per ton fuel = $0.85 \pm 1\%$

From liquid bunker fuel consumption[4]

CO_{2l} = CO_2 emissions in 10^6 metric tons of carbon

P_l = annual production or consumption in 10^6 tons

$FO_l = 1.0 \pm 3\%$

C_l = carbon content in tons C per ton fuel = $0.855 \pm 1\%$

From primary and secondary solid fuel production and trade[5]

CO_{2s} = CO_2 emissions in 10^6 metric tons of carbon

P_s = annual production or consumption in 10^6 tons coal equivalent[6]

$FO_s = 0.982 \pm 2\%$

C_s = carbon content in tons C per ton coal equivalent = $0.746 \pm 2\%$

From natural gas flaring7

CO_{2f} = CO_2 emissions in 10^6 metric tons of carbon

P_f = annual production or consumption in 10^{12} joules

$FO_f = 1.00 \pm 1\%$

C_f = carbon content in 10^6 tons C per 10^{12} joules = $13.454 \pm 2\%$

Note: 1. With respect to the above gas-related calculations, the following procedures and assumptions should be noted:

(1) If a solid was produced and then converted to a gas that was subsequently consumed, the assumption was made that the solid was produced and consumed. In this situation, none of the gas records were influenced.

(2) If a solid was produced and then converted to a gas that was exported, it was assumed that in the producing country a solid was produced and the gas was exported. As a result, gas consumption for this country could show a negative value (consumption = production + imports exports: C = (0 + 0) exports). In the consuming country, gas was imported and consumed.

(3) Natural gas contains 13.7 metric tons of carbon per terajoule.

(4) Some of the units seem contrived but are chosen to accommodate data reported in the primary data sources.

2. With respect to the above global liquid-related calculations, the following procedures and assumptions should be noted:

(1) Crude petroleum, natural gas liquids, and all secondary energy liquids were summed on an equal basis in mass units. That is, a ton of any liquid contains the same fraction of carbon.

(2) When calculating global total CO_2 emissions from liquids, we have estimated that a quantity of liquids equivalent to 6.7% of liquids produced are not oxidized each year and another 1.5% passes through burners unoxidized or is otherwise spilled. Hence, 91.8% of annual liquid production is oxidized each year.

(3) Liquid fuels contain 85.0% carbon by weight.

3. With respect to the above national liquid-related calculations, the following procedures and assumptions should be noted:

(1) Crude petroleum, natural gas liquids, and all secondary energy liquids were summed on an equal basis in mass units. That is, a ton of any liquid contains the same fraction of carbon.

(2) When calculating CO_2 emissions by country, non-energy secondary liquids were subtracted at the time of production and additional transactions (i.e., imports, exports, changes in stock) were not accounted further. Therefore, CO_2 production is only for energy products and CO_2 production from the oxidation of non-energy products is not included.

(3) When calculating national total CO_2 emissions from liquids, we have estimated that a quantity of liquids equivalent to 1.5% passes through burners unoxidized or is otherwise spilled.

(4) Liquid fuels contain 85.0% carbon by weight.

4. With respect to the above bunker liquid-related calculations, the following procedures and assumptions should be noted:
   (1) Crude petroleum, natural gas liquids, and all secondary energy liquids were summed on an equal basis in mass units. That is, a ton of any liquid contains the same fraction of carbon.
   (2) Liquid bunker fuels contain 85.5% carbon by weight.
   (3) Emissions from bunker fuels are calculated at the point where final fuel loading occurs but are not included in any national totals.
5. The UNSTAT Database provides specific values of the energy content (in kcal/kg) for solid fuels for many country-commodity-year combinations. Where no conversion factor exists in the UN data set for a country/commodity, the following standard factors (kcal/kg) are used:

Coal	7000
Lignite brown coal	2695
Peat	2275
Coke-oven coke	6300
Gas coke	6300
Brown coal coke	4690
Hard coal briquettes	7000
Brown coal briquettes	4690

6. The data for annual fuel production must recognize that all coal is not of the same composition, and thus may have varying energy content and CO_2 potential. There is a strong correlation between energy content and C content so the C content is quite constant when production is in units of tons coal equivalent where 1 ton coal equivalent is defined as 29.31 109 joules.
7. With respect to the above gas flaring-related calculations, the following derivation and assumption should be noted:
   (1) The carbon conversion factor of 13.454 metric tons of C TJ-1 is the result of dividing the average carbon content of a cubic meter of flared natural gas (525 g C/m3) by the average heating value of a cubic meter of flared natural gas (39.021 TJ/106 m3).
   (2)These calculations assume that flared gas is released to the atmosphere immediately as CO_2, even though it is known that a small fraction is initially discharged as methane or carbon monoxide.

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