國 立 交 通 大 學

經 營 管 理 研 究 所

博士論文

No. 108

納入自然資源投入之區域生產效率衡量

Measuring Regional Production Efficiency with Natural Resource Inputs Considered

研 究 生：王世全

指導教授：胡均立 教授

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中 文 摘 要

持續的經濟發展仰賴充份自然資源的投入，然而許多重要的自然資源皆有其供給的上限以及不可再生性。因此永續發展必須兼顧經濟發展的幅度以及自然資源的消耗。自然資源的使用效率需要不斷提升以臻於最佳化。本文納入能源及水資源，分別與勞動及資本存量形成經濟生產的投入要素，並據以實證方式分析區域能源及水資源的使用效率。

本文利用資料包絡分析法，分析中國各區域能源消費的目標投入量。再將此目標投入量除以實際投入量來建構出總要素能源效率 (TFEE) 指標。由於目標投入量即為擁有相同產出的最低投入量，此一能源效率指標值將會介於 0 與 1 之間。在使用的投入產出模型中，國內生產毛額 (GDP) 為單一產出，而勞動、資本存量、能源消費量以及作為生質能代理變數的可耕地面積為四個投入因素。研究分析 1995-2002 年間中國二十九個行政區的能源使用效率。分析結果顯示此一新建構的總要素能源效率指標較傳統的能源生產力效率指標更能顯現實際的結果。

本文亦探討中國各區域的水資源使用效率。中國的人均水資源量僅

有世界平均值的四分之一，極度缺水的狀況將對過去二十年來快速發展的經濟榮景產生隱憂。用水量調整率 (WATR) 指標同樣是以資料包絡分析法所建構的生產效率前緣為基礎，納入水資源為投入要素分析而得。本文分別對於各中國三十個行政區在 1997-2002 年間的生活用水及生產用水效率依據此一新建構之指標進行分析。

在使用新建構能源及水資源效率指標的實證研究中，自然資源使用效率值與人均收入的關係上，皆獲得與環境 Kuznets 曲線相符的 U 型曲線。中國的中部地區具有最低的資源使用效率，而能源與水資源投入的調整量更皆佔有中國全區總調整量的三分之二。高效率的生產方式以及進步的技術需要引進及實行，從而改善其自然資源使用效率。

最後本文提出具有永續發展概念的綠色國家創新系統架構，主張現有的國家創新系統應結合環境保護與資源保育的主旨，進而激勵相關的創新與研發，防範可能的污染並以最佳效能來使用有限的自然資源。文中美國及中國的個案分析闡述綠色國家創新系統的必要性以及此一系統在不同國家環境下的可能架構。

關鍵詞: 資料包絡分析法 (DEA), 總要素能源效率 (TFEE), 用水量調整率 (WATR), 綠色國家創新系統 (GNIS), 中國經濟, 能源投入, 水資源投入, 永續發展

Measuring Regional Production Efficiency with Natural Resource Inputs Considered

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ABSTRACT

Economic growth can not sustain without sufficient input of natural resources, however most inevitable natural resources are finite and non-renewable. Sustainable development as an ultimate goal for the entire human beings relies on balance between consumption of these finite natural resources and level of economic growth. The efficiency of consuming these finite natural resources needs to be promoted to an optimal level. The empirical studies analyzing efficiency of energy and water consumption are made in this dissertation. Energy and water resources are considered as input factors in an economic production together with conventional inputs: labor employment and capital stock.

We employ methodology of data envelopment analysis (DEA) to find the target energy input of each region in China at each particular year. The index of total-factor energy efficiency (TFEE) is obtained with dividing the target energy input by the actual energy input. The value of this index will be between 0 and 1 since the founded target energy input is the minimum input level of maintaining the same output level. In our DEA model, labor, capital stock, energy consumption, and total sown area of farm crops used as a proxy of biomass energy are the four inputs and real GDP is the single output. This paper analyzes energy efficiencies of 29 administrative regions in China in period of 1995–2002 by using this newly introduced index. The conventional energy productivity ratio regarded as a partial-factor energy efficiency index is computed for comparison in contrast to TFEE; the latter appears fitting better to real cases.

This dissertation also brings water into consideration. Over the past two decades China has seen the fruit of its rapid economic growth, but problem of water shortage becomes severe behind this prosperous development scenario which could further jeopardize the country's growth. The per capita amount of water resource is only one-fourth of the world's average. The index of water adjustment target ratio (WATR) is established from a production frontier constructed by DEA as well that includes water as an input. Water efficiency of 30 regions in China during 1997-2002 is obtained from this newly constructed index with both residential and productive water use.

A U-shape curve is discovered that matches to environmental Kuznets curve. The U-shape curve is between both regional total-factor energy efficiency and total-factor water efficiency and per capita real income among regions of China. The central area has the worst efficiency ranking and total adjustment amount of both water and energy are around two-third of China's total. High efficiency production processes and advanced technologies need to be adopted in the central area in order to improve its production efficiency with using natural resources.

Last, a conceptual framework of green national innovation system (GNIS) is introduced in this dissertation. The system combines existing national innovation systems with more innovations in title of environmental protection and preservation of natural resources. The related innovations and researches are therefore stimulated and formulated to prevent environmental pollutions at beginning stage. The consumption of natural resources is therefore promoted at the frontier of production efficiency. These are the core aspects of a GNIS. Case studies of the U.S. and China illustrate that the trend and necessity of a GNIS is regarded as further development to existing NIS. The distinct effective scenarios describe how this system works at different contexts.

Keywords : Data envelopment analysis (DEA), Total-factor energy efficiency (TFEE), Water adjustment target ratio (WATR), Green national innovation system (GNIS), China economy, Energy input, Water input, Sustainable development

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CHAPTER 1 INTRODUCTION

In the world, economy was quite developed in the recent several decades. Following with advantages from the growth, the natural resources are heavily consumed. The economic growth will not continue without input of these inevitable natural resources. It is important to get balance between economic growth and consumption of natural resources in order to remain sustainability for development.

China's economic growth was proceeding aggressively in the past two decades and is still expanding at a 9.5% annual rate in the fourth quarter of 2004 (Business Asia, 2005). At the same time, its natural resources input are under a severe supply constraint following such a roaring development. China is therefore taken as an example to study empirically for input efficiency of these finite natural resources behind its prosperous economic growth. There are two natural resources considered as essential inputs for economic production and growth, which are energy and water.

1.1 REGIONAL PRODUCTIVITY WITH ENERGY INPUT CONCERNS

China is the second largest energy-consuming economy in the world. The demand for electric power in the country is increased by 69% from 2000 to 2004. Much of the fixed asset investments have moved into energy-intensive industries, yet there is nearly a one-third shortage of electricity consumption in China. One forecast (Kadoshin and Nishiyama, 2000) shows that by 2010, China will consume three times its 1992 energy input. That is, China's share of the world's total energy consumption will grow from 8.6% in 1992 to 15.9% in 2010. Along with this fast demand for energy, the efficiency of energy use should be of concern especially under China's energy policy. Various plans are being carried out to increase investment and to speed up construction in order to establish a sufficient energy supply. However, the efficiency of energy consumption needs to be promoted simultaneously such that redundant energy consumption is eliminated.

Energy alone can not produce just any outputs. Energy must be put together with other inputs to consider in order producing outputs. Therefore, a multiple-input model is more reasonable to apply that correctly assess the energy efficiency in a region. In our study the regional targets of energy inputs can be found through the data envelopment analysis (DEA).

The out-of-date technology level and the inefficient production process generate a redundant portion of energy consumption that needs to be further adjusted. The amount of total adjustments, including slack and radial adjustments, is computed by DEA. The target level of energy use, called target energy input, is obtained when the amount of total adjustments is reduced from amount of the actual energy use. A new index of energy efficiency, named total-factor energy efficiency (TFEE), is constructed as the ratio of the target energy input that is suggested from DEA to the actual energy inputs in a region.

Energy efficiency improvement relies on total factor productivity improvement (Boyd and Pang, 2000). The TFEE index incorporates energies, labor, and capital stock as multiple inputs so as to produce economic output (GDP[1]). In contrast, a traditional energy efficiency index only takes energy into account as a single input (Patterson, 1996) to produce GDP output while neglecting other key inputs such as capital and labor. DEA can be easily applied to a multiple input–output framework to compute the index of TFEE. An empirical analysis of regional energy efficiency in China presents results from a real case application of the new index.

Sustainable development has to be considered with an energy policy (Gibbs, 2000) since energy supply is inevitable for economic growth. The concept should be introduced by covering areas on a local or regional level and then extending to the national level (Gibbs, 1998). Our study concentrates specifically on the regional level of energy efficiency in China where further improvements can be planned and executed accordingly. China is now in a transition period, having started from a high resource-consuming and low-efficiency economic development pattern (Fleisher and Chen, 1997). It is of particular importance to improve energy efficiency in the various regions within China in order to sustain its economic growth.

1.2 REGIONAL PRODUCTIVITY WITH WATER INPUT CONCERNS

Water is another essential input to economic production. However it is in sever shortage behind the prosperous economic booming in China. Many reports worry about how the situation will be improved and what could be scenario in the future. Water

[1] GDP represents gross domestic product.

resource is finite in China and also in the earth. Improving water efficiency to support sustainable development is a crucial task.

Same as energy, water alone as an input can not produce any outputs through production. It has to be accompanied by other inputs to produce real outputs. Therefore, a multiple-input model is reasonable to apply for evaluation of the water efficiency in a region. Regional targets of water input, including residential and productive use, can be found through DEA. The inefficient portion of the water input results in redundant water consumption and shall be reduced. This redundant water use portion is generated mainly from inefficient production processes and out-of-date technologies. The two types of redundant water use portion are slack and radial adjustments of water input and their summation is the total adjustment of water input. An index of water adjustment target ratio (WATR) is constructed via dividing the target water input by the actual water input in a region or in an economy.

Water efficiency improvement relies on total factor productivity improvement (Boyd and Pang, 2000). The index WATR incorporates water as input together with inputs in conventional economic analysis that are labor and capital stock. Multiple inputs therefore form an economic production function to produce the economic output (GDP). An analysis of regional water efficiency in China shows an empirical result of a real case application of this new developed index.

The perspective of sustainable development needs to consider water policy (Gibbs, 2000) since water is a finite source. Sustainable development should be introduced by covering areas on a local or regional level and then extending to the national level (Gibbs, 1998). This type of sub-national scale shall be emphasized as a key point. Our study concentrates specifically on water efficiency status at the regional level in China, which was of less concern before, but important now in order that further improvements can be planned and implemented accordingly. China is in a transition period starting from a high resource-consuming and low-efficiency economic development pattern (Yang, 2002; World Bank, 2001). It would be of particular importance to improve water efficiency in various regions in China in order to sustain its economic growth.

1.3 TOWARDS SUSTAINABILITY WITH INNOVATIONS

The national innovation system (NIS) is now regarded as the key driving force of economic growth and the primary source of competitiveness for a knowledge-based economy (OECD, 1999; 2002). The system is composed of a set of institutions as well as bridging mechanisms that act as intermediaries among all sectors (Niosi, 2003). The intermediaries between these institutions are the core where knowledge is generated, diffused, and adapted, that form a spiral of innovation. Flows of knowledge, finance, human capital, and regulation are the intermediaries which activate the system (OECD, 2002).

A 'green' innovation system therefore essentially addresses these issues through a feed-forward control methodology (Robbins, 1994). This methodology contains both radical and incremental levels of innovation (Patris et al., 2001), in order to fundamentally study environmental problems in beginning stages when the problems emerge instead of in the end-of-pipe and middle stages where hazards and pollution may have already been produced. The system is able to assist firms to eliminate constrains which introduce solutions to environmental problems, as well as conduct regulations, and compliances to allow EMS to be effectively implemented. Conway and Steward (1998) find that new technological products and processes must embody green characteristics. Porter and van der Linden (1995) state that green competitiveness can turn environmental concerns into economic competitive advantages, as radical change in advancing environmental innovation is inevitable for a nation desiring to enhance its long-term competitiveness.

'Green' has been widely adopted and well known as a word to represent and interpret concepts such as environmental protection and natural resources conservation. On the other hand, the concept of sustainable development emphasises that environmental and economic development should not be separated since the next generation still needs natural capital to meet its needs. These future needs should not be compromised in order to meet the needs of the present (Harrison, 2002). The concept of 'green' therefore should be embedded into economic development in order to achieve sustainable development.

We shall describe a framework of a GNIS, constructed to further sustainable development within a nation. The GNIS is developed on the basis of NIS with green sustainability aspects embodied. The three major dimensions in sustainable development are ecological sustainability, social sustainability, and economic sustainability (Munro, 1995; Giddings et al., 2002). GNIS emphasizes the balance between sustainability of the ecological system and economic development, so that sustainable development can be achieved.

CHAPTER 2 SUSTAINABLE REGIONAL DEVELOPMENT

In recent decades, in parallel to rapid world economic growth, the problems of environmental pollution and natural resource consumption have become more serious. But on the other hand, awareness of environmental protection and natural resource conservation has been fostered by different parties ranging from governments and companies to individuals (Cerin and Karlson, 2002). Environmental policy in nations that transferred from end-of-pipe regulation to implementation of an environmental management system is now required to be reformed again in a direction towards sustainable development (Ashford, 2002), as far–sighted preventive measures and structural change are needed. The change can be seen from Figure 1. The end-of-pipe monitoring system is based on a methodology of feedback control (Robbins, 1994) was operated in the late-1970s. Action was taken by end-of-pipe measuring and monitoring, and the system basically performed problem control in a feedback methodology (Robbins, 1994). The environmental management system (EMS) was then launched in the mid-1990s and operated a methodology of concurrent control (Robbins, 1994). Several

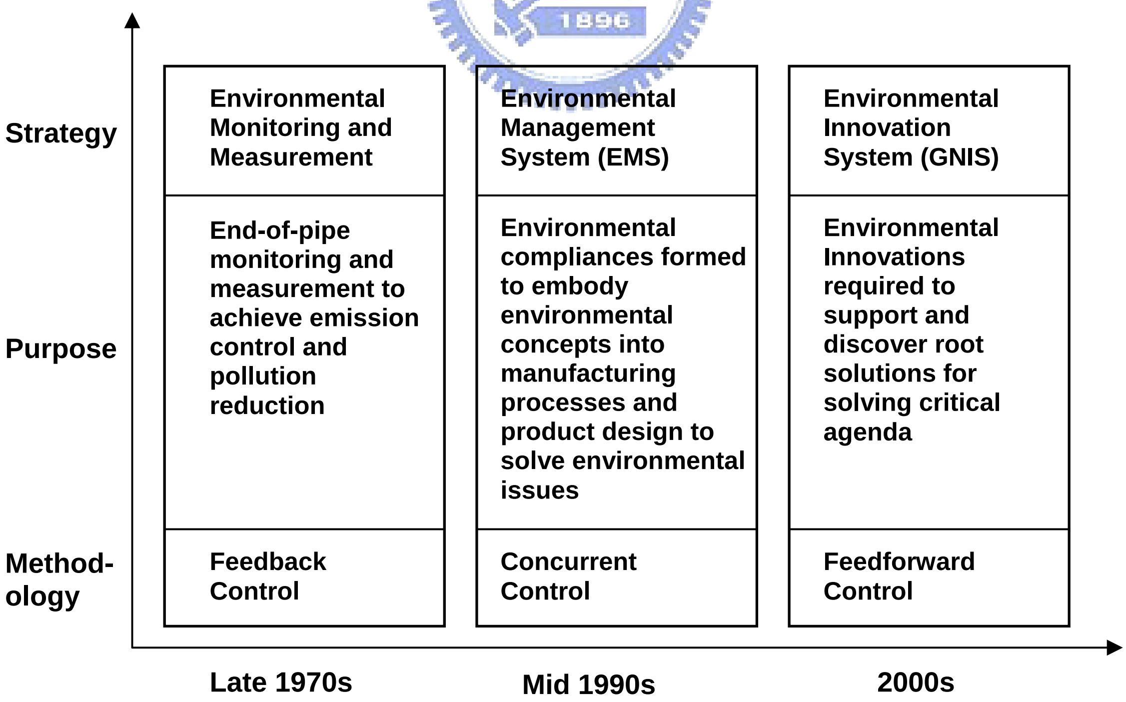


Figure 1

THE FOCUS IS SHIFTING ON ENVIRONMENTAL PROTECTION environmental standards were introduced, for example, the international standard of EMS - ISO14000[2].

Although environmental regulations as a management system have been widely deployed in many nations (Jackson et al., 1997), firms in most industries actually face constrains such as a lack of both financial and R&D capability, short-term oriented environmental strategies, inflexible organizational structures, and relationships with external stakeholders (Brio and Junquera, 2003; Niosi, 2003). The result hardly leads the existing system to create the physical means to solve the critical environmental issues that a nation confronts.

2.1 ENERGY EFFICIENCY AND SUSTAINABLE DEVELOPMENT

Energy is fundamental to economic system. As economies develop and become more complex, energy needs increase greatly. According to the first law of thermodynamics that energy can be neither created nor destroyed. Entropy is defined in the second law of thermodynamics as a measure of unavailable part of energy. Most energy is formed as type with low entropy in beginning, every time energy is transformed to type with higher entropy after use. Eventually energy soon becomes an unavailable or bound form. This explains the specialty and scarcity of energy.

It relies on sufficient and continuous energy supply to reach at goal of sustainable development. Therefore it is important to discover new energy sources on the one hand. On the other hand, it is essential to consume energy in the most efficient way. The optimal energy efficiency is therefore emphasized to achieve in order to consume energy at the highest efficiency.

Patterson (1996) comments that energy efficiency is a policy objective to link to commercial, industrial competitiveness and energy security benefits, as well as increasingly to environmental benefits. Energy efficiency is a generic term, and there is no one

[2] ISO14000 emerged in 1992 and is an international standard for EMS to promote common approach to EMS and enhance organization's ability to measure improvements in environmental performance. It covers environmental auditing, environmental performance evaluation, environmental labeling, life-cycle assessment, and environmental aspects in product standards.

unequivocal quantitative measure of 'energy efficiency'. In general, energy efficiency refers to using less energy to produce the same amount of services or useful output.

There are four groups of indicators used for measurement of energy efficiency according to existing literatures. They are introduced respectively as following.

(1) Thermodynamic: 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 (Sioshansi, 1986):

$$E_{\Delta H} = \frac{\Delta Hout}{\Delta Hin}, \qquad (1)$$

where

$E_{\Delta H}$ = Enthalpic efficiency ;

$\Delta Hout$ = Sum of the useful energy output of a process ;

ΔHin = Sum of all of the energy inputs into a process.

(2) Physical-thermodynamics: These are hybrid indicators where the energy input is still measured in thermodynamic units (Collins, 1992), but the output is measured in physical units. These physical units attempt to measure the service delivery of the process – for example that in term of tones of product or passenger miles:

$$E_{PT} = \frac{\text{Output (e.g. vehicle kilometers)}}{\text{Energy input}}, \qquad (2)$$

where

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

(3) Economic-thermodynamic: These are also hybrid indicators where the service delivery (output) of the process is measured in terms of market prices (Patterson, 1996). The energy input, as with the thermodynamic and physical-thermodynamic indicators, is

measured in terms of conventional thermodynamic units and named as energy productivity ratio:

$$\text{Energy productivity ratio} = \frac{\text{GDP}}{\text{Energy input}} . \quad (3)$$

This type of indicator is the most common used one among all indicators. It simply evaluates energy efficiency, base on energy productivity ratio, by observing how much GDP is produced when how much of energy is input.

(4) Economic: 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 (Berndt, 1978):

$$E_E = \frac{\text{GDP}}{\text{Cost of energy consumption}} , \quad (4)$$

where

E_E = Energy efficiency in economic term.

2.2 ENERGY SOURCES IN CHINA

China has been the largest coal production and consumption country in the world. The coal is the major energy source that supplies 60-65 % energy need in China as of 2000. However this type of energy generates severe pollutions, environmental degradation, and related operational problems. Crude oil and natural gas as energy sources from fossil fuels that supply 10-15 % energy need in the country. The level is 10-20 % lower than average in the region and the world. China faces an urgent need to diversify beyond crude oil, natural gas, and coal.

Biomass energy as the major renewable energy sources supply around 20% in China as of 2000. It contains straw, stalk, crop residue, fuel wood, and other varieties of organic wastes (Chang et al., 2003). Biomass energy is main energy source in rural area of China.

Energy consumption in China is rising so rapidly that even a national campaign to build windmills or solar-powered houses will barely reduce the country's dependence on fossil fuels. 60 million people are not available with electricity by far. The demand for energy in China grows about 20 % every year since the country opened market to develop economy from 1989. Industry sector is the major portion of consuming energy around 42 % of the total in the country, which is 5-10 % higher than average in the region and the world. Industries require high inputs and high energy consumption contributes to production outputs that are around 4 % of GDP total, but they also cause demand increasing for energy input for 12 %.

The ‘11th Five-Year Plan’ is China's socio-economic development strategy for the next five years to 2010. It indicates the country will further deduct energy’s dependence on coal and replace with crude oil. At the same time, the alternative of renewable energy sources is emphasized to development. On the other hand, energy efficiency has to be promoted to reach at goal of saving energy use.

2.3 WATER EFFICIENCY AND SUSTAINABLE DEVELOPMENT

Water is a finite resource and only 0.3 percent is available for the world’s population to share for agricultural, residential, manufacturing, community, and personal needs. While both world population and the demand on freshwater resources are increasing, supply still remains constant (U.S. EPA, 2004).

However, water is an inevitable resource for all species’ living in the plant and for sustainable development of human society. Water efficiency is an essential topic to investigate and a long-term ethic of conserving water resources through the employment of water-saving technologies

Baumann et al. (1979) named that water conservation is any socially beneficial reduction in water use or water loss. Water use efficiency is of central importance to conservation. At the same time, his definition suggests that efficiency measures should make sense economically and socially in addition to reducing water use per unit of activity. In economic dimension of water use efficiency, normally it refers to a directly proportional to the prices charged for water servicing.

There are not much existing literatures on the quantitative analyses of water efficiency. Related researches (Mo et al., 2005; Huang et al., 2005) concentrated mainly on agricultural productivity such as yield of the crop or amount of food per unit of water consumed. The total-factor water efficiency of an economy or a region is still left to discuss in this research as the first.

2.4 WATER RESOURCES IN CHINA

China has uneven endowments of water resources among its regions: Some regions suffer from floods but others suffer from droughts. In China 81% of its water resources are in the country's southern part, but the north part, the political center, having the largest part of arable land up to 64%, is in serious water scarce (Jin and Young, 2001). Water resources are characterized by richness in the south and shortage in the north, or richness in the east and shortage in the west (Zhong, 1999). On the other hand, the quantity of water resources greatly changes from year to year and also from season to season, making great difficulties in developing and using water resources (Zhong, 1999).

The total amount of continental fresh water was 2413 billion cubic meters in 2004, however per capita quantities of water were only 427 cubic meters. This amount is far away from 1700 cubic meters that defined by expertise of experiencing "water stress" (World Resources Institute, 2004). The national supply was 554.5 billion cubic meters in 2004, in which residential use portion was 46.1 billion cubic meters (8.3% of the total) and productive use was 500.2 billion cubic meters (90.2% of the total) (Ministry of Water Resources, 2004). That is, productive use is the dominant portion of the total water use in China.

No matter whether China's policymakers push for less-efficient, capital-intensive water-transfer projects or opt for more efficient recycling and conservation in the north, China's unreliable water supplies could significantly affect its growth. Failure to solve water shortages problem could reduce China's annual GDP growth by 1.5% to 1.9% (Varis and Vakkilainen, 2001). Resulting from the high uneven endowed distribution of water resources among regions in China and also the water resource is so high correlated to its productive use portion; it is worthy to investigate efficiency of water use by regions especially at their productive use portion.

Regional efficiency of water use is analyzed on basis of these three major areas. We would like to analyze efficiency level of water use among these areas. The result can therefore be reference for water supply improvement.

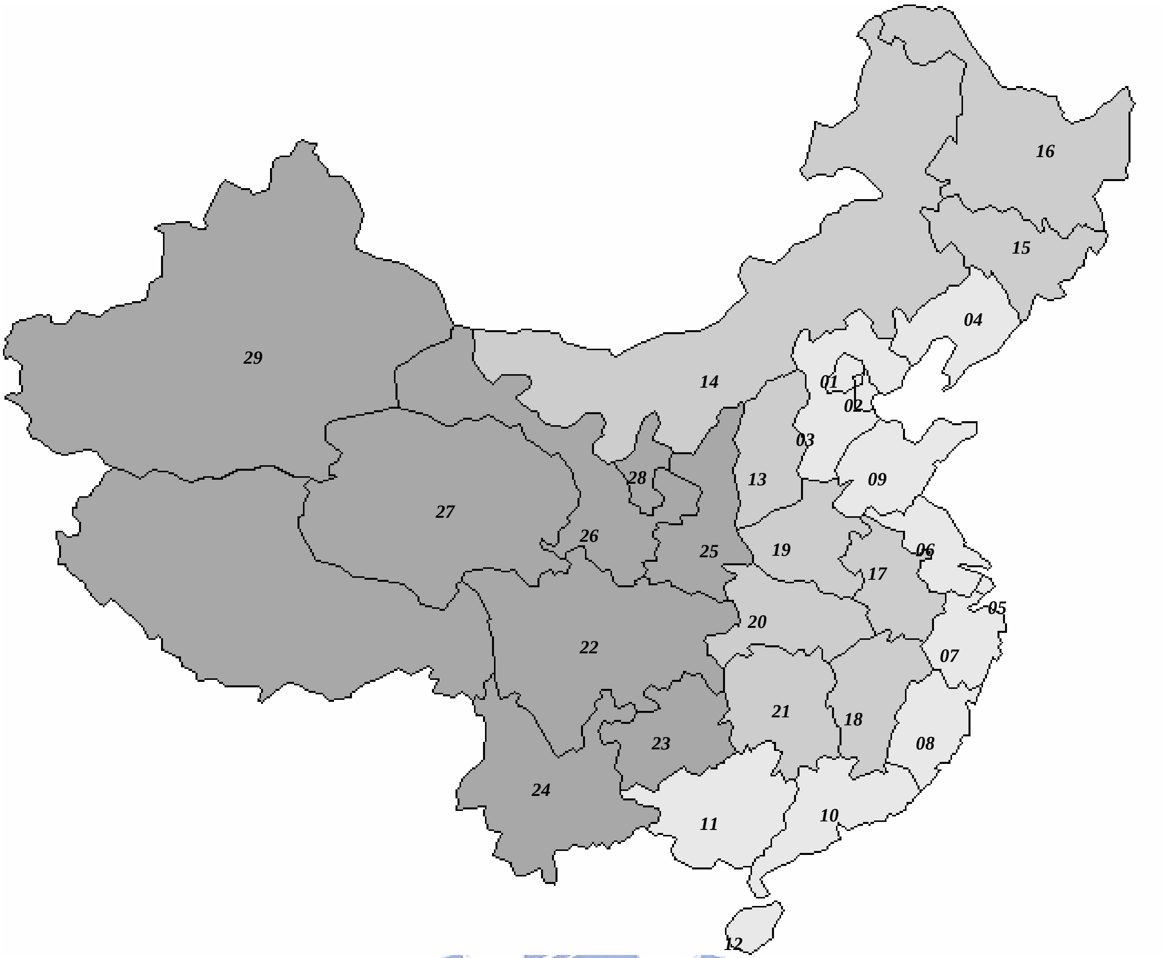
CHAPTER 3 REGIONAL DESCRIPTION AND DATA COLLECTION

3.1 REGIONAL DESCRIPTION

From the perspective of China's development and political factors, its provinces, autonomous regions, and municipalities are usually divided into three major areas: the east, central, and west as shown in Figure 2.

The east area is constituted by twelve regions that stretch from the province of Liaoning to Guangxi, including the coastal provinces of Shandong, Hebei, Jiangsu, Zhejiang, Fujian, Guandong, and Hainan, and the three municipalities of Beijing, Tianjin, and Shanghai. The east area is well known and has experienced the most rapid economic growth in China and its GDP output is around half of China's total. The east area has also attracted the most foreign investment, technology, and managerial know-how. The central area consists of nine regions that are all inland provinces: Heilongjiang, Jilin, Inner Mongolia, Henan, Shanxi, Anhui, Hubei, Hunan, and Jiangxi. This area has a large population and is a home base for farming. Foreign investment in this area is less and technology lags do exist. The west area covers more than half of the territory in China including the provinces of Gansu, Guizhou, Ningxia, Qinghai, Shaanxi, Tibet, Yunnan, Xinjiang, Sichuan, and the municipality Chongqing. Compared to the other two areas, this area has low population density and is the least developed area in China.

Since Chongqing was promoted to be the fourth municipality in China only in 1997, this municipality is still combined with the Sichuan province and they together are regarded as one region in this research. The energy input data of Tibet were not available for this research. Thus, a total of eight regions in the west area are included in this study. The three areas are abbreviated as E, C, and W for the east, central, and west areas, respectively. A total of twenty-nine regions are this study's targets to be analyzed for their energy efficiency.



East Area (12 Regions)				Central Area (9 Regions)				West Area (8 Regions)			
1	Beijing	8	Fujian	13	Shanxi	18	Jiangxi	22	Sichuan	27	Qinghai
2	Tianjin	9	Shandong	14	Inner Mongolia	19	Hennan	23	Guizhou	28	Ningxia
3	Hebei	10	Guangdong	15	Jilin	20	Hubei	24	Yunnan	29	Xinjiang
4	Liaoning	11	Guangxi	16	Heilongjiang	21	Hunan	25	Shaanxi		
5	Shanghai	12	Hainan	17	Anhui			26	Gansu		
6	Jiangsu			16	Heilongjiang			25	Shaanxi		
7	Zhejiang			17	Anhui			26	Gansu		

Figure 2

THE ADMINISTRATIVE REGIONS AND THREE MAJOR AREAS IN CHINA

3.2 DATA COLLECTION

3.2.1 REGIONAL ENERGY CONSUMPTION DATA IN CHINA

A panel dataset of twenty-nine regions from 1995[3] to 2002 is collected for analysis of total-factor energy efficiency. Data of labor employment and GDP are both collected from the China Statistical Yearbook. Data of capital stock are not available in any statistical yearbooks of China. In this study every regional capital stock in a specific year is calculated by the authors according to the formula (Li, 2003):

Capital stock in the current year

= capital stock (previous year) + capital formation (current year)

– capital depreciation (current year). (5)

The regional capital stocks in 1995 price are calculated accordingly with real price conversion from 1978's value and GDP deflators[4]. The GDP data are also deflated to 1995's value for analysis since 1995 is taken as fundamental period for analysis of energy efficiency.

Regional energy consumption levels are collected from the China Energy Statistical Yearbook. The data are available from 1995 to 2002 excluding that for region of Tibet. These energy datasets contain only the conventional energy consumption — mainly coal, petroleum, and natural gas. Those energy resources with a low calorific value are excluded, most of which are renewable energies. Biomass energy is almost 100% of this renewable energy source in China (Chang et al., 2003). There are also other renewable sources such as solar, wind, geothermal, and oceanic energies, but all are consumed at very low levels (International Energy Agency (IEA), 2004).

Biomass energy is one of the main sources for noncommercial energy use in China's rural areas, constituting 38.7% of China's total energy consumption in 1970, but then later dropping to 19.9% of China's total in 2000 (Chang et al., 2003). Few data sources of

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[3] Complete data for regional energy efficiency are available from 1995 and for only twenty-nine regions. The year 1995 is therefore the fundamental period for analysis of energy efficiency.

[4] Real capital stock data from Li is 1978 price. Therefore data need to convert to 1995 price first with GDP deflators for analysis in this study.

biomass energy consumption could be found, and those had been offered were incomplete for this study and relied on estimations (Sinton and Fridley, 2002).

Biomass energy still counts for around 20% of the total energy consumption in China as of 2000. China Rural Energy Statistical Yearbook once provides regional data of biomass energy consumption, but only up to 1999. Since biomass energy is mainly composed of straw, stalk, crop residue, and fuel wood (Chang et al., 2003), the total sown area of farm crops of the regions is selected as a proxy of the biomass energy consumption in this study[5]. The data of regional total sown area of farm crops (abbreviated as 'farm area' hereafter) are available in the China Statistical Yearbook for each sample year. A very high positive correlation coefficient of 0.841 is found between total biomass energy consumption level and farm area of regions in China during our 1995–1996 data collection. The factor farm area of regions is hence an appropriate proxy of the biomass portion of energy input in this study. The data are therefore complete for an analysis of energy efficiency in regions of China.

3.2.2 REGIONAL WATER CONSUMPTION DATA IN CHINA

Regional data for inputs and the output are collected from distinct sources. Inputs including regional labor employment as well as water consumption are collected from the China Statistical Yearbook from 1997[6] to 2002. The water consumption is separated as two parts that are residential use and productive use according to data classification in the China Statistical Yearbook. The real capital stock as one of input factors is constructed according to the same Li's method (Li, 2003) aforementioned. The data of real capital stock used in analysis of water efficiency are converted to 1997 prices. The single output is regional GDP and is collected from the China Statistical Yearbook. The collected GDP data are deflated to 1997 values as well with GDP deflator.

From China Statistical Yearbook, we establish a dataset for 30 regions in China (27 provinces and 3 municipalities) during 1997 to 2002. Note that Chongqing became a municipality out of Sichuan just since 1997 and some of its data are split from Sichuan

[5] We have tried to use the forest area as a proxy of fuel wood as one of the biomass energy sources. However, the sign of the correlation coefficient between real GDP and forest area is negative, hence violating the 'isotonicity' requirement between an input and an output.

[6] Complete data for regional water consumption in China is only available from 1997; therefore 1997 is fundamental period for analysis of water efficiency which is different from analysis of energy efficiency.

some years later. Therefore we combine outputs and inputs of this municipality together with Sichuan in this study for easier comparison and panel dataset for total thirty regions is therefore constructed. Macroeconomic performance is evaluated in a region of its capability to maximize the single desirable output GDP and to minimize the three input factors. Water is especially important since it is an inevitable natural resource to economic development.

The total thirty regions are categorized as three areas (shown in Figure 2). The three areas are the east area (abbreviated as 'E'), the central area (abbreviated as 'C'), and the west area (abbreviated as 'W').

CHAPTER 4 METHOD OF DATA ENVELOPMENT ANALYSIS (DEA)

In this section the DEA approach is introduced for analysis and measurement of overall technical efficiency.

4.1 MEASURING TECHNICAL EFFICIENCY: THE DEA APPROACH

DEA is known as a mathematical procedure using a linear programming technique to assess the efficiencies of decision-making units (DMU) that refer to a set of firms (Coelli, 1996) and a set of regions in this study. All DMUs take an identical variety of inputs to produce an identical variety of outputs (Ramanathan, 1999), but through distinct production processes and technologies decided and used in each DMU, the input and output levels and their production efficiency are eventually decided upon. A non-parametric piecewise frontier composed of DMUs, which own the optimal efficiency over the datasets, is constructed by DEA for comparative efficiency measurement. Those DMUs located on the efficiency frontier have their maximum outputs generated among all DMUs by taking the minimum level of inputs, which are efficient DMUs and own the best efficiency among all DMUs.

DEA needs to specify neither the production functional form nor weights on different inputs and outputs. It produces detailed information on the efficiency of the unit, not only relative to the efficiency frontier, but also to specific efficient units which can be identified as role models or comparators (Hawdon, 2003; Hu and Wang, forthcoming). Comprehensive reviews of the development of efficiency measurement can be found in Lovell (1993). There are K inputs and M outputs for each of these N DMUs. The envelopment of the ith DMU can be derived from the following linear programming problem:

$$
\begin{aligned}
&\text{Min}_{\theta,\lambda} \quad \theta \\
&\text{subject to} \quad -y_i + Y\lambda \geq 0, \\
&\qquad\qquad\quad \theta x_i - X\lambda \geq 0, \\
&\qquad\qquad\quad \lambda \geq 0, \qquad\qquad (6)
\end{aligned}
$$

where θ is a scalar representing the overall technical efficiency (OTE) score; λ is an $N\times 1$ matrix of constants; y_i is an $M\times 1$ output vector of DMU i; x_i is an $K\times 1$ input vector of DMU i; Y is an $M\times N$ output matrix; and X is an $K\times N$ input matrix. This satisfies $0 \leq \theta \leq 1$ and a value of one indicates a point on the frontier, hence a technically efficient DMU (Coelli et al., 1998). The above procedure constructs a piecewise linear approximation to the frontier by minimizing the quantities of the K inputs required to meet the output levels of the ith DMU. The weight λ serves to form a convex combination of observed inputs and outputs. It is an input-orientated measurement of efficiency.

Eq. (6) is known as the constant returns to scale (CRS) DEA model (Charnes et al., 1978). Banker et al. (1984) suggested an extension of the CRS DEA model to account for variable returns to scale (VRS) situation with adding following convexity constraint:

$$N1'\lambda = 1, \quad (7)$$

where $N1'$ is an $N\times 1$ vector of ones.

The solution of the VRS DEA model, which is the pure technical efficiency (PTE), helps further decompose the overall technical efficiency of each DMU into pure technical efficiency (PTE) and scale efficiency (SE). That is, OTE = PTE × SE. In order to pursue overall technical efficiency with inputs of natural resources, our study adopts the CRS DEA model since this model finds OTE of each DMU. 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 from out-put orientation to input orientation.

The efficiency frontier in DEA is constituted by those efficient decision-making units (DMUs). The existing gap from any DMU to this efficiency frontier shows how far the DMU should be improved to reach the optimal efficiency level. The distance of the gap can also be computed through DEA. We use the software Deap 2.1, kindly provided by Coelli (1996), to solve the linear programming problems.

4.2 SLACK AND RADIAL ADJUSTMENTS

DEA identifies the most efficient point on the frontier as a target for those inefficient DMUs to achieve through a sequence of linear programming computation (Coelli, 1996). For the *i*th DMU, the distance from an inefficient point where it is located to the projected point on the frontier by radial adjusting the level of inputs, $(1-\theta)x_i$, is called 'radial adjustment'. Moreover, 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. The distance of shifting along with the frontier in between is called 'slack'.

How a point with a practical minimum level for inputs on the frontier can be identified in DEA is illustrated in Figure 3 with a case of M = 1 and K =2. The maximum level y output by the DMUs located on the frontier is normalized to unity and generated from the specified (natural resources) inputs and other inputs which are also normalized by dividing y. Point B is the actual input set and point B' is the projected point on the frontier for DMU B as the target in order to improve its efficiency accordingly by reducing the radial adjustment BB'.

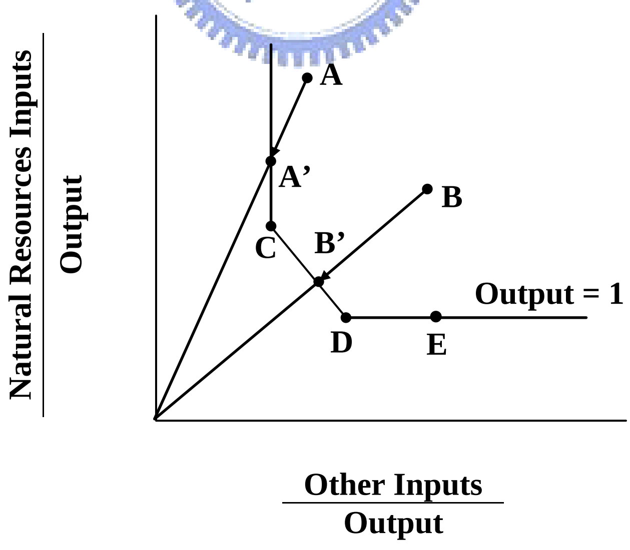

Figure 3

RADIAL ADJUSTMENT AND SLACK IDENTIFIED IN AN INPUT-ORIENTED CRS DEA

However, as aforementioned, the practical frontier is a piecewise linear format that requires the second-stage adjustment to determine a practical minimum point for inputs. In Figure 3, point A' is the projected point on the frontier for another DMU A as the target to reach by reducing the radial adjustment AA'. However, the input level at point A' could be further reduced to input level at point C while maintaining the same output level. The amount CA' that shall further be adjusted for the input level at point A' along with the frontier is called 'slack'.

The summation amount of slack (CA') and radial adjustment (A'A) for inputs is called the amount of total adjustments (CA), meaning that it is the total amount for inputs which should be adjusted by a DMU so as to reach its optimal production efficiency. The adjustments require both a promotion of technology level and an improvement of production process so that OTE is optimized. The amount of total adjustments is then removed and the output level is maximized when a DMU operates at the optimal position on frontier of production efficiency. The practice minimum input level is therefore called the target input level for a DMU.

Point E in Figure 3 indicates that DMU E has been operating on the frontier of production efficiency. The DMU E has already reached at the target input level of specified (natural resources) inputs in production. It can be observed that no amount of total adjustments exists for this input (natural resources). There is only slack amount of the 'other inputs' needs further adjustment, which is DE. The production efficiency at DMU E therefore moves to point D after DE is adjusted on the 'other inputs'. The DMU E then has the practical minimum input for all inputs on the frontier.

The CRS model of DEA can suggest the slack and radical adjustment of individual input for all observed units to be efficient and amount of target input amount can either be calculated accordingly. DEA calculation then decides this 'amount of total adjustments' for each DMU for production efficiency analysis.

4.3 THE ANALYSIS PROCESS

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

In this study, labor employment and gross capital are regarded as two major input factors in generation of GDP. The energy and water consumption are taken separately as a control variable to observe change of efficiency in this input and out relationship, thus efficiency of energy and water consumption can be analyzed and compared. In the following analytical process, labor employment, capital stock with energy consumption are considered as input terms to evaluate macroeconomic performance, the GDP, in terms of the regions with BCC (Banker et al., 1984) models.

CHAPTER 5 REGIONAL EFFICIENCY WITH ENERGY CONSIDERED

5.1 DESCRIPTIVE STATISTICS

The descriptive statistics of China's regions for their GDP performances in terms of production output, labor employment, capital stock, and energy consumption, including farm area as production inputs in our energy efficiency analysis, are first given in Table 1. A panel dataset for the analysis of total-factor energy efficiency is collected and constructed during 1995 to 2002 and from total twenty-nine regions. All monetary data, such as GDP and capital stock, are converted to 1995 price with GDP deflators[7].

The east area, frequently called the coastal area, includes regions that show the fastest development progress in China. Mean GDP output in this area is 3.77 trillion RMB[8], which is much higher than 1.75 trillion RMB of the central area and 0.88 trillion RMB of the west area during the sample years. The standard deviation of GDP output shows the same tendency and matches the economic growth pattern among these areas. The east area has a standard deviation of 210.4 billion RMB, which is also much higher than the other two areas, which are 72.7 billion RMB in the central area and 31.3 billion RMB in the west area. The fast-developing east area receives the largest investment—three times that of the central area and five times the west area.

The situation of energy consumption appears to be the same as that of the GDP result. The east area, as its economic growth shows, consumes the largest portion of energy amount in China. As shown in Table 1, the east area consumed 69.5 billion metric tons of standard coal equivalent (Btce) on an average from 1995 to 2002. This is much higher than 28.1 Btce consumed by the west area and 46.2 Btce consumed by the central area. While analyzing deviations of energy consumption among these areas, we find that the east area increased its energy consumption the fastest from 1995 to 2002 versus the central and west areas. As aforementioned, the central area is the home base of farming, and it consumes the largest level of biomass energy. The east area consumes the second biggest amount and the west area has the lowest level in accordance with farm area data shown in Table 1.

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[7] Detail explanation refers to Section 3.2.1 in page 15.

[8] The RMB is an abbreviation of Ren-Min-Bi, meaning 'people's currency' in Chinese. The RMB is the official currency of the People's Republic of China.

Table 1 SUMMARY STATISTICS WITH ENERGY AS INPUT BY REGION (1995-2002)

ID	Region		Input Factors								Output Factors	
			Labor Empolyment (10,000 persons)		*Capital Stock (100 million RMB)*		*Energy Consumption (Mtce)*		*Total Sown Area of Farm Crops (1000 hectares)*		*Gross Domestic Product (100 million RMB)*	
			Mean	STDev	Mean	STDev	Mean	STDev	Mean	STDev	Mean	STDev
1	Beijing	E	661.25	59.18	19,431.65	3,662.31	3,992.63	333.17	484.43	80.45	1,602.58	153.59
2	Tianjin	E	442.24	40.20	11,107.28	2,020.18	2,657.50	222.80	557.13	20.87	1,061.09	82.69
3	Hebei	E	3,397.53	21.04	13,978.40	4,551.14	9,670.38	926.31	8,944.05	123.98	3,295.88	215.68
4	Liaoning	E	1,907.96	121.90	56,457.27	7,175.74	9,924.25	650.52	3,693.11	126.81	3,008.53	132.15
5	Shanghai	E	721.56	48.05	33,191.94	6,886.27	5,189.75	576.34	529.55	30.49	2,873.36	228.68
6	Jiangsu	E	3,642.55	104.45	40,401.86	8,944.46	8,441.63	565.02	7,923.98	98.49	5,655.75	294.58
7	Zhejiang	E	2,717.79	59.95	23,761.19	6,167.38	5,633.00	942.97	3,689.34	358.03	3,965.71	291.14
8	Fujian	E	1,635.88	44.58	10,940.81	3,611.55	2,776.88	402.65	2,835.19	104.47	2,525.74	177.48
9	Shandong	E	4,682.25	34.71	30,967.33	8,605.29	9,297.88	856.50	11,079.03	144.98	5,606.69	321.22
10	Guangdong	E	3,806.29	112.26	28,601.31	7,684.30	8,892.13	1,358.10	5,292.34	203.30	6,254.00	356.32
11	Guangxi	E	2,483.00	61.21	6,172.15	1,395.27	2,580.25	197.51	6,173.84	198.20	1,510.36	136.10
12	Hainan	E	333.64	7.43	2,976.39	520.71	429.50	87.00	898.21	28.73	347.94	7.99
13	Shanxi	C	1,442.70	28.95	8,887.96	1,631.26	7,426.63	1,030.32	3,911.38	121.28	1,155.07	64.82
14	Inner Mongolia	C	911.20	327.73	6,564.68	1,320.36	3,481.75	651.83	5,727.68	357.67	925.19	48.86
15	Jilin	C	1,152.95	86.39	7,810.24	1,580.51	3,991.50	285.72	4,304.51	345.87	1,221.38	48.40
16	Heilongjiang	C	1,637.79	50.48	11,588.03	2,242.60	6,059.88	175.20	9,274.30	457.75	2,178.37	82.54
17	Anhui	C	3,323.05	64.27	11,235.34	2,649.00	4,710.75	373.81	8,635.93	256.74	2,102.41	80.19
18	Jiangxi	C	1,996.03	63.20	8,456.92	1,847.88	2,248.63	183.14	5,777.39	244.08	1,380.92	65.91
19	Hennan	C	5,172.75	333.13	18,718.26	4,528.35	7,398.13	783.89	12,690.29	465.98	3,377.12	170.38
20	Hubei	C	2,594.09	111.68	15,382.57	3,992.74	6,103.75	300.12	7,580.59	155.35	2,790.39	174.26
21	Hunan	C	3,504.71	50.32	9,905.99	2,598.71	4,803.25	532.53	7,933.06	83.34	2,437.29	104.82
22	Sichuan	W	6,180.41	131.67	14,503.10	4,351.39	9,852.44	450.88	13,118.30	168.69	3,814.44	132.03
23	Guizhou	W	1,976.33	80.42	4,169.23	989.50	4,049.88	441.30	4,517.35	174.14	659.48	21.96
24	Yunnan	W	2,270.11	49.94	6,833.66	1,676.02	3,265.75	410.90	5,441.01	365.69	1,322.75	61.22
25	Shaanxi	W	1,806.74	29.23	10,080.84	1,784.45	3,145.13	357.55	4,535.93	199.66	1,096.54	55.13
26	Gansu	W	1,190.28	26.59	5,588.69	1,047.75	2,832.63	157.32	3,743.80	50.83	651.46	40.80
27	Qinghai	W	237.13	5.80	1,797.95	333.37	824.88	131.36	552.01	27.09	175.98	10.89
28	Ningxia	W	265.48	12.47	1,963.38	342.72	838.75	50.58	1,014.99	58.95	178.71	6.38
29	Xinjiang	W	680.58	11.12	6,831.47	1,406.17	3,276.63	232.13	3,281.93	159.15	877.31	40.75
	Sum		62,774.23	446.37	428,305.91	94,995.22	143,796.06	10,986.60	134,754.26	54,336.87	64,052.43	3,002.45
	East		26,431.93	3,884.69	277,987.58	60,805.13	69,485.75	6,670.12	52,100.18	806.64	37,707.63	2,104.51
	Central		21,735.26	1,560.11	98,550.00	22,369.30	46,224.25	2,861.73	65,835.11	1,417.98	17,568.14	727.12
	West		14,607.04	2,083.07	51,768.32	11,912.26	28,086.06	1,747.12	36,205.31	735.26	8,776.66	312.93

Notes:

(1) All monetary values are in 1995 prices.
(2) Source: China Energy Statistical Yearbook, 1991-1996, 1997-1999, 2000-2002, China Statistical Yearbook, 1995-2002.
(3) E is the abbreviation for the east area, C is the abbreviation for the central area, and W is the abbreviation for the west area.
(4) Data for the administration region Chongqing are regarded as a part of Sichuan in this paper since they were promoted as one of the municipalities in China only from 1997.
(5) Data of energy consumption in Tibet are not included since they are not available in the sample period.

A correlation matrix is shown in Table 2, whereby a high correlation exists between these inputs and output. The correlation coefficient between the energy input and GDP output is 0.801 ($P<0.005$). A positive correlation coefficient of 0.539 is found between the farm area input and GDP output as well. These results all show 'isotonicity' of the four inputs and the one output in our DEA model. The energy input efficiency shall be analyzed in this study in order to understand individual energy efficiency states among all regions of China.

Table 2 THE CORRELATION MATRIX FOR OUTPUT AND INPUTS WITH ENERGY (1995-2002)

	GDP	Labors	Capital	Energy	Farm area
GDP	1.000				
Labors	0.739	1.000			
Capital	0.716	0.324	1.000		
Energy	0.801	0.718	0.701	1.000	
Farm area	0.539	0.887	0.148	0.628	1.000

Note:

(1) Farm area is an abbreviation of "Total Saw Area of Farm Crops" as explained in text.

5.2 REGIONAL TOTAL-FACTOR ENERGY EFFICIENCY

The amount of total adjustments in energy input is regarded as the inefficient portion of actual energy consumption in a region. The more the amount of total adjustments, the less efficient the energy consumed in the region. Thus, if there does not exist an amount of total adjustments of energy input (equal to zero), then the region is utilizing energy at the "target energy input" level, which is the optimal efficiency of energy consumption when its output is maximized. Therefore, energy efficiency in a region is defined in Eq. (8) as below, which is named total-factor energy efficiency (TFEE) for region *i* at time *t* since the index is established based on the viewpoint of total factor productivity:

$$\text{TFEE}(i, t) = \frac{\text{Target Energy Input}(i, t)}{\text{Actual Energy Input}(i, t)}, \tag{8}$$

which implies in the *i*th region and in the *t*th year.

As Eq. (8) shows, the index TFEE represents the efficiency level of energy consumption in a region. As the target energy input is the best practical minimum level of energy input in a region, the actual energy input is therefore always larger than or equal to this target energy input. This makes the index TFEE score to always be between zero and unity. When the actual energy input level of a DMU is equal to the suggested target energy input level, a TFEE score of unity is achieved. Conversely, if the actual energy input level is far away from the suggested target energy input level, then the index approaches to zero, which represents low efficiency. This index is shown in percentile format in this study for easier reading.

5.3 TOTAL-FACTOR ENERGY EFFICIENCY IN AN AREA

Index TFEE is also employed to analyze energy efficiency in an area. Assume area *a* covers *r* regions. Area *a*'s TFEE at time *t* is defined in Eq. (9):

$$\text{TFEE}\,(a\,,t\,) = \frac{\sum_{r\in a} \text{Target Energy Input}\,(r\,,t\,)}{\sum_{r\in a} \text{Actual Energy Input}\,(r\,,t\,)}\,, \tag{9}$$

which implies that the *r*th region belongs to area *a*.

Eq. (9) shows that the TFEE in an area is calculated by dividing the summation of target energy inputs by the total actual energy inputs of the area. This is a summation of actual energy input consumed in regions of the area. We calculate TFEE of an area in China in Section 5.5 in order to find its relation with per capita income of regions in China.

5.4 REGIONAL TOTAL ADJUSTMENTS OF ENERGY INPUT

Regions in the east area - the fast developing area - have an amount of total adjustments of their energy input at 15.96 Btce in 1995 and then it decreased to 13.49 Btce in 2002. The amount remained at around one-third of China's total and fell slowly during the research period. Liaoning (4) and Hebei (3) are the two major regions generating around two-thirds of the area's total. Shandong (9) reduced its 1995 adjustments' amount to half in 2002 with continuous improvement. Shanghai (5), Fujian (8), and

Table 3 TOTAL ADJUSTMENTS AMOUNT OF ENERGY USE BY REGION (1995-2002)

			1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
1	E	Beijing	1094.53	1104.27	1352.68	1336.31	1263.44	1286.48	1015.54	893.98
2	E	Tianjin	1065.11	862.70	849.51	901.04	804.54	930.04	874.57	726.68
3	E	Hebei	4163.53	3939.70	3970.14	3918.68	3875.62	5234.86	3744.19	4330.84
4	E	Liaoning	4861.31	4835.12	4804.35	4429.55	4353.00	5395.54	5025.00	4674.92
5	E	Shanghai	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	E	Jiangsu	1380.76	1336.77	1407.30	1628.80	1275.31	1213.20	887.79	643.60
7	E	Zhejiang	300.77	267.72	407.36	523.66	500.49	453.79	244.08	0.02
8	E	Fujian	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	E	Shandong	3097.46	3192.84	3386.02	3383.65	2873.38	1733.27	1874.18	1963.33
10	E	Guangdong	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	E	Guangxi	0.00	0.00	0.00	144.91	148.98	254.73	165.16	142.77
12	E	Hainan	0.00	0.00	43.57	67.09	63.07	90.75	114.03	109.68
13	C	Shanxi	7101.27	5530.22	5718.63	5353.53	5221.58	5441.85	6111.53	7198.79
14	C	Inner Mongolia	1638.16	1794.48	2396.75	2123.93	2764.61	2453.90	2487.75	0.00
15	C	Jilin	2777.67	2779.12	3032.67	2526.71	2278.99	2164.73	1893.43	2115.88
16	C	Heilongjiang	3306.50	2990.52	3605.66	3768.90	3794.19	3720.32	2522.89	2130.47
17	C	Anhui	1088.29	1229.93	1128.05	1188.91	1137.28	1766.90	1222.61	1208.48
18	C	Jiangxi	981.60	729.64	682.28	593.77	588.93	670.12	643.48	638.50
19	C	Hennan	2257.33	2037.60	1887.76	2131.44	2018.51	2637.65	1828.89	1792.59
20	C	Hubei	2994.68	2995.86	2893.44	2829.05	2632.96	2935.00	1323.62	1599.69
21	C	Hunan	752.89	589.36	232.20	113.95	0.00	0.00	0.00	0.00
22	W	Sichuan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	W	Guizhou	1610.57	2110.22	2384.96	2629.90	2251.12	2560.81	2710.67	2615.53
24	W	Yunnan	757.67	667.57	910.47	761.95	700.91	1087.97	815.62	928.05
25	W	Shaanxi	1994.61	2400.16	1919.72	1801.29	1427.53	1382.74	1554.33	1721.28
26	W	Gansu	2093.02	2018.59	1775.31	1806.03	1914.44	2144.81	1631.17	1583.77
27	W	Qinghai	469.33	476.00	485.12	560.22	715.36	645.59	638.22	680.50
28	W	Ningxia	533.22	565.65	573.56	643.56	636.07	669.05	592.73	577.14
29	W	Xinjiang	1690.38	2072.03	2036.59	2304.41	1965.99	1937.36	2029.38	1610.38
		Summary	48010.66	46526.06	47884.10	47471.22	45206.28	48811.47	41950.82	39886.84
		East	15963.47	15539.13	16220.93	16333.69	15157.81	16592.66	13944.51	13485.80
		Central	22898.39	20676.71	21577.44	20630.18	20437.05	21790.47	18034.20	16684.41
		West	9148.80	10310.22	10085.73	10507.35	9611.43	10428.33	9972.11	9716.64

Notes:

(1) The unit is 10,000 tce.
(2) E is the abbreviation for the east area, C is the abbreviation for the central area, and W is the abbreviation for the west area.
(3) Data for the administration region Chongqing are regarded as a part of Sichuan in this paper since it was promoted as one of the municipalities in China only from 1997.
(4) Data of energy consumption in Tibet are not included since they are not available in the sample period.

Guangdong (10) are the three regions in the area having no energy adjustments' amount in all years of the research period. Guangxi (11) and Hainan (12) have zero adjustments in 1995, but the amount rose in the later years. All detailed data are shown in Table 3.

Regions in the central area own the largest portion of total adjustments' amount of energy use in China, which were 22.9 Btce (47.69% of China's total) in 1995 and 16.7 Btce (41.83% of China's total) in 2002. The adjustments' amount actually dropped rapidly during the research period, but was still above 40% of China's total. All regions in this area had non-zero adjustments among all the years of the research period except for Inner Mongolia (14) and Hunan (21) in the later years. Shanxi (13) created the largest energy adjustments' amount in this area, which was around one-third of the area's total in 1995 and then it rose up to half of the area's total in 2002. Heilongjiang (16), Hubei (20), Jilin (15), and Hennan (19) are the four regions that generated high amounts of adjustments in the area. Their amounts totaled one-third of the area's adjustments' amount in 1995 and were half of the area's total in 2002. The detailed data are shown in Table 3.

The west area contains the lowest level of total energy adjustments. Its adjustments' amount began at 9.15 Btce, increased up to 10.51 Btce in 1998, and then decreased to 9.72 Btce in 2002, remaining relatively flat as shown in Table 3. Sichuan (22) is the only region to have no adjustments among all the years of the research period. Gansu (26), Shannxi (25), and Xinjiang (29) are three regions that had higher levels of energy adjustments' amount at about two-thirds of the area's total. Guizhou (23) is the only region having it adjustments' amount increase during the period.

The total adjustments' amount of the energy input significantly decreased during 1995-2002 for all areas in China, and the results are shown in Figure 4. It shows a total of 48.01 Btce in 1995 and then it dropped to 39.89 Btce in 2002. The major reduction comes from regions in the east area as well as the central area, though regions in the central area still constitute over 40 % of China's total energy adjustments. Regions in the west area contain the least portion of China's total, but it is worth noting that their adjustments' amount slightly increased.

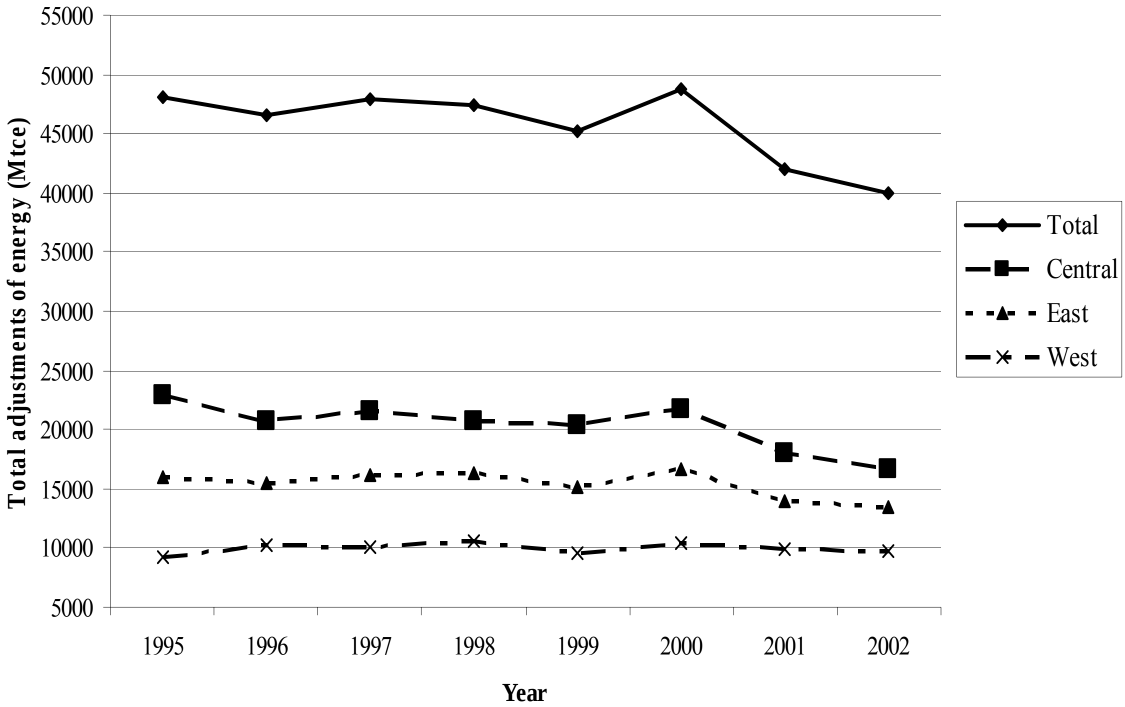

Figure 4

SLACK AND RADIAL ADJUSTMENT OF ENERGY BY AREA AND YEAR (1995-2002)

5.5 REGIONAL TFEE

Table 4 shows the regional result during 1995-2002 based on the TFEE index. The TFEE score is computed for a comparison of energy efficiency among regions. The ratio of the actual energy input to the target energy input is analyzed instead of using an absolute amount for comparison. A total of four regions in China are found to always have the optimal efficiency during the research period. Three of these regions are located in the east area: Shanghai (5), Fujian (8), and Guangdong (10). The one region left is Sichuan (22), located in the west area.

These four regions, having the optimal efficiency result in our analysis, actually constitute the efficiency frontier of energy consumption among all regions of China. They have the best technology level and production process so that their inputs and output are operating at the optimal level. The other regions in China which are not yet at the frontier efficiency position can, therefore, base themselves on these frontier

Table 4 TOTAL-FACTOR ENERGY EFFICIENCY BY REGION (1995-2002)

			1995	1996	1997	1998	1999	2000	2001	2002
1	E	Beijing	68.9	69.9	64.7	65.8	68.3	69.5	76.5	80.1
2	E	Tianjin	58.5	65.5	65.5	63.1	68.5	66.7	70.0	76.0
3	E	Hebei	53.7	55.9	56.0	57.2	58.7	47.1	64.0	62.6
4	E	Liaoning	49.7	50.3	49.3	51.4	53.6	49.9	52.8	55.9
5	E	Shanghai	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
6	E	Jiangsu	82.8	83.5	82.4	79.9	84.4	85.9	90.0	93.3
7	E	Zhejiang	93.4	94.5	92.0	90.0	90.8	92.4	96.3	100.0
8	E	Fujian	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
9	E	Shandong	64.7	65.2	63.0	62.5	68.3	78.9	81.2	82.2
10	E	Guangdong	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
11	E	Guangxi	100.0	100.0	100.0	94.1	94.0	90.5	93.8	95.2
12	E	Hainan	100.0	100.0	88.8	83.5	85.4	81.1	78.1	80.4
13	C	Shanxi	15.6	19.2	18.1	19.2	19.7	19.2	23.3	22.9
14	C	Inner Mongolia	37.8	36.4	29.0	30.4	27.3	30.7	38.9	100.0
15	C	Jilin	32.4	33.4	30.0	32.6	38.3	40.8	51.0	51.4
16	C	Heilongjiang	44.3	49.0	44.0	36.9	37.4	39.7	58.2	64.5
17	C	Anhui	74.1	72.8	74.4	74.0	75.7	63.8	76.1	77.3
18	C	Jiangxi	59.0	66.1	68.0	70.7	72.4	69.8	72.4	75.4
19	C	Hennan	65.1	69.4	71.9	70.6	72.6	66.5	77.8	79.2
20	C	Hubei	47.0	50.1	52.6	53.2	56.0	53.2	78.1	76.2
21	C	Hunan	86.1	89.2	95.2	97.7	100.0	100.0	100.0	100.0
22	W	Sichuan	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
23	W	Guizhou	49.4	42.8	39.8	39.1	44.0	40.8	38.9	41.5
24	W	Yunnan	71.3	75.9	73.4	77.3	78.7	66.1	76.6	76.4
25	W	Shaanxi	36.4	31.9	38.3	40.4	46.5	49.4	52.3	53.6
26	W	Gansu	23.6	28.0	31.2	32.8	34.4	28.8	43.8	47.5
27	W	Qinghai	31.8	31.8	31.4	24.2	23.8	26.6	31.4	33.2
28	W	Ningxia	29.7	29.4	28.7	22.2	25.0	23.0	33.4	36.6
29	W	Xinjiang	40.3	35.7	36.9	29.7	38.8	41.6	42.0	55.5
		Total	64.1	65.8	65.2	65.6	67.7	66.4	72.7	76.0
		East	74.6	76.0	75.1	75.1	77.6	76.8	81.7	83.6
		Central	49.4	53.5	52.4	53.3	53.9	52.0	62.7	68.2
		West	64.1	61.7	62.8	62.8	65.6	63.1	65.9	69.1

Notes:

(1) The unit is percentage.
(2) E is the abbreviation for the east area, C is the abbreviation for the central area, and W is the abbreviation for the west area.
(3) Data for the administration region Chongqing are regarded as a part of Sichuan in this paper since they were promoted as one of the municipalities in China only from 1997.
(4) Data of energy consumption in Tibet are not included since they are not available in the sample period.
(5) Scores with a gray shadow covered are those regions reaching the optimal efficiency with a unity (100%) TFEE score.

regions as targets to adjust their technology levels and production processes accordingly. A target is hence identified by TFEE analysis based on DEA so that feasible steps for improvement of the OTE do exist. This is one of the benefits from TFEE analysis in a comparative study of energy efficiency.

As shown in Table 4, regions in the east area have the highest TFEE rank over all areas in China. In contrast, regions in the central area have the worst rank of efficiency. Regions in the west area have the second best rank for TFEE. The TFEE scores are in average 77.6%, 55.7 %, and 64.4 % over the research period for the east, central, and west areas, respectively. The central area was predicted to be the second best energy-efficient area before performing this empirical study. It does have the second largest amount of investments and labor employment, it consumes the second largest level of energy, and it contributes the second largest GDP output in China. However, its efficiency level does not perform the same as with the rank of inputs and output, while it does have the worst TFEE.

5.6 ENERGY EFFICIENCY VS. REGIONAL DEVELOPMENT

A U-shape relation is found to exist between the area's TFEE and per capita income in China. The east area has the highest level of per capita income and also the highest score of an area's TFEE among the three areas. The central area has the second highest level of per capita income, but the worst score of an area's TFEE. The west area has the lowest level of per capita income, but is the second best in TFEE. The per capita income actually represents the economic development level in the region or the area. The U-shape relation is illustrated in Figure 5.

The discovered U-shape relation between TFEE and per capita income in an area, therefore, explains that an improvement of energy efficiency is followed by economic growth in an area, though it declines in the beginning period. This discovery matches the real condition of regional development in China. As shown in Table 4, most regions and areas in China have their improved TFEE followed up with economic growth in the period from 1995 to 2002 since China showed dramatic economic growth during this period. The east and central areas both improved during the sample's period. Especially, the central area had significant improvement in the period, although its

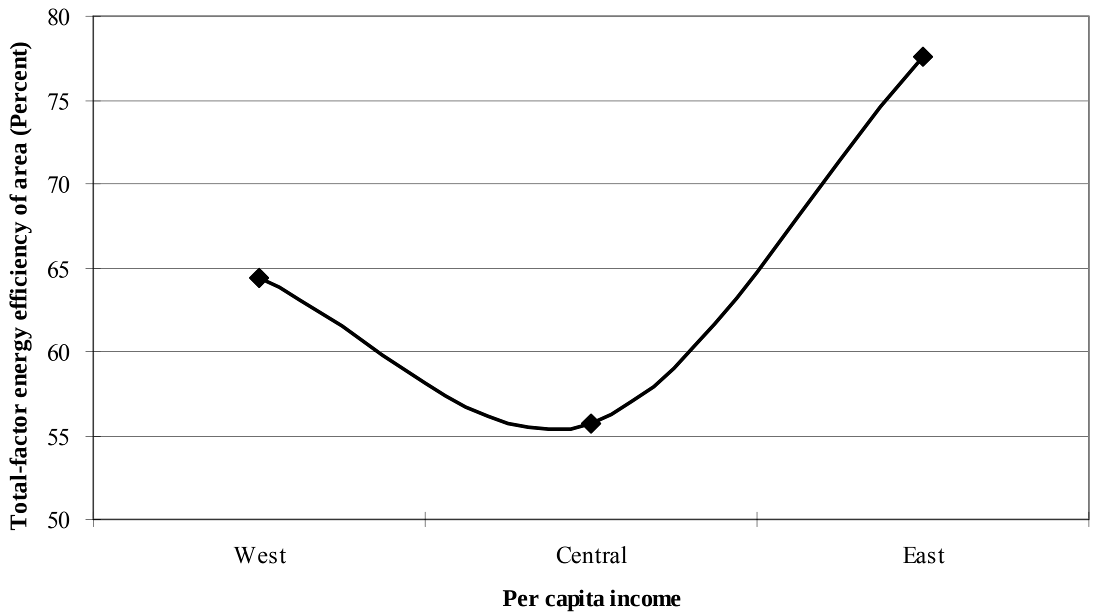

Figure 5

THE U-SHAPE RELATION EXISTING BETWEEN TOTAL-FACTOR ENERGY EFFICIENCY OF AN AREA AND PER CAPITA INCOME OF AN AREA IN CHINA

average level is the lowest rank among all areas. The west area just started its development in recent years and therefore its TFEE score degraded in the beginning of the research period, and kept flat in the later years. However, there are no significant changes on the TFEE of regions in the west area.

5.7 COMPARISON TO PARTIAL-FACTOR ENERGY EFFICIENCIES

The commonly used indicator of energy efficiency, the index of energy productivity ratio (Patterson, 1996), is also computed for comparison with TFEE. In contrast with the concept of TFEE, the commonly used index of energy productivity ratio can be regarded as a partial-factor energy efficiency (PFEE) index since energy is the only input factor considered in the index. The index PFEE computes the efficiency ratio by directly dividing GDP output by energy input as an indicator of energy efficiency. In contrast, the index TFEE incorporates the key inputs, labor and capital stock, together with the energy input, including the farm area proxy, to form a multiple-inputs model to assess energy efficiency on the basis of a total-factors effect.

Table 5 shows the PFEE score of the three main areas and that of China's total. The east area drops the most, over 10 %, from 62.46 % in 1995 to 51.45 % in 2002. The west area drops the least at just 3 % from 28.68 % in 1995 to 25.51 % in 2002. The central area's efficiency increased in period from 1995 to 1998, but then dropped in the period from 1999 to 2002: the lowest ratio is 36.44 % in 2002. The PFEE score of China's total dropped from 45.31 % in 1995 to 39.64 % in 2002. As can be seen from these results, energy efficiency among areas in China and that of China's total are dropping in the sample period.

The result is different from that found from the TFEE score. First, all areas' PFEE scores are declining in the period, meaning that energy efficiency drops in all areas of China. The more developed the area is, such as the east area, the more the energy efficiency drops. In TFEE the energy efficiency drops the most for an area in a developing stage, but not in a developed stage. This is because in a developing stage out-of-date technologies and inappropriate production processes need to be upgraded while more output is still generated. The upgraded technologies and more advanced production processes should have been launched when an area or a region enters a developed stage and a better efficiency level is therefore expected. Second, energy efficiency is proportional to an economy's developmental progress in an area. TFEE does not mean that a proportional relation exists between the state of economic development and energy efficiency, but a U-shape relation does, which fits better to the real condition.

The comparative result also shows that the substitution among inputs (labor, capital stock, and energy) to produce the output (GDP) is significant. The PFEE scores could be over-estimated if energy is taken as the single input in the production. A certain portion of GDP output is produced not only by the energy itself, but also by other inputs (labor and capital stock). Hence, a multiple-inputs framework is integral to correctly evaluating energy efficiency, with which the index TFEE is established.

Table 5 REGIONAL PARTIAL FACTOR ENERGY EFFICIENCY – THE ENERGY PRODUCTIVITY RATIO (1995-2002)

			1995	1996	1997	1998	1999	2000	2001	2002
1	Beijing	E	39.7	40.2	39.6	40.0	39.6	39.4	41.2	41.1
2	Tianjin	E	35.8	40.2	42.3	42.5	41.2	39.3	39.4	39.1
3	Hebei	E	31.7	35.2	36.7	36.2	35.4	34.5	33.5	30.4
4	Liaoning	E	28.9	29.5	30.9	33.2	32.3	29.1	29.5	29.7
5	Shanghai	E	55.1	55.3	59.2	58.9	56.3	55.5	53.2	50.9
6	Jiangsu	E	64.1	67.4	70.1	69.0	68.5	66.8	66.9	63.7
7	Zhejiang	E	77.0	77.8	76.8	74.3	71.4	67.8	64.6	60.8
8	Fujian	E	94.8	96.9	99.3	100.5	93.0	89.2	84.0	77.3
9	Shandong	E	57.0	59.3	61.0	61.9	61.4	69.8	59.3	55.0
10	Guangdong	E	78.1	76.7	77.2	73.6	70.4	68.5	65.4	59.7
11	Guangxi	E	67.4	70.3	64.9	60.8	57.4	51.5	52.2	47.4
12	Hainan	E	120.2	102.9	88.2	83.9	79.4	72.4	65.6	62.2
13	Shanxi	C	13.0	17.4	17.8	18.8	16.8	16.4	14.0	12.4
14	Inner Mongolia	C	31.6	31.8	27.2	30.4	24.2	26.5	23.7	21.9
15	Jilin	C	27.5	29.2	28.0	32.3	32.8	33.4	32.9	29.7
16	Heilongjiang	C	33.9	37.3	35.3	36.9	34.7	35.3	36.9	37.3
17	Anhui	C	47.8	47.2	50.9	47.7	45.1	41.7	40.2	38.7
18	Jiangxi	C	52.1	64.2	67.5	71.1	66.8	60.5	58.4	54.3
19	Hennan	C	46.4	50.4	51.0	46.8	45.0	43.7	42.8	41.3
20	Hubei	C	42.3	45.1	47.4	47.7	46.8	45.7	48.1	42.7
21	Hunan	C	40.5	44.1	52.2	51.1	59.1	60.8	53.9	49.6
22	Sichuan	W	37.1	40.7	42.2	38.9	37.5	37.7	39.3	36.8
23	Guizhou	W	19.2	17.8	16.8	15.2	16.5	15.4	15.3	15.3
24	Yunnan	W	45.7	49.1	40.2	41.5	41.0	40.8	37.2	32.7
25	Shaanxi	W	31.7	30.4	35.8	35.6	40.5	40.7	35.4	31.6
26	Gansu	W	20.2	23.2	25.4	25.2	23.2	21.9	23.1	22.2
27	Qinghai	W	24.0	24.0	24.0	23.2	18.4	20.1	20.2	19.3
28	Ningxia	W	22.4	22.0	22.0	21.4	20.7	20.5	21.0	20.8
29	Xinjiang	W	29.2	25.8	27.3	26.5	26.4	27.6	26.6	25.4
	Average		45.3	46.6	46.8	46.4	44.9	43.9	42.2	39.6
	East		62.5	62.6	62.2	61.2	58.8	57.0	54.6	51.5
	Central		37.2	40.7	41.9	42.5	41.3	40.4	39.0	36.4
	West		28.7	29.1	29.2	28.4	28.0	28.1	27.2	25.5

Notes:

(1) The unit is percentage.
(2) E is the abbreviation for the east area, C is the abbreviation for the central area, and W is the abbreviation for the west area.
(3) Data for the administration region Chongqing are regarded as a part of Sichuan in this paper since they were promoted as one of the municipalities in China only from 1997.
(4) Data of energy consumption in Tibet are not included since they are not available in the sample period.

CHAPTER 6 REGIONAL EFFICIENCY WITH WATER CONSIDERED

An empirical study to analyze the efficiency status of water use for regions in China is conducted based on a defined production function including water as an input and is constructed by DEA. Based on this new index we analyze the regional condition of water use in China and prove this index is an effective indicator for the analysis of water efficiency.

A panel dataset for this analysis with water consumption considered are collected and constructed during 1997 to 2002. Total thirty regions' data are available during this period. All monetary data, such as GDP and capital stock, are converted to 1997 price with GDP deflators[9].

The summation of slack and radial adjustment for input is the total adjustment amount, meaning the total amount needs to adjust to reach at 'target' input with keeping output unchanged. For water input, this summation provides a 'water adjustment target' (WAT) in a region and the formula is defined as follows:

$$\text{WAT} = \text{Radial adjustment of water input} + \text{Slack of water input.} \qquad (10)$$

An inefficient economy unit can save or reduce WAT in water use without reducing to the real economic growth. The production efficiency is therefore improved.

The regional WAT of water input in China is then computed according to this method.

6.1 INDEX OF WATER ADJUSTMENT TARGET RATIO

The WAT computed by DEA shows a target amount of water input to be reduced in an economy or a region so as to reach the optimal production efficiency at the frontier. However, it is hard to compare directly for the regional result since differences from the scale of economy and size of the region are not yet considered. A ratio format of WAT enables fair comparisons of regions by eliminating these differences.

[9]Detail explanation refers to Section 3.2.2 in page 16.

Therefore, a simple index named the water adjustment target ratio (WATR) is constructed as the ratio format of WAT to measure the ratio of WAT to the amount of total water use in the region (Hu and Wang, forthcoming). The WATR index is constructed as below:

$$\text{Water Adjustment Target Ratio } (i, t)$$

$$= \frac{\text{Water Adjustment Target } (i, t)}{\text{Actual Water Input } (i, t)}, \qquad (11)$$

which is in the *i*-th region and the *t*-th year.

The index WATR represents the target adjustment ratio of water use in each region. It reflects how much the ratio of water use is able to decrease without deducting any of the regional economic output level. The ratio is between zero and unity since WAT is equal to or larger than zero and is always smaller than the total water use. The zero of this index represents an optimal and efficient production status in a region that has no water input amount that needs to be saved since its water use condition is at the most efficient level, the minimum level, for economic output. Alternatively, the non-zero ratio of this index shows a certain ratio of amount of water use that needs to be reduced and adjusted in order that a minimum level of water use is adopted at economic production, which is at the production frontier. We will apply the WATR index to analyze water efficiency in regions of China in the following section.

6.2 DESCRIPTIVE STATISTICS

Table 6 shows first the summary statistics of the aforementioned inputs and output, including water as an input, from 1997 to 2002. All the data are shown in order by region and area. The mean GDP output in the east area is 4.10 trillion RMB, which is much higher than 1.90 trillion RMB of the central area and 0.95 trillion RMB of the west area during the sample's years. The variation of GDP output is the same tendency and fits the economic growth scenarios among these areas in that the east area has about twice and four times the standard deviation of that for the central and west areas, respectively. For production inputs, the east area has the highest capital stock. The mean of capital stock of the east area is also around twice and four times higher than

Table 6 SUMMARY STATISTICS WITH WATER AS INPUT BY REGION (1997-2002)

ID	Region		Inputs								Output	
			Labor Empolyment (10,000 persons)		*Capital Stock (100 million RMB)*		*Residential Use Water (1 million tons)*		*Productive Use Water (1 million tons)*		*Gross Domestic Product (100 million RMB)*	
			Mean	STDev	Mean	STDev	Mean	STDev	Mean	STDev	Mean	STDev
1	Beijing	E	659.58	69.84	24,988.62	3,201.89	663.14	151.11	332.80	101.36	1,759.75	241.89
2	Tianjin	E	426.67	33.05	14,254.40	1,745.93	261.81	32.02	293.65	27.91	1,161.07	147.46
3	Hebei	E	3,400.70	23.81	18,742.61	4,484.50	692.34	125.97	976.01	198.33	3,604.71	428.92
4	Liaoning	E	1,860.98	100.39	71,317.28	4,658.69	979.77	197.44	1,646.47	148.41	3,252.34	352.79
5	Shanghai	E	704.30	42.06	43,254.53	5,186.85	1,096.10	235.76	1,161.69	133.76	3,159.97	351.02
6	Jiangsu	E	3,601.02	82.72	52,522.91	8,093.94	1,379.83	204.98	1,789.32	150.58	6,128.55	776.99
7	Zhejiang	E	2,719.92	70.52	31,382.28	5,447.00	774.61	152.75	916.63	50.92	4,325.27	608.96
8	Fujian	E	1,652.58	37.65	14,740.25	3,442.23	505.22	64.36	619.77	76.18	2,766.25	320.79
9	Shandong	E	4,691.35	35.76	40,857.52	8,441.60	878.99	140.35	1,302.66	106.79	6,093.32	770.49
10	Guangdong	E	3,845.47	101.36	37,630.67	7,491.29	2,432.26	461.27	1,879.02	109.00	6,784.71	823.17
11	Guangxi	E	2,508.18	46.54	7,996.16	1,367.61	570.47	57.46	659.13	51.38	1,560.91	284.26
12	Hainan	E	832.17	1,225.52	3,797.87	480.51	142.20	24.73	45.12	13.16	365.48	44.37
13	Shanxi	C	1,432.63	26.00	11,375.91	1,519.93	337.98	25.27	455.26	56.60	1,220.60	195.18
14	Inner Mongolia	C	1,019.02	15.81	8,463.75	1,208.72	204.77	33.26	352.68	27.21	1,004.19	127.60
15	Jilin	C	1,109.48	73.11	10,045.65	1,513.60	370.42	42.59	960.20	17.68	1,314.32	163.90
16	Heilongjiang	C	1,659.00	37.28	14,825.56	2,234.12	560.47	49.54	853.86	53.27	2,338.68	310.11
17	Anhui	C	3,351.93	41.71	14,701.02	2,354.58	606.29	68.49	1,228.82	51.98	2,250.54	323.71
18	Jiangxi	C	1,905.63	189.28	10,968.99	1,710.33	480.60	45.11	820.64	231.34	1,494.07	211.75
19	Hennan	C	5,305.32	264.27	24,394.35	4,425.40	739.68	80.68	1,029.00	144.87	3,657.20	449.16
20	Hubei	C	2,554.20	98.05	20,218.53	3,793.83	1,350.67	124.07	1,643.90	419.78	3,049.24	363.31
21	Hunan	C	3,492.48	53.04	12,959.73	2,639.65	923.10	63.73	1,612.82	96.48	2,624.25	326.09
22	Sichuan	W	6,128.15	102.25	19,157.13	4,549.15	1,085.91	130.31	1,198.51	291.11	4,102.72	551.32
23	Guizhou	W	2,007.47	66.07	5,425.26	967.06	191.54	34.94	194.26	50.81	709.75	85.33
24	Yunnan	W	2,291.70	35.02	8,928.69	1,610.76	229.20	54.11	179.09	39.70	1,420.93	189.92
25	Tibet	W	300.62	432.97	1,692.84	110.58	32.16	6.76	10.92	2.43	82.98	14.04
26	Shaanxi	W	1,810.88	33.30	12,852.80	1,701.00	353.14	68.80	270.42	42.33	1,187.44	150.94
27	Gansu	W	1,195.22	29.54	7,176.94	939.35	192.50	14.49	508.66	80.62	709.37	83.12
28	Qinghai	W	238.87	5.70	2,294.02	331.70	62.75	9.14	68.45	9.03	190.31	25.76
29	Ningxia	W	270.77	9.11	2,496.11	338.90	77.20	13.43	131.46	13.47	191.83	24.13
30	Xinjiang	W	683.00	11.99	8,799.90	1,352.47	230.33	20.78	210.66	22.42	948.34	110.00
	Sum		63,659.28	3,393.76	558,262.28	87,343.17	18,405.42	2,733.74	23,351.85	2,818.91	69,459.08	8,856.49
	East		26,902.92	1,869.24	361,485.11	54,042.03	10,376.74	1,848.20	11,622.25	1,167.79	40,962.32	5,151.11
	Central		21,829.70	798.57	127,953.48	21,400.17	5,573.97	532.75	8,957.18	1,099.20	18,953.10	2,470.81
	West		14,926.67	725.96	68,823.69	11,900.97	2,454.72	352.78	2,772.42	551.92	9,543.67	1,234.57

Notes:

(1) All monetary values are in 1997 prices.
(2) Source: China Statistical Yearbook, 1997-2002.
(3) Data for the administration region Chongqing are regarded as a part of Sichuan.

that of the other two areas, which are 36.1, 12.8, and 6.88 trillion RMB, respectively. Input of labor employment is not too much different between the east area and the central area. The west area has the least labor employment since this area has also the lowest population in China.

The situation of water use appears with a similar scenario of GDP output and capital stock input. The east area, from its economic growth result, consumes the largest water amount in China for both residential use and productive use. As Table 6 shows, the east area consumes 10.4 billion tons (Bt) of water for residential use and 11.6 Bt of water for productive use on average during the sample's period. These amounts are already over 50% of China's total. The central area is the second largest consumption area of water, which consumes 5.6 billion tons (Bt) of water for residential use and 9.0 Bt of water for productive use on average. The water amounts this area consumes, both for residential use and productive use, occupy more than 30% of China's total. On the other hand, it is worth noting that only this area, the central area, consumes water more for productive use than for residential use. As for the lower population in the west area, this area consumes the least residential use water amount among the three areas. The productive use amount of water consumption in this area is also the lowest among the three areas.

Table 7 THE CORRELATION MATRIX FOR OUTPUT AND INPUTS WITH WATER (1997-2002)

	GDP	Capital	Labor	Water_resi	Water_prod
GDP	1.000				
Capital	0.728	1.000			
Labor	0.726	0.358	1.000		
Water_resi	0.852	0.665	0.573	1.000	
Water_prod	0.807	0.675	0.637	0.830	1.000

A correlation matrix is shown in Table 7, whereby a high correlation exists between these three inputs and GDP output. All inputs have positive correlation coefficients with the output, which explains that all inputs satisfy the isotonicity property with the output. The correlation coefficient is 0.852 between residential use water input and GDP output and 0.807 between productive use water input and GDP output, which are all statistically significant. The high correlation reveals that proportional relationships do exist between GDP output and both residential use and productive use of water consumption. It further explains that water consumption performs as a significant input to generate economic output together with the other inputs in the production function. Water efficiency shall be analyzed on the basis of this production function with multiple inputs in a framework of total factor productivity. As water is an inevitable and finite resource for economic development and all life on earth, the efficiency of water use should be put under high concern.

6.3 WATR OF RESIDENTIAL USE

The regional water adjustment target ratio (WATR) of residential use water consumption in China is computed and constructed by DEA through the aforementioned method. Table 8 shows the result. The average 4.03% WATR of total residential water amount is found in China during the research period. It can be further reduced in order to improve the efficiency of total factor production onto its frontier position.

Regions of the east area and west area have low WATR for their residential water use amount. Regions of the east area have an average rate of 1.6% WATR during the sample years. Guangxi (11) is the only region in this area that has non-zero WATR from its residential water use. This region has an average rate of 20.3% in its residential use water amount, which represents 116.54 million tons of water. This amount can be reduced from this region without any impact to its current GDP output level. The WAT amount can be found from Table 9 in a yearly format. Beijing (01) is another region to be noted that has a higher average rate of WATR, which is 4.8% during the research period. As shown in Table 9, this region has WAT existing only by 2002, which is 236.22 million tons of water. This amount is 22.76% of the area's total and is a significant portion in this area. Some other regions in this area have a lower but non-zero WATR in certain years: For example, Hebei (03) has 10.54% WATR in 1999 and Hainan (12) has 6.38% WATR in 2000. There are no apparent patterns that can be observed in these regions during the period.

Regions in the west area have an average rate of 0.56% WATR that must be improved during our research period. Guizhou (23) has a non-zero WATR for four years in the period, which are 4.33% in 1997, 0.74% in 2000, 11.32% in 2002,

Table 8 WATR OF RESIDENTIAL USE BY REGION (1997-2002)

ID	Region		1997	1998	1999	2000	2001	2002	*Average*
1	Beijing	E	0.00	0.00	0.00	0.00	0.00	28.80	4.80
2	Tianjin	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Hebei	E	0.00	0.00	10.54	0.00	0.00	0.00	1.76
4	Liaoning	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Shanghai	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Jiangsu	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Zhejiang	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Fujian	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Shandong	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Guangdong	E	0.00	0.00	0.00	0.0	0.00	0.00	0.00
11	Guangxi	E	28.59	22.77	19.19	12.62	17.80	20.84	20.30
12	Hainan	E	0.00	0.00	0.00	6.38	0.00	0.00	1.06
13	Shanxi	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Inner Mongolia	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Jilin	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Heilongjiang	C	0.00	0.00	1.64	8.19	0.00	0.00	1.64
17	Anhui	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	Jiangxi	C	0.00	4.63	0.53	0.00	0.00	0.00	0.86
19	Hennan	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Hubei	C	37.36	37.39	32.44	32.79	11.65	7.24	26.48
21	Hunan	C	29.51	27.96	22.89	0.00	25.78	15.54	20.28
22	Sichuan	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	Guizhou	W	4.33	0.00	0.00	0.74	0.00	11.32	2.73
24	Yunnan	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Tibet	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Shaanxi	W	0.00	0.00	9.13	0.00	0.00	0.00	1.52
27	Gansu	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	Qinghai	W	11.93	0.00	0.00	0.00	0.00	0.00	1.99
29	Ningxia	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	Xinjiang	W	0.00	0.00	1.06	0.00	0.68	0.00	0.29
	Total		5.34	5.09	4.72	2.79	3.06	3.17	4.03
	East		1.66	1.30	1.93	0.67	1.09	3.06	1.62
	Central		14.06	14.19	11.54	8.38	7.46	4.34	9.99
	West		0.73	0.00	1.48	0.05	0.07	1.03	0.56

Notes:

(1) The unit is a percentage of the target to actual residential water use of the region or the area.
(2) E is the abbreviation for the east area, C is the abbreviation for the central area, and W is the abbreviation for the west area.
(3) Data for the administration region Chongqing are regarded as a part of Sichuan in this paper.

Table 9 WAT AMOUNTS OF RESIDENTIAL USE FOR REGIONS AND AREAS IN CHINA (1997-2002)

ID	Region		**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	*Average*	*Regional Ratio*
1	Beijing	E	0.00	0.00	0.00	0.00	0.00	236.22	39.37	22.76
2	Tianjin	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Hebei	E	0.00	0.00	94.96	0.00	0.00	0.00	15.83	9.15
4	Liaoning	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Shanghai	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Jiangsu	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Zhejiang	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Fujian	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Shandong	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Guangdong	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Guangxi	E	164.77	132.59	112.54	70.51	83.81	135.01	116.54	67.36
12	Hainan	E	0.00	0.00	0.00	7.61	0.00	0.00	1.27	0.73
13	Shanxi	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Inner Mongolia	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Jilin	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Heilongjiang	C	0.00	0.00	9.18	46.68	0.00	0.00	9.31	1.69
17	Anhui	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	Jiangxi	C	0.00	22.48	2.57	0.00	0.00	0.00	4.18	0.76
19	Hennan	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Hubei	C	495.53	512.15	433.19	432.09	138.18	113.54	354.11	64.21
21	Hunan	C	262.25	253.95	204.92	0.00	220.98	161.09	183.86	33.34
22	Sichuan	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	Guizhou	W	8.21	0.00	0.00	1.37	0.00	29.38	6.49	44.84
24	Yunnan	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Tibet	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Shaanxi	W	0.00	0.00	35.58	0.00	0.00	0.00	5.93	40.94
27	Gansu	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	Qinghai	W	8.43	0.00	0.00	0.00	0.00	0.00	1.40	9.70
29	Ningxia	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	Xinjiang	W	0.00	0.00	2.50	0.00	1.43	0.00	0.65	4.52
	Total								738.95	Area's Ratio
	East								173.00	23.41
	Central								551.46	74.63
	West								14.48	1.96

Notes:

(1) The unit is million tons of water.
(2) E is the abbreviation for the east area, C is the abbreviation for the central area, and W is the abbreviation for the west area.
(3) Data for the administration region Chongqing are regarded as a part of Sichuan in this paper.

and 2.73% during the period. The result shows quite a dynamic water utilization condition in this region and it may result from a complex geographical limitation of mountainous terrain, limestone karsts, spiky hills, and diverse river basins (World Bank, 1998), making it such that water resource management is difficult to maintain to balance water use in this region. Other regions in this area always have non-zero WATR during the research period. Shaanxi (26) has 9.13% in 1999. Qinghai (28) has 11.93% in 1997, but finally goes to zero in the period, which demonstrates a significant improvement of residential water use efficiency after 1997. Xinjiang (30) has low non-zero WATRs, which are 1.06% in 1999 and 0.68% in 2001. Generally speaking, a low level of WATR represents high total-factor water efficiency in this area.

The central area gets high WATR for residential use water according to our analysis result shown in Table 8. The high redundant portion of residential use water shall be considered as being reduced. The area has an average rate of 9.99% WATR during the research period. This ratio is much higher than that of the other two areas. It reflects that the central area is a major source of inefficient residential water use in China. Two regions are the main sources to generate these inefficient water use amounts in this area. Hubei (20) owns an average WATR of 26.48%, 354.11 million tons of residential water can be considered to be saved in total. Hunan (21) gets an average WATR of 20.28%, representing 183.86 million tons of residential water that can be saved. There are two other regions that also have non-zero WATR in certain years, but are small compared to that of Hubei and Hunan. Heilongjiang (16) has 1.64% WATR in 1999, and the ratio quickly rises to 8.19% in 2000 and then returns to zero later in the research period. Jiangxi's (18) WATR is 4.63% in 1998 and then decreases to 0.53% in 1999. It has zero WATR after 1999, which is regarded as an improvement of efficiency.

From the result we obtained from WATR, the central area is the main source where those reducible amounts of water use are located and more improvements should be planned and executed in this area. Two regions in this area, Hubei and Hunan, are considered a higher priority for saving their redundant portion of residential water use. The WATR of residential use water is relatively small in both the east and west areas. Efficiency shall be further retained in these two areas and one must investigate to try and find if any plans can be further implemented to reduce these WATs, though they are relatively small.

6.4 WATR OF PRODUCTIVE USE

Benefiting by the data collection from separate portions of water consumption in residential use and productive use, we are capable of reviewing water use efficiency on the part of productive use. Water is well known as an essential natural resource to most economic production, which significantly influences economic growth directly. The WATR of productive use water induces that the ratio of productive use water can be further saved and reduced. It is emphasized that the same economic output can still be retained at the same time when this redundant portion is removed. Since water is a finite resource on this planet, we need to improve productive water use to be efficient in order to maintain sustainability of economic development.

Table 10 shows the result of productive use WATR for regions in China. It can be observed that high WATR does exist in productive use water within China's total. The average rate of 14.32% shows reducible amount of productive use water. The ratio is much higher than average rate of 4.03% in WATR to be reduced in the residential use water portion. In terms of quantity, the saved target of productive use is 3317.62 million tons of water, which is almost four times larger than 738.95 million tons of WAT of total residential use water. All three areas have a high WATR average rate in productive use water versus that in residential use water, as can be seen in Table 10. The east area has an average 6.76% WATR in productive use water, which is about five times larger than its WATR of residential use, 1.62%. Same as that of the central area, its average WATR is 26.74% in productive use water, which is much more than the average 9.99% WATR in its residential use water. The west area also has a high WATR for productive use versus that for residential use, which on average is 5.65% and 0.56%, respectively.

In the east area, Liaoning (04) and Guangxi (11) are the two major regions for generating WAT of productive use water. Liaoning (04) has an average 23.93% WATR to be adjusted which refers to 392.37 million tons of water. Guangxi (11) has 23.66% WATR on average of productive use water that refers to 150.91 million tons of water. Jiangsu (06) and Hebei (03) are two other regions in this area that generates the main source of WATR in this area. Jiangsu (06) has an average 8.05% WATR of productive

Table 10 WATR OF PRODUCTIVE USE BY REGION (1997-2002)

ID	Region		1997	1998	1999	2000	2001	2002	*Average*
1	Beijing	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Tianjin	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Hebei	E	18.40	19.48	0.00	0.00	0.00	0.00	6.31
4	Liaoning	E	12.08	20.55	27.57	23.03	38.45	21.92	23.93
5	Shanghai	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Jiangsu	E	0.00	9.18	8.86	3.33	9.02	17.91	8.05
7	Zhejiang	E	0.00	0.00	0.00	0.00	3.28	6.19	1.58
8	Fujian	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Shandong	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Guangdong	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Guangxi	E	12.22	13.40	16.20	16.39	42.39	41.34	23.66
12	Hainan	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Shanxi	C	0.00	2.99	2.03	3.45	0.00	4.92	2.23
14	Inner Mongolia	C	7.16	9.07	10.87	9.16	16.84	22.18	12.55
15	Jilin	C	28.12	33.42	36.17	38.68	48.27	50.47	39.19
16	Heilongjiang	C	15.36	13.91	17.06	21.36	25.53	29.53	20.46
17	Anhui	C	21.74	24.29	30.15	31.27	39.39	39.28	31.02
18	Jiangxi	C	3.46	10.17	12.04	1.65	46.74	35.69	18.29
19	Hennan	C	8.46	10.37	0.00	2.85	0.00	0.00	3.61
20	Hubei	C	36.64	40.20	37.35	27.19	21.14	0.00	27.09
21	Hunan	C	40.94	45.13	49.36	0.00	62.82	59.78	43.00
22	Sichuan	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	Guizhou	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	Yunnan	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Tibet	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Shaanxi	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	Gansu	W	27.42	27.11	28.88	27.21	26.54	28.55	27.62
28	Qinghai	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	Ningxia	W	9.52	9.76	8.65	6.65	17.72	15.61	11.32
30	Xinjiang	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total		11.71	14.39	14.47	9.36	19.50	16.47	14.32
	East		4.21	7.07	6.33	4.83	9.80	8.34	6.76
	Central		23.46	26.87	27.56	16.54	35.05	30.96	26.74
	West		5.50	4.97	5.48	5.25	6.69	6.00	5.65

Notes:

(1) The unit is a percentage of target to actual productive water use of the region or the area.
(2) E is the abbreviation for the east area, C is the abbreviation for the central area, and W is the abbreviation for the west area.
(3) Data for the administration region Chongqing are regarded as a part of Sichuan in this paper.

use water to be adjusted, which refers to 143.63 millions tons of water. Hebei (03) has an average 6.31% WATR of productive use water, which is 76.51 million tons of water. Zhejiang (07) is the other region which has non-zero WATR that is on average 1.58% WATR of productive use water. The WATR was zero during 1997 to 2000, but up to 3.28% in 2001 and 6.19% in 2002. It is regarded that the reducible amount of productive use water is increasing and water use efficiency is decreasing in this region. This increasing WATR of productive use water should be placed with more concern.

As stated previously, the west area also has high WATR at productive use water than that for residential water. Gansu (27) and Ningxia (29) are the two main sources of generating the area's WATR. The former has an average 27.62% WATR and the latter has an average 11.32% WATR in their productive use water amount. These two ratios refer to 140.22 million tons and 14.62 million tons of water to be adjusted, respectively. Gansu's WAT amount is 90.56% of the area's total, making Gansu dominant WAT in this area.

The central area is the worst in efficiency at consuming productive use water. As seen in Tables 10 and 11, none of the regions in this area are at optimal efficiency in utilizing productive use water. Hunan (21), Jilin (15), Anhui (17), Hubei (20), Heilongjiang (16), Jiangxi (18), and Inner Mongolia (14) have high WATR on average that are respectively 43.0%, 39.19%, 31.02%, 27.09%, 20.46%, 18.29%, and 12.55% of their productive use water amount. These ratios refer to 687.12, 375.34, 378.87, 495.86, 172.13, 179.17, and 43.34 million tons of water capable of being reduced without suffering from economic performance. The other two regions that have a lower WATR are Hennan (19) and Shanxi (13). Their WATRs are 3.61% and 2.23%, respectively, which is a total of 2383.99 million tons of water that can be considered to be reduced without impact to economic development in this area. Less efficient production processes and out-dated technology incorporated in production are the main causes for this high WAT amount in this area. Importing advanced technologies and efficient production processes externally can reduce this portion of productive use water.

Table 11 WAT AMOUNTS OF PRODUCTIVE USE FOR REGIONS AND AREAS IN CHINA (1997-2002)

ID	Region		**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	*Average*	*Regional Ratio*
1	Beijing	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Tianjin	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Hebei	E	229.87	229.21	0.00	0.00	0.00	0.00	76.51	9.82
4	Liaoning	E	210.91	367.93	467.39	376.90	630.99	300.10	392.37	50.38
5	Shanghai	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Jiangsu	E	0.00	182.65	153.78	57.52	140.80	327.03	143.63	18.44
7	Zhejiang	E	0.00	0.00	0.00	0.00	30.98	61.16	15.36	1.97
8	Fujian	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Shandong	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Guangdong	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Guangxi	E	88.94	91.21	109.17	108.08	271.14	236.91	150.91	19.38
12	Hainan	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Shanxi	C	0.00	15.17	9.84	16.66	0.00	19.11	10.13	0.42
14	Inner Mongolia	C	27.84	33.78	39.90	30.63	53.72	74.18	43.34	1.82
15	Jilin	C	275.28	323.88	351.28	368.02	448.71	484.88	375.34	15.74
16	Heilongjiang	C	141.94	122.75	148.91	182.30	209.30	227.57	172.13	7.22
17	Anhui	C	282.84	300.62	368.35	385.93	488.09	447.36	378.87	15.89
18	Jiangxi	C	25.01	74.80	86.10	11.40	602.82	274.90	179.17	7.52
19	Hennan	C	106.84	116.84	0.00	28.54	0.00	0.00	42.04	1.76
20	Hubei	C	749.18	828.52	696.60	417.86	283.02	0.00	495.86	20.80
21	Hunan	C	690.54	752.15	830.46	0.00	992.34	857.20	687.12	28.82
22	Sichuan	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	Guizhou	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	Yunnan	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Tibet	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Shaanxi	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	Gansu	W	171.03	139.20	148.45	140.88	135.99	105.79	140.22	90.56
28	Qinghai	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	Ningxia	W	14.28	14.11	11.48	8.24	21.46	18.16	14.62	9.44
30	Xinjiang	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total								3317.62	Area's Ratio
	East								778.78	23.47
	Central								2383.99	71.86
	West								154.84	4.67

Notes:

(1) The unit is million tons of water.
(2) E is the abbreviation for the east area, C is the abbreviation for the central area, and W is the abbreviation for the west area.
(3) Data for the administration region Chongqing are regarded as a part of Sichuan in this paper.

6.5 WATER EFFICIENCY VS. REGIONAL DEVELOPMENT

We sum the area's WAT from both residential use water and productive use water, obtaining the total adjustment amount of WAT in the three areas in Figure 6. In the figure we see that total WAT of the central area is the dominant portion of China's total during the research years. It is about three-fourths of China's total. The other portion is composed of WAT from east and west areas, which are relatively small especially for WAT of the west area.

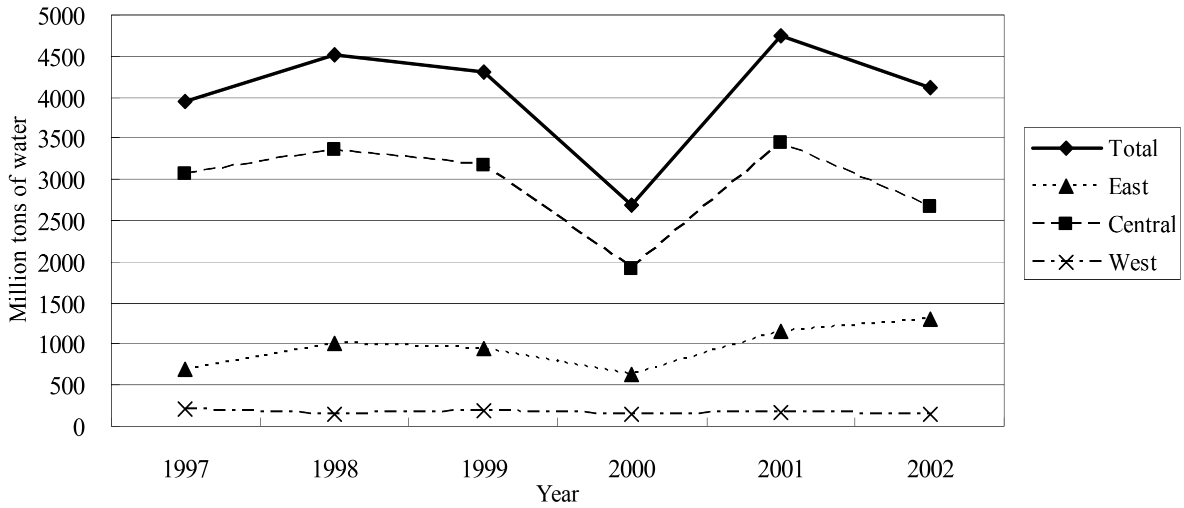

Figure 6

TOTAL ADJUSTMENT AMOUNT OF WATER USE BY AREA AND YEAR (1997-2002)

The WATR reveals an inefficient portion of water use in each region. When a region is capable of reducing and adjusting its inefficient portion of water use, then the water use efficiency shall reach the optimal level that is located at the frontier position identified by DEA. Therefore, the region's total-factor water efficiency (WE) is explained by the complementary part of WATR, which is shown as Eq. (12) below:

$$WE = 1 - WATR. \quad (12)$$

Based on Eq. (12), the WE of China's total is computed as 81.56%. By the same computation, the WE scores are 95.67%, 79.80%, and 96.76% in the east, central, and west areas, respectively. As shown in Figure 7, a U-shape relation exists between the total-factor water efficiency and per capita real income in an area.

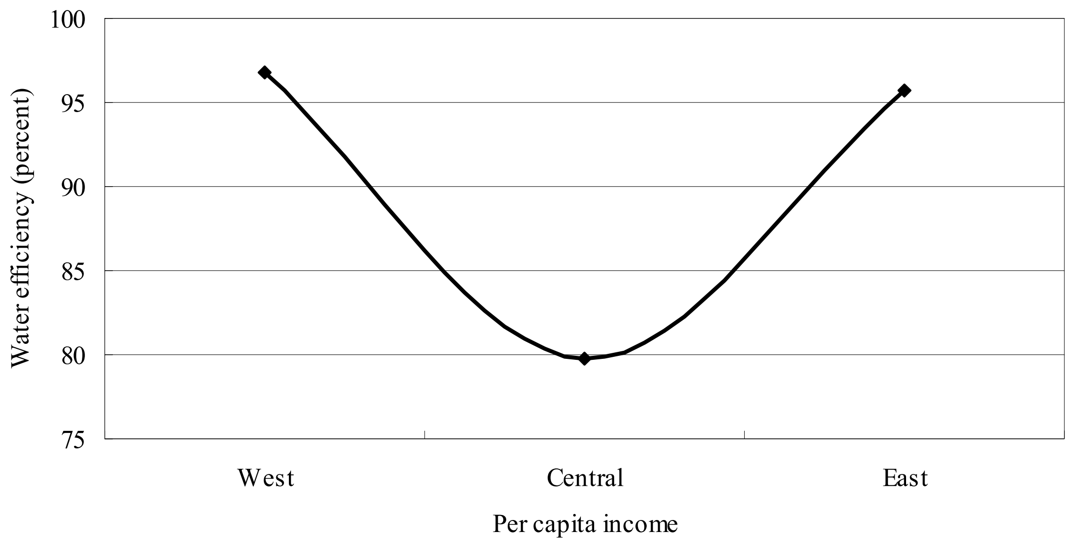

Figure 7 THE U-SHAPE RELATION BETWEEN TOTAL-FACTOR WATER EFFICIENCY AND PER CAPITA REAL INCOME FOR AREAS IN CHINA

The east area has the highest level of per capita real income and the second most efficient water use condition in China. The west area has the highest water efficiency, but this area actually just starts its development only recently. Therefore, the area has the lowest level of per capita real income. The central area has the second highest level of per capita real income, but it has the lowest water efficiency among all areas. This area has around three-fourths the ratio of China's WAT in the research period, implying that it must be further reduced and adjusted. The discovered U-shape relation conforms to the reality in China that out-dated production processes and production technology produces not only the total adjustment amount of water, but also generates worse environmental quality.

Since regions of the east area reach a high level of per capita real income, the focus has turned to water efficiency and environmental quality. Therefore, the area has adopted more efficient production processes and up-to-date technology. This area's WE as a result has actually improved significantly. The worst WE appear in the central area where inefficient production processes need to be significantly improved. These cases show that the index of WATR constructed through DEA is in an inverted U-shape relation. The WATR needs to further be reduced in order to reach sustainability of economic development.

CHAPTER 7 THE CONCEPTUAL FRAMEWORK FOR GNIS

GNIS takes ecological sustainability as the main consideration for knowledge and innovation, and adopts it through economic activities to act as the main driving force for long-term competitiveness. (Giddings et al., 2002). GNIS broadens the territory of a NIS and comprises a wider range of interactions between knowledge networks in the system. GNIS encourages the innovation of an issue-driven science instead of a curiosity or emotion-driven science, therefore avoiding irreversible changes and endangering sustainability of life. The way in which the GNIS broadens the territory of the NIS through the incorporation of green aspects is illustrated in Figure 8.

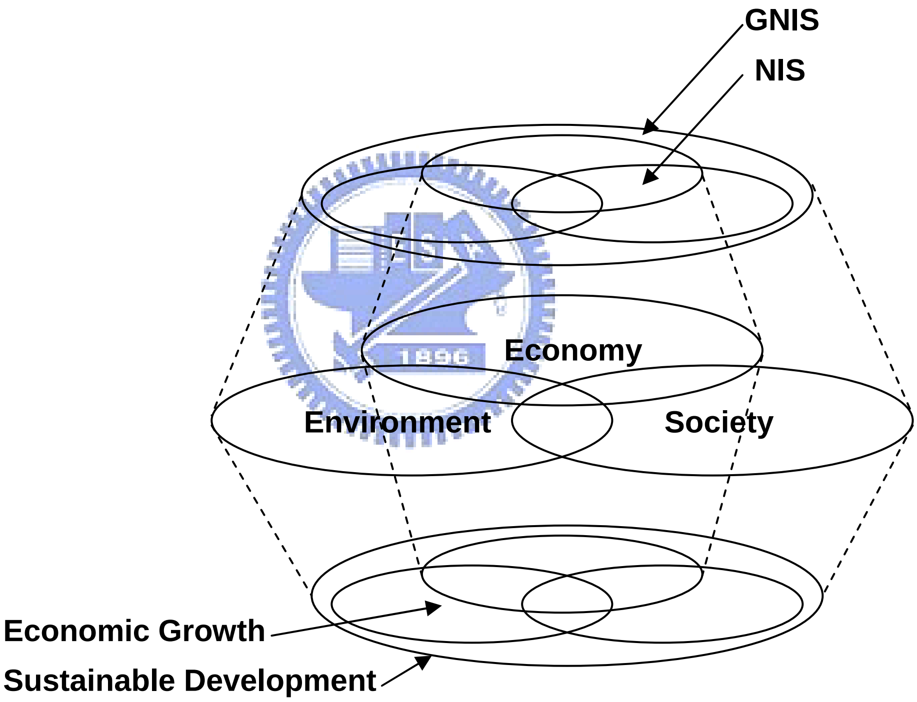

Figure 8

GNIS IS AN INNOVATION SYSTEM FOR A NATION TOWARDS SUSTAINABLE DEVELOPMENT INCLUDING ASPECTS OF ENVIRONMENTAL CONSERVATION AND SOCIETAL BALANCE IN PARALLEL TO ECONOMIC GROWTH

We shall first introduce what a GNIS is composed of and how its sectors will work and interlink. These sectors include: policy formulation, basic science research, applied industrial research, training and education, and citizens. A GNIS is composed of these sectors with 'green' aspects embedded. Interlinks occur in the system to formulate networks to generate, diffuse, and adopt knowledge and innovation with regard to 'green' concerns. These flows can be observed inside the system as knowledge flows, financial flows, regulatory flows, and human capital flows. A GNIS therefore generates 'green' knowledge and enhances diffusion of the knowledge in order to motivate more 'green' innovations.

7.1 POLICY FORMULATION

Policy formulation is the most important part of both GNIS management of the knowledge incorporated in green concepts and the encouragement of innovations that are embedded with sustainability concerns. The policy has to be formulated through an integration of technology and innovation policy on an economy-wide basis. Therefore policy in a GNIS is formed though integration of policies concerning sustainability of the environment, natural resources, and ecology.

Green innovations become indispensable in a country, because these innovations are an important base from which to develop and enhance its long-term competitiveness towards sustainable development (Porter and van der Linden, 1995). The policies in a GNIS therefore can be formulated in this direction for both 'curative' and 'preventive' innovations (Cramer and Reijenga, 1999). Thus critical ecological issues can be dealt with through the development of specialised knowledge. Potential and hidden ecological problems can be prevented at the start.

The sector of policy formulation in a GNIS takes sustainability aspects into consideration and turns the policy goal in an existing NIS towards the direction of sustainable development. It extends the vision of existing NIS and strengthens interaction between institutions of science and technology as well as environment and ecology. Many research studies stress the necessity of a radical change to the existing system for green-based innovations especially in the 'preventive' type of innovation (Ashford, 2002; Cramer and Reijenga, 1999; Hart and Milstein, 1999; Conway and Steward, 1998), and a reform to build a GNIS to encourage sustainable innovation is therefore indispensable.

7.2 BASIC SCIENCE RESEARCH

Knowledge and innovation for sustainability at the basic science level are the fundamental basis of GNIS. Knowledge and innovations embedded with green aspects can expect to be generated from basic science research in GNIS. GNIS prioritizes green-oriented research and emphasizes the integration of green concepts to all research activities to innovate at the basic science level for the agenda of sustainable development.

Munro (1995) advocates the importance and urgency for having a 'good science': Science and knowledge are required to address the realities of sustainability, but it should be an issue-driven science instead of curiosity and emotion-driven science. The principle of a 'good science' in this context means that the science itself will not cause any irreversible changes. According to Munro, "many of the problems that we face today are not resulted from incidental failures, but are of technological and scientific successes." Therefore, science should have as part of its new goal and vision a concern for ecological and environmental topics. This implies a requirement to build up multi-disciplinary and trans-disciplinary knowledge networks to support this concept and generate "good science".

To construct a paradigm for this broader definition of science for sustainability of the environment and ecology to replace past definitions, it is important to relocate the priority and agenda of basic science research in a NIS so as to generate knowledge with green aspects. At the same time, it is necessary to have a new definition of science in order to avoid irreversible changes made from curiosity and emotion-driven science. With these perspectives included, the basic science level of research can be transformed into a green-based basic science research sector in a GNIS.

The sector of science research in a NIS is the main driver where knowledge and innovations are generated in favor of economic growth. In a GNIS this sector works in much the same way, but does more of integrating green concepts into knowledge networks and prioritizes research that is directly relevant to sustainability issues. The sector of green aspects-based basic science research is the driving force behind green-based knowledge and innovations in favor of environmental sustainability.

7.3 INDUSTRIAL APPLIED RESEARCH

According to the World Business Council for Sustainable Development (WBCSD, 2003) innovation is of primary importance in fostering sustainable development, "Innovation is the only way to meet the needs of a burgeoning population and a growing economy without causing unacceptable environmental damage. As the main source and user of technology, business clearly has a stellar role to play in meeting this challenge (WBCSD, 2003)."

Industry is the main driving force for economic growth, but it is seen as a major environmental contamination generator (Brio and Junquera, 2003). Without ecological thinking and green perspectives, pollutants and other environmental hazards will still be generated at high levels. Industry has to take immediate action and responsibility to reduce and where possible remove these undesired outputs. Concepts such as recycling, renewable resources and low power consumption should be taken into account to reduce harmful outputs.

Clean production is important to reduce waste at all stages of the production process. Ways to reduce and eliminate solid, liquid, and toxic waste and pollutants have been widely discussed across many industries. On the other hand, "green" product design targets energy saving, waste recycling and reduction, and hazardous substance prevention as the main objectives.

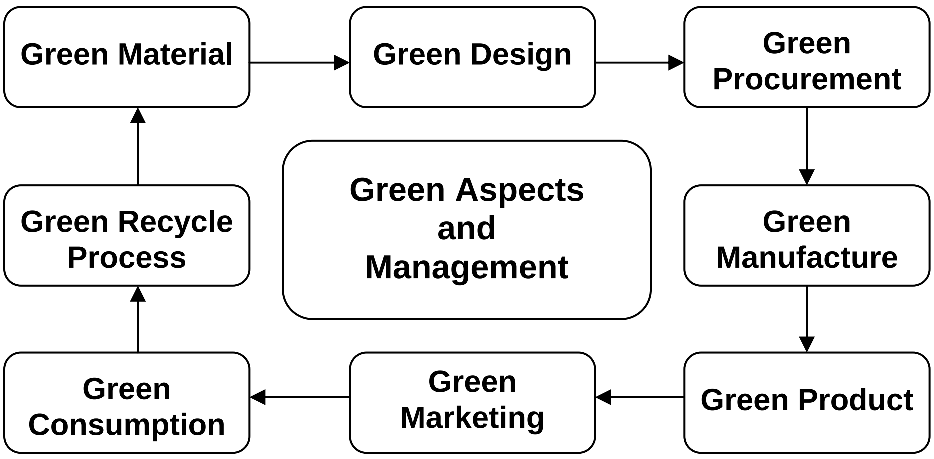

Figure 9

GREEN VALUE CHAIN (WBSCD, 1995)

Aside from clean production and "green" product design, a wider range of green-based industrial action, research, and innovation should be considered as part of a green value chain (WBCSD, 2002). The green value chain, illustrated in Figure 9, is an extension of the industrial value chain with the above perspectives, so as to integrate with green concepts.

7.4 EDUCATION AND TRAINING

In Agenda 21 (Section 36) that looks into how to assist a country towards sustainable development, the education system is seen as one of the important foundations. Education is regarded as an essential factor for a country to turn people's attitudes fundamentally in favour of sustainable development. "Education, both formal and non-formal educations are indispensable to change people's attitudes so that they have the capacity to access and address their sustainable development concerns (UNEP, 1992)."

There are three main goals in having a sector of education and training in a GNIS. The first is to educate personnel who shall be equipped with the professional knowledge and capability for research and innovation. The second is to embody green concepts with the population in order to affect behavior and perspectives, so as to gradually embed a green-based consciousness into an entire society which can become the foundation for a country to move towards sustainable development (Vanek, 2002). The third is to train people who have responsibilities in the areas of pollution reduction or natural resource conservation and who need to be equipped with the right perspectives as well as up-to-date knowledge and discipline to effectively perform their administrative and executive duties (U.S. EPA, 2003).

7.5 CITIZEN

The ultimate goal of GNIS is to build a citizen-centered society where most citizens are well educated and fully awareness of ecological and environmental sustainability. Such a society can utilize renewable resources through a sound recycled material system and citizens can enjoy a good quality of life in the future. In order to reach this goal, a good balance is required in all aspects of the economy, society, and environment. GNIS is constituted of sound knowledge networks embedded with green concepts in order to influence citizens' behavior and perspectives. The process of influencing people is conducted through the training and education sectors, policy and regulation, and various means of mass communication.

The green consumer is defined as a well-disciplined citizen in the environmental context and has a basis of green consumerism that encompasses buying environmentally and ecologically beneficial products. Green consumerism feeds back to firms, the policy sector and the training and education system through environmental non-governmental organizations (NGOs). This forms interactions among distinct actors in a GNIS in order to generate useful innovation.

7.6 KNOWLEDGE FLOW

The establishment of networks and clusters is emphasized in order to diffuse green knowledge across sectors. Knowledge flow means the inter-linking and networking of multi-disciplinary knowledge that is embedded with knowledge of green concepts. Knowledge flow is part of NIS, but the main difference is that green aspects are integrated into knowledge flow when it is built in GNIS. The green-based innovation is composed of environmental and ecologically-centered innovations that balance the agendas of economic growth, environmental conservation, and societal development in a nation as illustrated in Figure 10.

As discussed previously, 'good science' should consider reversible changes that are essential to sustainability. Scientific research, technological development, and innovations should be generated with green concepts in GNIS.

7.7 FINANCIAL FLOW

Increased R&D expenditure and a change in its aims are required for environmental innovation especially at the radical level of innovation (Green et al., 1994). Radical environmental innovation is required in order to discover solutions to environmental issues today and the near future. Environmental financing is necessary to support all these activities. This necessary finance can be established via environmental policies and regulation. Budget support comes from governments at the national, regional, and local level. Effective administration and use of economic tools is also required.

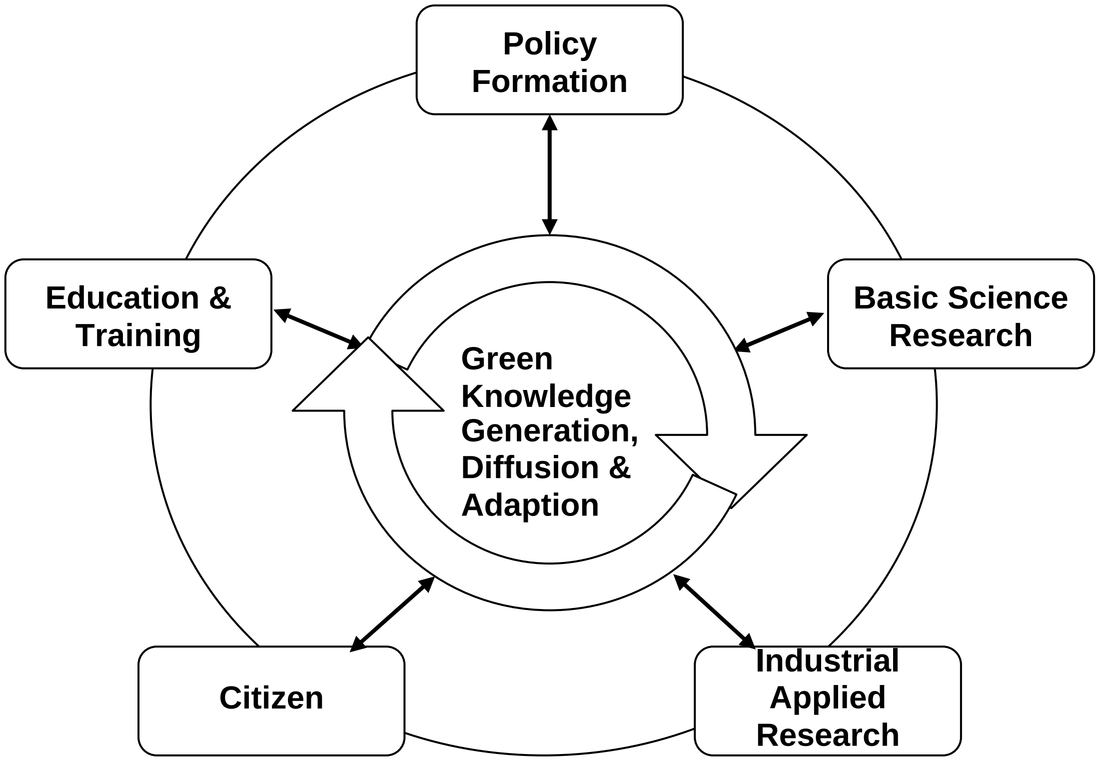

Figure 10

THE FRAMEWORK OF GREEN-BASED NATIONAL INNOVATION SYSTEM

Funding and expenditures supported by governments should be well planned and managed in the policy formulation sector so as to priorities research programs for sustainability and to maximize the performance and efficiency to form a positive loop for financing.

7.8 REGULATORY FLOW

The intellectual property rights and patents resulting from environmental research and innovation should be well regulated and protected (OECD, 1999). On the other hand, a market should be formed to trade and exchange these property rights and patents in order to diffuse this knowledge and make the best use of them for real applications, but with rewards for the intellectual copyright holder. A market's performance can also be leveraged to encourage more innovations in the environment field.

Patents and intellectual property are normally regarded as strengths of innovation in a nation. Research (Green et al., 1994) proves the outcomes of these are positively related to intensity of invested expenditure and budget. There are many countries running award systems to encourage environmental research and innovation. The gradual embedding of environmental aspects into all development activities in a nation so as to form a sound GNIS, a well-established regulatory flow, a trade market, as well as an award system should occur in order to stimulate and motivate more innovations embedded with green aspects.

7.9 MOBILITY OF HUMAN CAPITAL

As emphasized in most innovation systems (OECD, 1999), human capital is also one of the important elements in GNIS. Human capital relies on a sound education system and deployment of appropriate policies. Human capital mobility is the most important bridge for knowledge and skill's transfer and exchange (OECD, 1999). The successful story of Silicon Valley in the U.S. is evidence that human capital mobility and knowledge spillover contribute strongly to successful innovations. In GNIS, human capital is cultivated with green aspects and encouraged to move under a well managed system so that green knowledge and perspectives can be transferred and diffused widely and efficiently.

Table 12 SECTORS AND FLOWS IN A GREEN NATIONAL INNOVATION SYSTEM

	GNIS
Policy Formulation	A council that is composed of representatives from distinct agencies and departments in all aspects to establish a sound policy system to lead innovations for sustainable development
Science Research	Public and private science research institutions should embed with green perspectives in order to form research and innovations for sustainable development
Industrial Applied Research	The R&D departments in firms shall integrate green concepts into product design and manufacturing processes to formulate green design and clean production, thus reduce and remove harmful effects to the ecology for sustainable development
Education and Training	Education institutions will provide inter- and trans-disciplines that embody green perspectives to all levels of citizens and enhance relevant professionals and sponsors with state of the art knowledge
Citizen	Citizens must embody with a green consciousness and awareness on behalf of sustainability through out daily life
Knowledge Flow	Networks and clusters need to form for diffusion, adoption, and generation of green-based knowledge though all sectors in GNIS in order to formulate different levels of green-based knowledge and innovations
Financial Flow	Financial flow should establish to support green-based innovations, education, and researches among different sectors in a nation
Human Mobility	Human mobility is encouraged and analyzed among all sectors to stimulate multi-disciplinary green innovations
Regulatory Flow	Proper regulatory flow needs to build in a nation to encourage knowledge sharing and exchange, innovations are treated precious in such an environment then to be stimulated more often

CHAPTER 8 CASE STUDIES OF THE UNITED STATES AND CHINA

Case studies are conducted through the methodology of secondary data analysis; the cases of the U.S. and China are investigated in this section to prove that GNIS or at least a part of it has been running in these countries. The studies show distinct scenarios how GNIS works in these two countries. Some activities specified in GNIS we propose have been introduced but there has not been a complete implementation of the system. These practical studies show the importance of establishing a GNIS in order to achieve the goal of sustainable development.

8.1 THE CASE OF THE UNITED STATES

In the United States, science and technology have been regarded as the indispensable foundation for reaching environmental goals to prevent pollution, protect human health, and reduce environmental risks. Environmental innovations are encouraged to find the best solutions to deal with complicated environmental challenges through efforts from the public, private, academic, and non-profit sectors.

8.1.1 DIVERSE POLICY FORMULATION AT THE NATIONAL LEVEL

There are several governmental departments and agencies in the U.S. that oversee policies of research and innovation in the direction of sustainable development. The overall policy formulation mechanism observed is diversified but inter-cooperated. The impact of different types of science and technology in terms of both magnitude and probability is assessed and evaluated. The assessment procedure works by taking specific actions, solutions, and preventative measures to mitigate risks and make other appropriate polices (UNCED, U.S. Country Profile 2002).

Within the Federal government, several offices play key roles in formulating and promoting science policies including the National Science and Technology Council (NSTC, 2004), the Office of Science and Technology Policy (OSTP), the Office of Technology Policy (OTP), and the Council on Environmental Quality (CEQ). Working together with major Congressional committees, these offices set priorities for funding, program oversights, and policy leadership regarding the scientific priorities for and movement towards sustainable development (UNCED, U.S. Country Profile 2002).

Through technological and scientific insights, government agencies make important strides in studying the theory behind natural systems and therefore help more effectively manage resources and improve environmental quality, both of which contribute significantly to sustainable development. For instance, the National Oceanic and Atmospheric Administration (NOAA), through development of its world-renowned scientific capabilities, forecasts U.S. weather and climate, monitors and archives ocean and atmospheric data, manages marine resources and exploration, and conducts cutting-edge oceanic atmospheric and solar research.

Another example is the U.S. Department of Agriculture (USDA). Its recent program, Research, Education, and Economics (REE), is assigned with Federal leadership responsibility for creation and dissemination of knowledge. The program incorporates knowledge from biology, physics, and the social sciences into agricultural research to form a comprehensive analysis and generate more sophisticated knowledge. The REE program enhances the U.S. position as a global leader in highly competitive food and fiber industries, promotes sustainable agricultural practices in harmony with the natural environment, and makes contributions to agricultural prosperity and thriving rural communities. (UNCED, U.S. Country Profile 2002).

8.1.2 Highly Financed Scientific Research

The National Science Foundation (NSF) is the main public institutions for environmental research and its corresponding funding in this area had risen to $643 million per year in 2002 (U.S. Country Profile 2002). There are also several other public research institutions conducting research in the same field. The research programs in these institutions could not have been executed as they are today without sufficient funding. These institutions include the Environmental Protection Agency (EPA), the U.S. Geological Survey, the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), the U.S. Department of Agriculture (USDA), the Department of Energy (DOE), and other federal agencies. As figure from the NCSE show (NCSE, 2003), the total funding for environmental R&D in these public research institutions increased by 4.82% to a total of USD$7,877 million in 2003.

The total R&D budget increased about 13.8% from FY2002 to FY2003 up to a total of $117.3 billion. Environmental R&D occupies accounts for 6.72% of this budget. The budget as distributed among all these research institutions can be seen in Figure 11.

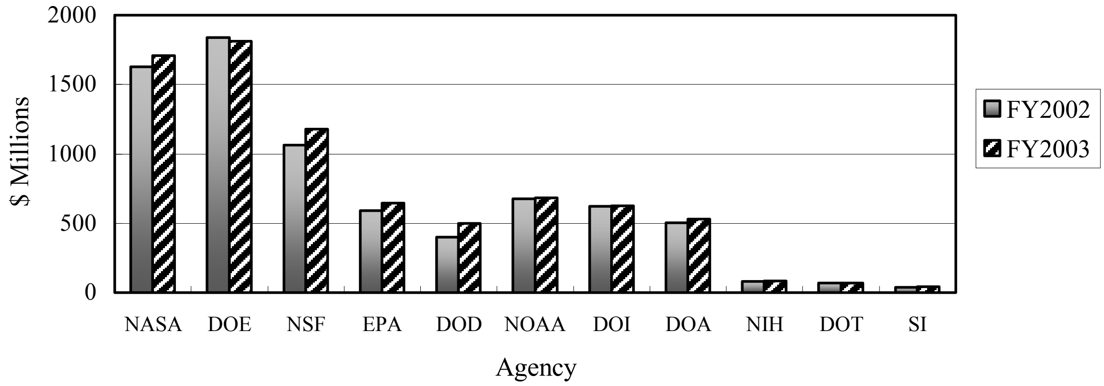

Figure 11

ENVIRONMENTAL AND NATURAL RESOURCE RELATED R&D FUNDS IN THE UNITED STATES (NCSE, 2003)

8.1.3 Abundant Industrial Applied Research

Several programs are executed and conducted through industries, universities, and federal research institutions to achieve the target of green product design and clean manufacturing (U.S. GCRIO, 2003). For instance, life cycles assessment (LCA) has been widely used to evaluate environmental impacts between cathode ray tubes (CRTs) and the new active matrix liquid crystal display (LCDs) for computer display screens. The same technique was also applied to soldering, finding the necessity to remove lead. The program 'Design for Environment' (DfE) is one example that has been well executed by EPA in cooperation with industrial firms. The program is run through industrial leaders and trade association representatives that conduct assessments and build partnerships to design and adopt safer, more efficient products (U.S. EPA, 2003).

8.1.4 SOUND EDUCATION AND TRAINING

The U.S. has established a dedicated institution, the National Environmental Education Advisory Council (NEEAC), to perform environmental education across the country. The work of the NEEAC is composed of both formal and informal environmental education. Formal education institutions concentrate on developing awareness, knowledge, skills, and motivation among students, teachers, and school administrators (Holtz 1996; NAAEE 1998). Informal environmental education mechanisms include adoption of the media, targeting specific audiences, developing supplementary materials, and training educators (NAAEE, 2004). The government, non-government organizations, universities, colleges, schools, technical training centers, the business sectors, and the media are regarded as important parties to deliver environmental education.

8.2 THE CASE OF CHINA

China is in transition from a high resource-consuming, low-efficiency, and heavily-polluting economy (UNCED, China Country profile 2002; Chai, 2002). Therefore, science and technology that can stimulate transformation of the economy are given priority since there is still a heavy shortage of such science and technology in China. Revitalizing China through science and education has served as a major strategy in government policy.

8.2.1 CENTRALIZED POLICY FORMULATION

The Ministry of Science and Technology (MOST) is the main institution in China's government responsible for formulating policies and strategies for scientific and technological development at the national level. The restructuring of this organisation in 1998 apparently symbolised that China's government decided to construct a sound national innovation system with a high level of international cooperation. The policies and strategies for S&T development have included sustainable development as one of main goals, and these have been clearly announced in the national 10th five-year plan up to 2010.

The State Environmental Protection Administration (SEPA) is the main department in China's government with the task of formulating policies, laws, and administrative regulations for national environmental protection plans and the supervision of activities in exploiting and utilising natural resources. SEPA guides S&T developments towards providing solutions to worsening environmental and natural resources-related issues. Like MOST, this department is regarded as one of the institutions of policy formulation sector in GNIS. The sub-level department of Science, Technology and Standards (DSTS) in SEPA is responsible for organising and coordinating scientific and technological research in the nation for protecting the environment and using natural resources efficiently. DSTS is also in charge of promoting the development of relevant technologies into real applications, administrating national environmental standards, and monitoring the progress of technological development in the nation (SEPA, 2004).

The report, 'Technological Innovation System Enhancement to Strengthening Revolution of Environmental S&T Structure (SEPA, 2004)', published in 2000, recommends the close cooperation between MOST and SEPA so as to jointly align their respective policies of S&T development. The S&T activities should contribute to the national development goal of reaching sustainable development. The report states that green concepts should integrate into a NIS framework, and that S&T is a key to fundamentally solve serious issues related to the environment and natural resources.

8.2.2 NEWLY ESTABLISHED BASIC SCIENCE RESEARCH

The topic of natural resources and the environment has been recognised as one of the five major research topics in China. The Chinese Academy of Science (CAS), as a subordinate department of the State Council, is one of the key public institutions in this area of research. It is responsible for implementing plans on basic science research at the national level. The CAS has set up over 30 research sub-institutions and 80 field observation posts with experimental labs to carry out research on topics of natural resources and the environment. Such a research system emerges from multi-disciplinary team working and international cooperation, it converges knowledge from fields of natural resources, ecology, and the environment to generate a comprehensive format of knowledge which is beneficial to ecological sustainability.

The Chinese Research Academy of Environmental Sciences (CRAES), a subordinate institution to SEPA, is another research institution at the national level that conducts basic scientific research. This research concentrates on topics of the environment and natural resources, and also places emphasis on multi-disciplinary teamwork and international cooperation. The CRAES was established in 1980 and is composed of around 400 scholars, using 1400 sets of measuring instrument. The outcomes from CRAES research studies have been recognised as valuable technological resources in supporting the goal of sustainable development in the nation.

The institution also closely cooperates with institutions at the international level, such as UNEP, ERM, and WHO in conducting state-of-the-art research.

These two institutions are examples in China as foundation of the sector of basic science research in GNIS. In addition to these two national-level research institutions, there are further 29 institutions at the state level and 235 institutions at local level which perform scientific research mainly relevant to the environment and natural resources. Table 13 illustrates how these research institutions were constituted in distinct levels from 1997 to 2003. The basic science research institutions at the national level have been in operation since 1999 (China Environment Yearbook, 1999). Research institutions are established by MOST, CSA, CRAES, and SEPA respectively from time to time and some of their research topics could be overlapping with other institutions. It will require more complete integration in the future to carry out research more efficiently.

Table 13 DEPLOYMENT OF ENVIRONMENTAL BASIC SCIENCE RESEARCH INSTITUTIONS IN CHINA (SOURCE: CHINA ENVIRONMENT STATISTIC YEARBOOK, 1997-2003)

	1997	1998	1999	2000	2001	2002	2003
National Level	0	0	4	4	5	5	3
State level	29	31	28	29	30	29	30
Local Level	176	185	194	207	211	235	230
Total Research Projects	1550	719	1688	1792	2915	3786	3862

8.2.3 POLICY TO FORCE INDUSTRIAL APPLIED RESEARCH

Issues of environmental pollution and resource consumption have threatened China's fast economic growth and development. About 70-80% of rivers and 90% of the water supply in major cities are seriously polluted. According to data in year 2000, 16 out of 20 of the most polluted cities in the world are located in China; acid rain covers 1/3 of the land in China; and 5 billion tons of soil are eroded every year. Many natural resources are close to becoming exhausted, for example fourteen kinds of important minerals are forecast to be used up within the next 20 years (Niu and Harris, 1996; Cannon, 2000).

The 'Clean Production Promotion Law' was published formally by the State Economic and Trade Commission (SETC) in June 2002 and took effect starting from 2003. The target of this law is to promote clean production and to increase the efficiency of resource consumption. After this law was issued, 329 technical development projects for clean production have been approved with a total investment of RMB$79.4 billion. Furthermore, five industries in ten cities have been selected as models for clean production and around 11,000 factories were forced to close since their operations violated the law.

Clean production has just begun its first steps in China, however green product design is still far away from starting. Financial support and awards to relevant industrial activities regularly offered as motivation from the government for industrial applied research and innovations. The interaction between industries has therefore evolved and forms a positive loop for knowledge diffusion and adoption. Human capital mobility plays an important role in knowledge exchange between these institutions and sectors.

8.2.4 EDUCATION AND CITIZEN PERSPECTIVE: BEING FORMULATED

China's government has attached great importance to education on sustainable development. The Centre for Environmental Education and Communication (CEEC) under SEPA is a foundation aiming to promote environmental education activities and spread environmental consciousness. One of its promotional programs, called 'green schools' has been successfully executed and there are now around 6,000 'green schools' across China. The 'green schools' received extra funding from China's government to teach environmental issues as a part of their curriculum, and there have been around one million children that have participated in this program with their ages ranging from five to fifteen (CEEC, 2003).

Several universities have set up new faculties, departments, and colleges of environmental protection, and progress is being made to establish more environmental academic organizations (such as research centers, societies, and research institutes). Moreover, environmental sections have been added into textbooks in primary and middle schools, with the aim of enhancing the young generation's environmental awareness. The Chinese media has also greatly supported training and education for sustainable development. The People's Daily, CCTV, and the Central People's Radio have given broad coverage to the concept of ecological sustainability and Agenda 21 (UNCED, China Country profile 2002).

CHAPTER 9 CONCLUSION

This study appears to be the first to incorporate inevitable natural resources, including energy and water, into considerations to analyze regional production efficiency. We believe that regional development performances shall be biased when neglecting a number of important respects such as mentioned natural resources.

We conclude our empirical findings from this research by taking China as an example for measurement of regional production efficiency. Finally we conclude GNIS as a conceptual framework that it will improve these issues with perspective of sustainable development considered in a NIS.

9.1 EMPIRICAL ANALYSIS FINDINGS

9.1.1 REGIONAL EFFICIENCY WITH ENERGY CONSIDERED

The index of total-factor energy efficiency (TFEE) is first constructed in this study by taking the ratio of actual energy input to target energy input and this is conducted through DEA. The formula is constructed in Eq. (8). The multiple-inputs model is adopted for an assessment of energy efficiency since energy is not the only input to produce output and it has to be accompanied by other inputs to produce real economic outputs. On the other hand, a certain portion of GDP output is generated not only by energy input, but also by inputs of labor and capital stock. A substitution effect, whereby GDP output is generated from other inputs rather than energy input, is therefore well considered under such a multiple-inputs model. Index TFEE therefore evaluates energy efficiency in an appropriate approach.

A unity TFEE score identifies a DMU which operates optimally at the efficiency of energy consumption. The DMU with a unity TFEE score consumes the minimum level of energy input and generates the maximum economic output including other inputs considered. An efficiency frontier of energy consumption is constituted by these DMUs. For those DMUs which have a TFEE score of less than unity and are not yet at the frontier efficiency of energy consumption, they are capable of taking one of those DMUs located at the frontier as a target to adjust their technology levels and production processes accordingly for efficiency improvement. The slack and radial adjustments provide adequate input targets for a DMU with a TFEE less than unity to achieve the optimal energy efficiency.

This paper reports the result of an empirical study of regional energy efficiency in China based on the index TFEE. The commonly used index of the energy productivity ratio (Patterson, 1996) as PFEE is calculated as well for comparison. The index PFEE observes only the partial effect between energy input and GDP output, but not the total factor effects observed in TFEE based on the multiple-inputs model. As a result of comparison, index TFEE shows the advantage of assessing energy efficiency as being more practical than PFEE. A U-shape relation is found between the TFEE and per capita income in an area, which explains that an improvement in energy efficiency is followed by economic growth though it declines in the beginning period. As Figure 5 shows, TFEE in most regions of China especially for those located in the east and central areas is improving during the research period. The more economic growth there is, the more is energy efficiency a concern and can improve. These results cannot be observed from a conventional PFEE index.

The developed area (east area) in China has the highest TFEE rank and the least developed area (west area) has the second best rank. However, the developing area (the central area) has the worst TFEE rank even though this area creates the second highest level of GDP output in China. Shanghai (5), Fujian (8), Guangdong (10), and Sichuan (22) are the four regions which constitute the efficiency frontier of energy consumption in our analysis. These regions are going to be targets and learning models for other regions which are not yet at the optimal level of energy efficiency so that they can improve their technology level and production process accordingly.

It is noted that the index TFEE assesses the energy efficiency of each region in China based on China's own frontier, and not on the other economies' or countries'. This means that the feasible improvement steps do exist for those energy-inefficient regions to move onto the frontier. Similarities do exist on a variety of inputs, technology, and production processes among these regions, and the target is reachable and total adjustments are possibly reduced from the actual inputs in these regions by improving technology and production processes.

Because sustainable economic development relies upon efficient energy consumption, energy efficiency on a regional basis is the main focus in this study.

Further improvement actions can be taken respectively at the regional level and a more detailed analysis can be conducted by taking a reference for each region's root causes at a deeper level. Industrial structure, energy policies, energy consumption type, and treatments from local governments can be further incorporated together. A world energy efficiency frontier can be also established with the same method to overview China's efficiency rank of energy consumption globally, but it would require more data to be collected. As long as a good balance between economic growth and efficiency of energy consumption is reached, sustainable development with sufficient energy supply can be achieved.

9.1.2 REGIONAL EFFICIENCY WITH WATER CONSIDERED

The WATR is first constructed in this study as an index to evaluate regional water efficiency in a framework of total factor production. The production frontier is constructed by DEA by including water as an input in accompaniment with conventional inputs used in an economic analysis, such as labor employment and capital stock. Target water input is computed by DEA for each region, and the index WATR is therefore produced by dividing the target water input by the actual water input. Eq. (11) explains how this index is constructed in detail. Water input data are collected from two parts of water use: residential use water and productive use water. The data enable our study to understand WATR for these two kinds of water use. A U-shape relation between the total-factor water efficiency and per capita real income among areas of China is discovered, conforming to the environmental Kuznets curve (EKC) shown in Figure 7.

The index WATR shows regional water efficiency based on China's own frontier, but not from other economies' frontiers. The multiple-input production model is adopted in this study since water alone cannot produce any outputs and it has to be accompanied by other inputs to construct real outputs, even though water is an essential factor for economic production. On the other hand, a certain portion of GDP output is generated not only by labor and capital stock, but also by water input. With a multiple-input model considered in a production function, the efficiency can therefore be evaluated through a more appropriate approach.

From the analysis result obtained by using the index WATR, the central area has the worst rank for water efficiency in China and contains the most water adjustment amount which is around three-fourths of China's total. The adjustment amount of productive use water of this region is a major portion of this amount as can be seen in Figure 6. The reason behinds this result is due to less efficient production processes and technical lags do exist in the central area. The efficiency of productive use water needs to improve with major attention drawn to this area. The total adjustment amount of water use in the east area and the west area are relatively low compared to that of the central area, but these two areas have high WATR in productive use water. The east area consumes the most water amount in China, though water consumption in this area is at the high efficiency level. This result shows that water efficiency can improve with appropriate policies and plans, so that high efficient water use can be performed on the consumption of both residential and productive use water.

A U-shape relation similar to the EKC is discovered between the ratio of total water efficiency and per capita real income in an area. This finding discloses that the WATR is an effective ratio to evaluate water efficiency among regions with the viewpoint towards total factor production. The developed area (east) in China has a higher per capita real income, and its water efficiency has already been a major concern for improvement. However, this case does not happen at the mild developed area (central) in China, as this area consumes the second largest amount of water, but has a low efficiency. The regional performance of water use can be illustrated by the index WATR. The regions that need a major adjustment amount in the area can be identified from this index as a reference for further study at a deeper level.

Sustainability of economic development is a target that stretches from the national level to the regional level in China. A sufficient water supply is essential in order to reach this goal since it is finite and an inevitable resource for production, development, and people's lives. This study reviews water efficiency in China by using a newly-introduced index WATR. The same analysis should be applied to major economies in the world so that a global water input frontier can be constructed. The index WATR is based on the global frontier to evaluate water efficiency among major economies. The further study may induce the next step at water saving on the economy level. Such an optimal condition of water use can be formed internationally. The goal of sustainable development would thus become feasible in term of water use.

9.2 GREENING THE NIS

The GNIS is first introduced in this study and two case studies are conducted with both USA and China. The GNIS bases on well-known NIS that formed as driving force for economic growth in a knowledge-based economy, but it emphasizes to integrate and embody the system with green perspectives through broadening sectors in NIS in order to generate ecology and sustainability-oriented knowledge, which interpreted as green knowledge from GNIS, that will improve and remove those critical issues that human kinds will be confronting. The goal for establishment of GNIS is to achieve sustainability in nation that balances economic growth and ecological conservation by leveraging green sciences and technologies. As found from two case studies in this paper, we would conclude what shall be enhanced in the near future to constitute the GNIS properly for sustainability.

9.2.1 INTEGRATION IN POLICY FORMULATION

As what found from the two case studies, the policy formulation sector in GNIS needs higher integration and inter-cooperation in either of cases. In NIS, the sector of policy formulation essentially affects all actives in the system for S&T development, so does that in GNIS. Resulting from diverse and comprehensive goal to be achieved in sustainable development, the departments within sector of policy formulation have to jointly set clear targets and activities for nation to move ahead. In GNIS, the path to integrate concepts and real activities of environmental protection, nature resource consumption and sustainability into scientific and technological innovations has to be investigated and built. We should re-prioritize and review projects and activities in term of these green concepts so that knowledge will be eventually generated from GNIS in direction of positively beneficial to the human development and avoid irreversible changes. The sector of policy formulation in GNIS is important to construct so that all innovation activities in NIS can be addressed into sustainability direction, which called 'good' science and knowledge to innovate for human beings.

The structure of the policy formulation sector in GNIS can vary with different cases and most are observed to be joint style to integrate those existing policy sectors in environment, S&T, natural resources, and energy to form a committee for policy making. The committee shall review and prioritize innovations jointly to broaden concepts of NIS and link the system for sustainability.

9.2.2 Trans-Disciplinary Knowledge Network

The inter-linkages and networks over distinct institutions that base on NIS but in a wider sector range are expected to appear in GNIS to generate multi-disciplinary knowledge. Through integration with green concepts and multiple goals to achieve for sustainable development for economic growth, environment conservation and society retaining, trans-disciplinary innovations in GNIS are formulated. These knowledge and innovations base on ecology and multi-disciplinary researches provide solutions to those environmental issues and consumption of natural resources that are crucial for sustainable development.

9.2.3 Data Collection and Analysis

It is important to investigate and analyze dynamics in network and cluster situation over institutions and performance and efficiency for a GNIS to develop. The relevant data are urged to collect and analyze in order to establish GNIS successfully and assess its status in a regular base. Data collection and analysis should be extended to factors that important in GNIS in order to provide clear information for refine and construct the system efficiently.

9.2.4 More Innovations Activated

As multi- and trans-disciplinary innovations and researches are promoted in GNIS to generate sophisticate and comprehensive level of knowledge to deal with topics on sustainability, the scope and range of innovations are wider than those existing innovation systems that mainly concentrating on economic growth. More innovations are expected to appear in favor of beneficial to ecology and type of reversible change science are foreseen to generate more. The ‘good science’ and green innovations are expected to be generated more in order to reach at sustainability in ecological reserve and economic growth, which are the eventual goals for GNIS constructed to achieve.

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