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รายงานการวิจัย

INPUT-OUTPUT ASSESSMENT OF ENERGY CONSUMPTION AND CARBON DIOXIDE EMISSION IN THAILAND

คณะผู้วิจัย

หัวหน้าโครงการ

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Ram Sharma Tiwaree

บทคัดย่อ

การดำเนินกิจกรรมทางเศรษฐกิจมีบทบาทสำคัญในการใช้ทรัพยากรธรรมชาติ พลังงานนับเป็นปัจจัยการผลิตที่สำคัญในทุกกิจกรรมทางเศรษฐกิจทั้งทางด้านการผลิตและด้านการบริโภค ในปัจจุบันพลังงานที่ใช้ส่วนใหญ่ยังคงเป็นเชื้อเพลิงฟอสซิล ซึ่งการใช้พลังงานประเภทนี้จะก่อให้เกิดผลกระทบด้านการทำลายสิ่งแวดล้อม เนื่องจากการปล่อยก๊าซคาร์บอนไดออกไซด์อันเป็นองค์ประกอบหลักของก๊าซเรือนกระจกออกมาด้วย

ระบบเศรษฐกิจของประเทศไทยมีการเจริญเติบโตอย่างรวดเร็ว ตั้งแต่ปีพุทธศักราช 2538 และโครงสร้างพื้นฐานทางเศรษฐกิจได้เปลี่ยนแปลงจากภาคเกษตรกรรมเป็นภาคอุตสาหกรรม การใช้พลังงานปฐมภูมิที่เพิ่มขึ้นโดยมีสัดส่วนของการใช้เชื้อเพลิงฟอสซิลและอัตราการเกิดก๊าซคาร์บอนไดออกไซด์สูงขึ้น มีผลกระทบอย่างมากต่อสิ่งแวดล้อมเนื่องจากการก่อให้เกิดสภาวะที่อุณหภูมิของโลกสูงขึ้น การวิเคราะห์การใช้พลังงาน(ทั้งทางตรงและทางอ้อม) และการเกิดก๊าซคาร์บอนไดออกไซด์จากการใช้พลังงานเพื่อการผลิตสินค้าและบริการของสาขาการผลิตต่างๆ ในระบบเศรษฐกิจของประเทศไทย จะช่วยให้มีข้อมูลที่เป็นประโยชน์สำหรับผู้ที่มีหน้าที่รับผิดชอบในการวางนโยบายด้านพลังงานและสิ่งแวดล้อมของประเทศ

งานวิจัยนี้ใช้แบบจำลองปัจจัยการผลิตและผลผลิตในการวิเคราะห์การใช้พลังงานและการเกิดก๊าซคาร์บอนไดออกไซด์ในสาขาการผลิตต่างๆในระบบเศรษฐกิจของประเทศไทยในปีพุทธศักราช 2528 และ 2538 โดยใช้ข้อมูลปัจจัยการผลิตและผลผลิต และข้อมูลการใช้พลังงานของประเทศเป็นหลัก ผลการวิจัยพบว่าอัตราการใช้พลังงานต่อผลผลิตของระบบเศรษฐกิจโดยรวมลดลงในปีพุทธศักราช 2538 เมื่อเทียบกับปีพุทธศักราช 2528 แสดงให้เห็นแนวโน้มที่ลดลงในอนาคต เช่นเดียวกันกับอัตราการเกิดก๊าซคาร์บอนไดออกไซด์ต่อผลผลิต ถึงแม้ว่าสัดส่วนของการใช้พลังงานทางตรงจะเพิ่มขึ้นในปีพุทธศักราช 2538 แต่สัดส่วนการใช้พลังงานทางอ้อมก็ยังคงอยู่ในเกณฑ์สูง ซึ่งชี้ให้เห็นความสัมพันธ์ที่สูงมากระหว่างระบบเศรษฐกิจและสิ่งแวดล้อม ผลการศึกษาพบว่าสาขาการผลิตส่วนใหญ่สามารถที่จะลดอัตราการใช้พลังงานและอัตราการเกิดก๊าซคาร์บอนไดออกไซด์ต่อผลผลิตลงได้ในช่วงเวลา 10 ปี ถึงแม้อัตราดังกล่าวจะสูงขึ้นในบางสาขาการผลิต ผลการวิจัยพบว่าในทั้งสองปีสาขาการผลิตที่มีอัตราการใช้พลังงานและอัตราการเกิดก๊าซคาร์บอนไดออกไซด์ต่อผลผลิตสูงนั้นนอกจากสาขาการผลิตด้านพลังงานอันได้แก่ การผลิตน้ำมันและผลิตภัณฑ์ปิโตรเลียม การผลิตและจำหน่ายไฟฟ้า การผลิตและส่งก๊าซแล้ว สาขาการผลิตอื่นที่มิใช่ด้านพลังงานก็มีอัตราการใช้พลังงานและการเกิดก๊าซคาร์บอนไดออกไซด์ต่อผลผลิตสูงเช่นเดียวกัน โดยเฉพาะอย่างยิ่ง สาขาการผลิตซีเมนต์ การผลิตอาหาร การก่อสร้าง และการขนส่งทางบก

ผลจากการศึกษาชี้ให้เห็นว่าประเทศไทยควรมุ่งเน้นในการใช้มาตรการประหยัดพลังงาน การใช้กรรมวิธีการผลิตที่ใช้พลังงานอย่างมีประสิทธิภาพ และการใช้พลังงานที่สะอาด โดยเน้นในสาขาการผลิตที่มีอัตราการใช้พลังงานหรือการเกิดก๊าซคาร์บอนไดออกไซด์ต่อผลผลิตสูงเป็นลำดับต้น

ABSTRACT

Economic activities play a significant role in natural resources exploitation. Energy is an essential input for all economic activities either production or consumption activities. At present, the energy requirements are largely met by fossil fuels, and the use of these fuels causes the deterioration of the global environment, mainly, due to large emission of carbon dioxide (CO_2), a major component of greenhouse gas.

Thailand has achieved high economic growth since 1985 where the orientation of the economy has shifted from agricultural-to industrial-oriented. An increase in primary energy consumption with high share of fossil fuels and corresponding CO_2 emission has a considerable impact on the environment due to global warming. Accounting of total (direct and indirect) energy used in and corresponding CO_2 emission by different economic sectors of Thai economy for the production of goods and services would provide useful information for energy-environment policy maker.

In this study, an analysis using input-output model has been done to account for energy consumption in and corresponding CO_2 emission from various economic sectors in Thailand for the years 1985 and 1995, based on the national input-output tables and energy statistics. The analytical results showed that the overall energy intensity for the whole economic system has been decreased in the year 1995 compared to 1985. These results have indicated a possibility of a downward trend in the average total energy intensity and the corresponding average total CO_2 intensity. Most of the economic sectors were fairly able to reduce their total (direct plus indirect) energy intensities or corresponding CO_2 intensities in 1995 although there was an increase of the same for some sectors in 1985. It is interesting to note that although the share of the overall direct embodied energy (final demand) increased in 1995 as compared to 1985, the overall indirect embodied energy (final demand) of Thai economy still had large share in 1995. This is an indication of the strong economic and environmental interdependence among various economic sectors of Thai economy. The results demonstrate that in addition to energy sectors such as oil products, electricity generation & distribution, and gas distribution, economic sectors especially cement, food & allied, construction, and land transport had very high total energy intensities or corresponding total CO_2 intensities in both years. The study suggests that Thailand should, further, concentrate on the introduction and implementation of energy saving practices, energy efficient production methods, use of cleaner

energies in both energy and non-energy sectors with prime consideration to those economic sectors with high total energy or CO_2 intensities.

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LIST OF ABBREVIATIONS

BOT	=	Bank of Thailand
CO_2	=	Carbon-dioxide
DEDP	=	Department of Energy Development and Promotion
GDP	=	Gross Domestic Product
IEA	=	International Energy Agency
IPCC	=	Intergovernmental Panel on Climate Change
IPP	=	Independent Power Producer
ktoe	=	Thousand tonnes of oil equivalent
$mtCO_2$	=	Million tonnes of CO_2
mtoe	=	Million tonnes of oil equivalent
NEPO	=	National Energy Policy Office
NESDB	=	Office of the National Economic and Social Development Board
SPP	=	Small Power Producer
tCO_2	=	Tonne of CO_2
TEI	=	Thailand Environment Institute
toe	=	Tonne of oil equivalent
UNFCCC	=	United Nations Framework Convention on Climate Change
US$	=	United States Dollar

CHAPTER 1

INTRODUCTION

1. Background Information

Economic activities play a significant role in natural resources exploitation. Energy is an essential input for all economic activities either production or consumption activities. At present, the energy requirements are largely met by fossil fuels, and the use of these fuels causes the deterioration of the global environment, mainly, due to large emission of carbon dioxide (CO_2), a major component of greenhouse gases.

Energy is consumed in an economic sector both directly and indirectly in the form of goods and services procured for use in that sector. In an economic sector, the energy content for the total production is equal to the energy value of the goods and services procured plus the energy directly used, and is referred to as the 'embodied energy'. Hence, embodied energy is a measure of the total energy required to produce goods and services in a sector (Battjes et al, 1998). The embodied energy intensity of an economic sector is equal to the total amount of energy required to produce one unit of output in that sector.

Thailand has achieved high economic growth since 1985 where the orientation of the economy has shifted from agricultural to industrial oriented. During the period of 1985-1995, the average gross domestic product (GDP) growth rate of the country was 9.02% per annum with high share of industrial sector (Office of the National Economic and Social Development Board [NESDB], 2000). In the same period, the average annual growth rates of total primary (commercial and non-commercial) energy consumption (from 26,514.5 thousand toe in 1985 to 65,068.4 thousand toe in 1995) and corresponding CO_2 emission (from 85,624.3 thousand tonnes in 1985 to 200,771.6 thousand tonnes in 1995) were 10.32% and 10.00%, respectively (Department of Energy Development and Promotion [DEDP], 1999). Such an increase in primary energy consumption with high share of fossil fuels (from 57% in 1985 to 70% in 1995 and 85% in 1999), and corresponding CO_2 emission, has a considerable impact on the environment due to global warming. In Thailand, CO_2 has the highest share in total emissions of greenhouse gas (GHG) which comes largely from fossil fuels burning (DEDP, 1999). The total emissions of CO_2 from fossil and bio-mass fuels burning in various inter-industry or economic sectors of the Thai economy were 85,624 thousand tonnes in 1985 and 200,772 thousand tonnes in 1995

(International Energy Agency [IEA], 2000). In order to enhance domestic energy policy towards reducing the emission of global CO_2, it is therefore important to perform a techno-economic analysis of different economic sectors of Thailand regarding these sectors' emission of CO_2 from energy use.

2. Literature Review

2.1 Energy

Energy is defined as the ability to do work. Schwaller and Gilberti (1996) divided sources of energy into three broad categories. These categories are renewable, nonrenewable, and nondepletable energy sources.

Renewable energy sources: include animal power, human power, and the chemical energy stored in plants, animals, and organic wastes. Plants and organic wastes as energy sources are often referred to as biofuels or biomass.

Nonrenewable energy sources: are exhausted or depleted once they are used. Nonrenewable energy sources include coal, geothermal heat, natural gas, oil shale, petroleum, tar sands, thorium, and uranium. They can be further subdivided into hydrocarbon resources and nuclear energy.

Nondepletable energy source: is one that cannot be exhausted through collection or extraction. Thus, nondepletable energy sources are limitless and offer the greatest potential for achieving future economic and social growth. These energy sources include solar radiation, hydro power and wind power, tidal energy, geothermal energy in the mantle and deep crust of the earth, and ocean thermal energy conversion.

Energy has a strong influence on both economic development and increased CO_2 emissions since it is an important input for economic activities either in the form of primary energy sources such as coal, oil, natural gas, biomass fuels, renewable energy sources, or secondary energy sources or transformed energy such as refined oil products or electricity (from fossil fuels, renewable energies or nuclear energy). Energy is traded commodity and also contributes indirectly to economic growth as it is an important factor in moving goods that are traded internationally (IEA, 1997).

Since the beginning of the industrial era, fossil energy has fuelled economic growth, leading to a sharp increase in greenhouse gas emission levels and their build-up in the atmosphere. At present, fossil fuels account for 84 % and 92 % of commercial energy use in the International Energy Agency (IEA) participating countries and in the rest of the world, respectively.

In practice, energy has been classified into two main forms, i.e., primary energy and secondary energy.

Primary energy: is defined as the non-processed energy. It is extracted from nature and prepared for market, includes coal, natural gas, crude oil and petroleum products, primary electricity (which are so-called commercial energies) and renewable energy (which is non-commercial energy).

Secondary energy: is defined as the processed energy and is transformed from primary energy, such as coke, refined petroleum and electricity generated from primary energy.

Total primary energy supply (TPES): is expressed as indigenous production plus imports minus exports and international marine bunkers.

Units of energy: are commonly expressed in terms of tonne of oil equivalent (toe), gigacalorie (Gcal), gigajoule (GJ) or British thermal unit (btu).

2.2 Embodied Energy and Energy Intensity

The basic idea of embodied energy is that in the consumption of any goods and services, energy is consumed. It means that primary energy extracted from the earth is processed by the economy and finally goes to the final demand which are consumers' consumption. The energy content for the total output in an economic sector is equal to the energy embodied in the goods and services purchased and the energy used directly. The total energy requirement to produce one unit of output is called the '*energy intensity*' (Morioka and Yoshida, 1995; Battjes et al, 1998). In computing the energy intensity of a product, it is necessary to distinguish between primary energy sectors: coal, crude oil, natural gas, primary electricity; and secondary energy sectors: petroleum refinery or electricity. The secondary energy sectors take primary energy as an input and convert it into more useful forms of energy. The total amount of primary and secondary energy required to produce the same output must be equal, net of energy lost in converting primary energy to secondary energy forms (Miller and Blair, 1985).

2.3 Energy Input-output Analysis

The methodology for relating economic activities to the environment by using an input-output analysis is widely known. Input-output analysis provides an effective framework for determining the energy use and other activities such as environmental pollution related to industrial production. Leontief in 1930s (Gay and Proops, 1993; Miller and Blair, 1985) originally developed the framework to account for these activities and has been in extensive application in recent years.

Miller and Blair (1985) classified environmental input-output models into three basic categories: *Generalized Input-Output Models, Economic-Ecologic Models, and Commodity-by-Industry Models*

Energy input-output typically determines the total energy required to generate a product to final demand, both directly as the energy used by an industrial process and indirectly as the energy embodied in that industry's input. A target product is either a good or service, and a list of goods and services directly required to make the product is compiled. These inputs to the target production include fuels (direct energy) and non-energy goods and services. The non-energy inputs are then analyzed to determine the inputs to their production processes, which include some fuels and non- energy goods and services. The process traces input back to primary resources; the first round of energy inputs is the direct energy requirement, and the subsequent rounds of energy inputs consist of the indirect energy requirement. The sum of these two is the total energy requirement (Miller and Blair, 1985).

An advantage of the input-output approach to fuel use is that only primary fuels need will be considered directly. Secondary fuels such as electricity, will be dealt automatically within the industry input structure (Gay and Proops, 1993).

The demands for data made by the basic input-output model are significantly increased when the model is extended to incorporate the generation of pollutants. These can be problems relating to the sectoral classification in the input-output table. They often over-aggregate important energy sectors and industries with significantly different pollution characteristics. There is the evidence that the sectoral classification of an input-output table can influence the sensitivity of the model (Hawdon and Pearson, 1995).

2.4 CO_2 Emission

Carbon dioxide is produced from consumption of fossil fuels, such as coal, oil and natural gas, and bio-mass fuels, such as fuel wood and bagasse in various economic activities, e.g., electricity generation, industry, transport, etc. Carbon-dioxide is also emitted through deforestation, while the growth of trees and forests absorbs it and transforms it into plant biomass.

Recent research into the earth's climate suggests that the release of greenhouse gases into the atmosphere, particularly carbon-dioxide is likely to cause major and potentially irreversible changes in global climate by the year 2050 (Gay and Proops, 1993). The domestic energy consumption or the corresponding carbon-dioxide emission in both industrialized and developing economies is on the rise and has a linear relationship with the economic development. The trade of energy or carbon-dioxide embodied in goods and services between the two economies is increased. Industrialized countries have higher per capita domestic energy consumption and carbon-dioxide emission than developing countries and they should make a strong effort to reduce or limit emissions of greenhouse gases into the atmosphere (Tiwaree and Imura, 1995).

Prior to the industrial revolution (1750-1800), the concentration of CO_2 in the world atmosphere was about 270 ppm. As the world became more industrialized, population increase and agriculture developed, there was a dramatic increase in both natural and human-made CO_2 in the atmosphere. In the year 1997, the concentration of CO_2 in the atmosphere was approximately 356 ppm. And it is expected to be double that of the pre-industrial level by the next century (Intergovernmental Panel on Climate Change [IPCC], 1990).

2.5 Greenhouse Effect

Greenhouse gases are normally found in the atmosphere in small quantities and absorb infrared radiation or heat energy, warming the atmosphere and the land, making the earth inhabitable. The major green house gases in the atmosphere are carbon dioxide, methane, nitrous oxide and ozone. Greenhouse gases occur naturally in ecosystems, however, as humans have interfered with nature's processes, the concentration of these gases in the atmosphere has increased and causes the '*Greenhouse Effect*'.

Prediction on how climate would change as a result of double concentration of CO_2 in the atmosphere has been made by Intergovernmental Panel on Climate Change (1990) and United Nations Framework Convention on Climate Change (1994) as follows:

(1) An increase in global mean temperature of approximately 2 ° C by the year 2100, for the mid range of 1.5-3.5 ° C.

(2) Regional temperature changes may differ significantly from the change in the global mean although it is not yet possible to describe certainly.

(3) The sea-level rise is estimated to range from 15 to 95 cm, with the best estimate of 50 cm by the year 2100. Sea level would continue to rise even though the global climate and the mean temperature would have stabilized.

(4) As a consequence of changes in temperature and water availability, a substantial fraction (a global average of one third) of the existing forest areas of the earth will face major changes in broad vegetation types.

(5) Developing countries will most likely be more seriously affected by climate change than developed countries, and may also have less options for adapting.

2.6 Embodied CO_2 and CO_2 Intensity

An economic sector uses fossil fuels and biomass fuels and correspondingly emits CO_2 directly and indirectly in the form of goods and services sold to the final consumption or to other economic sectors to produce their output. The total CO_2 emission from the total primary energy use for the production in an economic sector is equal to the CO_2 value of the goods and services procured and the CO_2 directly emitted. This is referred to as the embodied CO_2 (Battjes et al, 1998). Thus, embodied CO_2 intensity (also known as total CO_2 intensity) of an economic sector is equal to direct plus indirect amount of CO_2 emissions from primary energy used to produce one unit of economic output in that sector.

3. Objectives

The main objectives of this research were:

3.1 To account and compare the total (direct plus indirect) energy induced by the demand of goods and services, and corresponding CO_2 produced by various economic sectors of Thailand for the years 1985 and 1995.

3.2 To analyze the effect of technology change or change in fuel mix on the energy consumption as well as on the emission of CO_2 from different economic sectors of Thailand.

4. Scope and Limitations of the Study

4.1 This study used a modified input-output model to account for both energy and carbon-dioxide embodied in each unit of goods and services produced by different economic sectors of Thai economy.

4.2 Data from the publications 'Input-output Table of Thailand' for the years 1985 and 1995, which were in monetary units (thousand Baht) have been used to prepare required matrices or vectors as the input-output tables in physical units are not available.

5. Expected Benefits

5.1 Establishment of a data set on total energy consumption and carbon-dioxide emission intensities for different Thai economic sectors.

5.2 Obtaining the information of exclusive pollution emission rate of each economic sector.

5.3 Information on economic sectors having outstanding high energy consumption and pollution emission rate for further research, both in terms of energy conservation and environmental protection.

CHAPTER 2

METHODOLOGY

In this research, the modified input-output model is used for the analysis of total (direct plus indirect) energy intensities and CO_2 produced from energy use in different economic sectors of Thailand.

1. General Structure of Input-output Model

The concept of input-output model was originally developed by Leontief in 1930s (Gay and Proops, 1993; Miller and Blair, 1985). The basic principle is that in an economy, production activities are closely interrelated. Each producing activity is both a supplier; selling its output to other industries and to the final consumers, and a buyer; purchasing the products and services from other industries for its direct and indirect inputs.

The basic input-output concept is

$$x_i = \sum_j Z_{ij} + y_i \qquad (2\text{-}1)$$

where 'x_i' is the vector of gross output (intermediate plus final demand) from industry i. 'Z_{ij}' are the elements of a matrix (n×n) of intermediate demand (in monetary units) of industries j (j=1,....,n) from industries i (i=1,....n). A vector 'y' (n×1) is final demand from industries i (i=1,....,n).

Let 'A' be a matrix n×n of technological coefficients 'a_{ij}', which relate the output 'x_j' of industry j to its inputs from industries i by.

$$Z_{ij} = a_{ij}\ x_j \qquad (2\text{-}2)$$

or,

$$A = Z(\hat{X})^{-1}$$

where '$\hat{X}$' is a diagonal matrix generated from vector x.

So in matrix notation equation (1) can be written as

$$x = Ax + y \qquad (2\text{-}3)$$

$$x = Ax + y \tag{2-3}$$

or,

$$x = (I-A)^{-1} y \tag{2-4}$$

where 'I' is an identity matrix (n×n) and $(I-A)^{-1}$ is known as the Leontief inverse matrix. Since,

$$(I-A)^{-1} = I + A + A^2 + A^3 + \ldots \tag{2-5}$$

hence,

$$x = y + Ay + A^2y + A^3y + \ldots + A^ny \tag{2-6}$$

where 'A^ny' is the n^{th} order requirement for the production of the final demand (Gay and Proops, 1993; Lenzen, 1998; Miller and Blair, 1985; Tiwaree and Imura, 1994, 1995).

2. Embodied Energy Intensity and Energy Accounting

Figure 2-1 represents the energy input-output balance for an economic sector in the economic system of a country (Tiwaree and Imura, 1995):

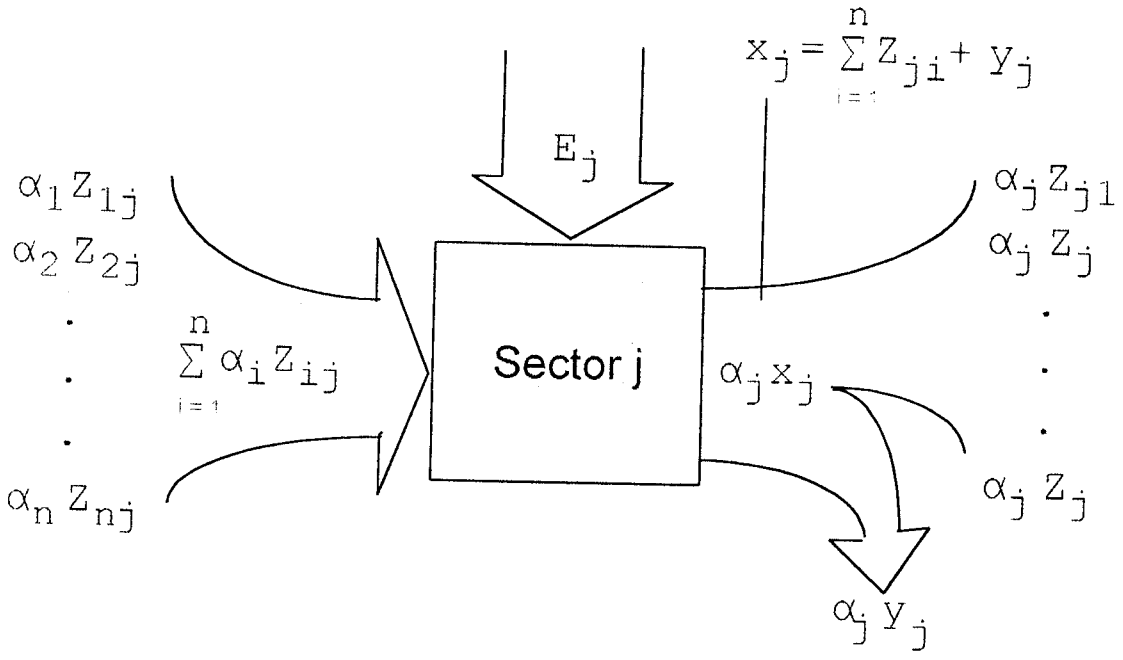

Figure 2-1 Energy input-output balance for an economic sector

The economic sector j requires the direct primary energy E_j and energy embodied in the goods and services received from sectors i to produce its output. Then the energy embodied in this output is consumed by its final consumers, y_j, and other inter-industry sectors of the economy in terms of goods and services, Z_{ji}.

The input-output model can be used to establish matrices of energy intensities for economic sectors in an economy in terms of energy per monetary unit of output. Two basic types of energy intensity are direct energy intensity and total energy intensity. The first type imputes productive energy use, E, to total output of the economy, x. The second type imputes productive energy use to final demand, y.

Hence,

$$\sigma_E.x = E \qquad (2\text{-}7)$$

where 'σ_E' is a m×n matrix represents the direct energy required to produce one monetary unit of goods and services, i.e., direct energy intensity.

and,

$$\alpha_E.y = E \qquad (2\text{-}8)$$

where 'α_E' is a m×n matrix represents the total (direct plus indirect) energy required to produce one value unit of goods and services, i.e., total energy intensity.

E = the total primary energy input (excluding residential sector) which is equal to aggregate embodied energy (final demand) in an economy.

To obtain σ_E, total productive energy use is allocated between the production sectors. Sector j purchases energy E_j for its production processes. Thus, for all n economic sectors in the economy, $E = \sum_j E_j$ where j = 1,....,n.

Since sector j has total output of value x_j, then σ_E is defined by

$$\sigma_{Eij} = E_{ij}/x_j \qquad i=1,\ldots,m;\ j=1,\ldots,n \qquad (2\text{-}9)$$

or,

$$\sigma_E = E(\hat{X})^{-1} \qquad (2\text{-}10)$$

where '$\hat{X}$' is a diagonal matrix generated from the gross output vector x.

The α_E can be derived from equations (2-4), (2-7), and (2-8) as follows. Substituting equation (2-4) into equation (2-7), one gets

$$\sigma_E (I-A)^{-1} y = E \qquad (2\text{-}11)$$

Finally, comparing (2-8) with (2-11) gives

$$\begin{aligned} \alpha_E &= \sigma_E (I-A)^{-1} \\ &= E (\hat{X})^{-1} (I-A)^{-1} \end{aligned} \qquad (2\text{-}12)$$

The embodied energy intensity can also be expressed as

$$\alpha_E = \sigma_E + \beta_E \qquad (2\text{-}13)$$

and then,

$$\beta_E = (\alpha_E - \sigma_E) \qquad (2\text{-}14)$$

$$= AE (\hat{X})^{-1} (I-A)^{-1}$$

$$= A\alpha_E \qquad (2\text{-}15)$$

The matrix 'β' is referred to as the indirect energy intensity.

3. Embodied Carbon-dioxide Calculation

Let 'σ_C' be a matrix (m×n) of direct embodied CO_2 due to m types of energy consumption in industrial sectors per unit of total output of n industries, i.e., direct CO_2 intensity.

$$\sigma_{Cij} = C_{ij}/x_j \qquad i=1,\ldots,m; \qquad j=1,\ldots,n \qquad (2\text{-}16)$$

or,

$$\sigma_C = C(\hat{X})^{-1} \qquad (2\text{-}17)$$

where '$\hat{X}$' is a diagonal matrix generated from vector x. 'C_{ij}' is the amount of total embodied CO_2 due to industrial consumption of energy.

Equation (2-17) can be written as

$$C = \sigma_C . x \qquad (2\text{-}18)$$

$$= \sigma_C(I-A)^{-1} y \qquad (2\text{-}19)$$

$$= C(\hat{X})^{-1}(I-A)^{-1} y \qquad (2\text{-}20)$$

Let 'α_C' be a matrix (m×n) of total embodied CO_2 due to m types of energy consumption in industrial sectors per unit of final demand of n industries, i.e., total CO_2 intensity.

$$\alpha_{Cij} = C_{ij}/y_j \qquad i= 1,...., m; \quad j=1,...., n \qquad (2\text{-}21)$$

or,

$$C = \alpha_C.y \qquad (2\text{-}22)$$

By comparing equations (2-20) with (2-22) gives

$$\alpha_C = C(\hat{X})^{-1}(I-A)^{-1} \qquad (2\text{-}23)$$

4. Assessment Procedure

In order to accomplish the model calculation described above, necessary data were compiled and prepared in the following way:

4.1 Preparation of the A Matrix

Data of 179 economic sectors in Thai Baht from the Input-output Tables of Thailand for the years 1985 and 1995 (NESDB, 1989, 1999) were compiled and converted into tabular form to construct matrices/vectors of intermediate demand (Z), gross output (X) and final demand (y) as shown in Table 2-1. Total gross output values obtained were the row total of intermediate demand matrix and final demand vector. Then the 179 sector A matrix was derived by dividing the inter-industry flows (Z) by the diagonal matrix of gross output (X). Leontief's inverse matrix $(I-A)^{-1}$ was also then prepared.

Table 2-1. Input-output table structure of Thailand (1985 and 1995).

unit: thousand Baht

Intermediate Demand								Final	Gross
Sector	1	2	3	.	.	179	Sum	Demand	Output
1									
2									
3									
.									
.									
179									

4.2 Preparation of the E and $E(\hat{X})^{-1}$ Matrices

Six types of primary energy consumption data: coal, natural gas, crude oil, oil products, electricity, and solid biomass fuel in physical unit has been used to prepare the E matrix. In this study, six rows of energy sectors in the I-O table in monetary unit were replaced by energy consumption data in physical unit obtained from the International Energy Agency (2000) and the Department of Energy Development and Promotion (1986, 1999). The International Energy Agency (IEA) has divided the whole economy into 56 sectors for energy data. Therefore, to match with the 179 economic sectors used in this study, some of the energy related sectors were first aggregated to 34 sectors and then disaggregated into 179 economic sectors. In this way, E matrix (6×179) was prepared. Then, the $E(\hat{X})^{-1}$ or direct energy intensity (σ_E) matrix (6×179) was obtained by dividing the E matrix by the gross output diagonal matrix ($\hat{X}$).

4.3 Calculation of the α_E and the Embodied Energy (Final Demand)

The total or embodied energy intensity (α_E) in a matrix form (6×179) was obtained by multiplying the direct energy intensity σ_E by the Leontief's inverse matrix $(I-A)^{-1}$. The obtained (6×179) matrix was aggregated column-wise (i.e., 1×179) and was then transposed. To calculate the energy emission (final demand), the α_E obtained was multiplied by the corresponding final demand value for each sector. To express the calculated α_E values (toe/Thai Bht 1,000) in

toe/US$ 1000 unit, Thai Baht to US dollar conversion factors of 27.21 and 24.94 were used for the years 1985 and 1995, respectively (BOT, 2000). The results obtained for 179 economic sectors were finally aggregated into 34 appropriate economic sectors so that it was possible to make their interpretation clearly and concisely.

4.4 Preparation of the C and $C(\hat{X})^{-1}$ Matrices

The four types of primary energy: coal, natural gas, oil and its products, and solid biomass fuels produce CO_2 while they are used by various inter-industry or economic sectors as their energy inputs. The C matrix (4×179) was prepared by replacing the rows of the four energy sectors of Z matrix in monetary units by CO_2 data in physical units obtained from the International Energy Agency (2000) and the Department of Energy Development and Promotion (1986, 1999). The International Energy Agency (IEA) has divided the whole economy into 41 sectors for CO_2 data that were produced from fossil fuel consumption. To evaluate the CO_2 emission from solid biomass fuels, information regarding emission factor for each type of these fuels as well as oxidation fraction of fuel during combustion is necessary. In this study, emission factors considered were: fuel wood = 4.65, paddy husk = 4.84 and bagasse = 9.26 t-CO_2/toe. The oxidation fraction considered was 90% for fuel wood, paddy husk and bagasse (Thailand Environment Institute, 1997).

To match with the 179 economic sectors used in this study, some of the CO_2 related sectors were first aggregated to 34 sectors and then disaggregated carefully into 179 economic sectors and thus, C matrix was prepared. Finally, $C(\hat{X})^{-1}$ or direct CO_2 intensity matrix (σ_C; 4×179) was obtained by dividing the C matrix by the gross output diagonal matrix ($\hat{X}$).

4.5 Calculation of the α_C and CO_2 Emission (Final Demand)

The total or embodied CO_2 intensity (α_C) in matrix form (4×179) was obtained by multiplying the direct CO_2 intensity σ_C by the Leontief's inverse matrix $(I-A)^{-1}$. The obtained matrix (4×179) was aggregated column-wise (i.e., 1×179) and was then transposed. To calculate the CO_2 emission (final demand), α_C, thus obtained was multiplied by the corresponding final demand value for each sector. Similar to energy, to express the calculated α_C values (t-CO_2/Thai Bht 1,000) in t-CO_2/US$ 1,000 unit, Thai Baht to US dollar conversion factors of 27.21 and 24.94

were used for the years 1985 and 1995, respectively. The results obtained for 179 economic sectors were finally aggregated into 34 appropriate economic sectors.

4.6 Calculation of Energy Consumption and CO_2 Emission Reduction

Improvement in the production technologies would result in reduction of energy consumption and the corresponding CO_2 emission. In this study, the production technologies (matrix A) employed in 9 selected economic sectors in the years 1995 are upgraded by 20%, i.e., the intermediate demand (in matrix Z) of these sectors are decreased by 20%, while the final demand and the gross output of all economic sectors are still the same. Then the new energy and CO_2 intensities as well as energy consumption and CO_2 emission are calculated and compared with the old ones to obtain the percentages of energy consumption and CO_2 emission reduction.

4.7 Modification of Input-Output Monetary Units

For meaningful comparison of energy and CO_2 intensities between the years 1985 and 1995, modification of the input-output table for the year 1995 to the year 1985 constant prices is necessary. In this study, the single value annual consumer price index of Thailand provided by the Bank of Thailand (2000) has been used for all economic sectors since the sector-wise information for this purpose was not available. Thus, a factor of 0.638 (67.5/105.8) was used to convert the data of the year 1995 input-output table into the year 1985 constant price.

CHAPTER 3

RESULTS AND DISCUSSION

1. Energy Intensities and Embodied Energy in 1985

1.1 Total Energy Intensities

The total (direct plus indirect) energy intensities (toe/US$ 1,000) of various economic sectors in Thailand for the year 1985 are shown in Table 3-1. The ranked top 10 economic sectors with high total energy intensities were electricity generation and distribution (4.08), oil products (2.32), gas distribution (1.44), cement (1.15), land transport (1.08), bricks & tiles, ceramics, non-metallic mineral, air & water transports, and coal mining. At the same time, the bottom 5 economic sectors with low total energy intensities were wholesale & retail (0.11), mechanical engineering (0.10), ship, train, aircraft (0.07), oil & natural gas (0.05), and charcoal & fuel wood (0.04), respectively. It can be seen in Table 3-2 that a great majority of the 34 economic sectors were responsible for indirect energy consumption than direct one to produce a monetary unit of goods and services.

1.2 Direct Energy Intensities

Table 3-2 represents the ranked sector-wise direct energy intensities (toe/US$ 1,000) of 34 economic sectors. It is noteworthy that 8 of the top 10 economic sectors with high direct energy intensities were among top 10 economic sectors with high total energy intensities except for food & allied, and drink & tobacco sectors. Electricity generation & distribution (3.33), oil products (2.15), and gas distribution (1.27) were top 3 sectors with both direct and total energy intensities ranking. The share of direct energy intensities in total energy intensities was 29.67%, while indirect energy intensities took a share of 70.33%.

Table 3-1 Total energy intensities in 1985

Unit : toe/US$ 1,000

Rank	Sectors	Intensities
1	Electricity generation & distribution	4.08
2	Oil products	2.32
3	Gas distribution	1.44
4	Cement	1.15
5	Land transports	1.08
6	Bricks & tiles	0.66
7	Ceramics	0.61
8	Non-metallic mineral	0.59
9	Air & water transports	0.54
10	Coal mining	0.47
11	Food & allied	0.46
12	Water supply & sanitation	0.45
13	Construction	0.40
14	Drink & tobacco	0.35
15	Hotel & restaurant	0.31
16	Other manufacturing	0.30
17	Rubber & plastics	0.27
18	Textile	0.27
19	Agriculture, forestry & fishing	0.27
20	Iron & steel	0.26
21	Non-ferrous metal	0.26
22	Metallic mineral	0.25
23	Pulp, paper & printing	0.24
24	Timber & its product	0.22
25	Chemicals & fertilizers	0.20
26	Leather, etc.	0.20
27	Automobiles, bicycles	0.16
28	Other services	0.12
29	Electrical engineering	0.12
30	Wholesale & retail	0.11
31	Mechanical engineering	0.10
32	Ship, train, aircraft	0.07
33	Oil & natural gas	0.05
34	Charcoal & fuel wood	0.04
	Average	0.36

Table 3-2 Direct and indirect energy intensities in 1985

Unit : toe/US$ 1,000

Rank	Sectors	Direct	Indirect	Total
1	Electricity generation & distribution	3.33	0.75	4.08
2	Oil products	2.15	0.17	2.32
3	Gas distribution	1.27	0.17	1.44
4	Food & allied	0.23	0.22	0.46
5	Cement	0.20	0.95	1.15
6	Non-metallic mineral	0.20	0.39	0.59
7	Drink & tobacco	0.20	0.15	0.35
8	Bricks & tiles	0.19	0.47	0.66
9	Land transports	0.16	0.92	1.08
10	Coal mining	0.15	0.32	0.47
11	Other manufacturing	0.14	0.15	0.30
12	Ceramics	0.14	0.47	0.61
13	Air & water transports	0.12	0.43	0.54
14	Rubber & plastics	0.11	0.16	0.27
15	Chemicals & fertilizers	0.08	0.13	0.20
16	Agriculture, forestry & fishing	0.04	0.22	0.27
17	Iron & steel	0.02	0.24	0.26
18	Pulp, paper & printing	0.01	0.22	0.24
19	Construction	0.00	0.40	0.40
20	Textile	0.00	0.26	0.27
21	Metallic mineral	0.00	0.25	0.25
22	Leather, etc.	0.00	0.19	0.20
23	Timber & its product	0.00	0.22	0.22
24	Other services	0.00	0.12	0.12
25	Charcoal & fuel wood	0.00	0.04	0.04
26	Oil & natural gas	0.00	0.05	0.05
27	Non-ferrous metal	0.00	0.26	0.26
28	Mechanical engineering	0.00	0.10	0.10
29	Electrical engineering	0.00	0.12	0.12
30	Ship, train, aircraft	0.00	0.07	0.07
31	Automobiles, bicycles	0.00	0.16	0.16
32	Water supply & sanitation	0.00	0.45	0.45
33	Wholesale & retail	0.00	0.11	0.11
34	Hotel & restaurant	0.00	0.31	0.31
	Average	0.11	0.26	0.36
	%	29.67	70.33	100.00

1.3 Embodied Energy (Final Demand)

The embodied energy of an economic sector can be obtained by multiplying the total energy intensity by the final demand for goods and services of that sector. In Table 3-3 the embodied energy (final demand) excluding residential sector in the year 1985 was summed to 18,040 thousand toe. The top 10 economic sectors with high values in the unit of 1,000 toe were land transport (3,192), food & allied (2,963), construction (2,004), electricity generation & distribution (1,562), oil products (1,235), hotel & restaurant, other services, textile, air & water transport, and drink & tobacco, respectively. At the same time, the bottom 5 economic sectors were metallic mineral (9.9), coal mining (9.5), bricks & tiles (6.5), charcoal & fuel wood (5.4), and gas distribution (0.03), respectively. It is notable that 4 of the top 10 economic sectors with high total energy intensities were among top 10 economic sectors with high embodied energy (final demand) in the same year. These economic sectors were electricity generation & distribution, oil products, land transports, and air & water transport. It is also noteworthy that in the year 1985, the overall indirect embodied energy (final demand) of Thai economy had a large share, which was 70.33 % of the embodied energy (final demand) as shown in Table 3-4.

1.4 Direct Embodied Energy (Final Demand)

The rank-wise direct embodied energy (final demand) in 1,000 toe unit of the 34 economic sectors for the year 1985 were demonstrated in Table 3-4. It is noticeable that 6 of the top 10 economic sectors with high embodied energy (final demand) were in top 10 economic sectors with high direct embodied energy (final demand) in the same year. The four economic sectors not included were construction, textile, other services, and hotel & restaurant that ranked 12^{th}, 13^{th}, 24^{th}, and 34^{th} positions respectively.

Table 3-3 Embodied energy (final demand) in 1985

Unit : 1,000 toe

Rank	Sectors	Energy
1	Land transports	3,191.65
2	Food & allied	2,962.77
3	Construction	2,003.96
4	Electricity generation & distribution	1,562.02
5	Oil products	1,234.81
6	Hotel & restaurant	1,009.85
7	Other services	1,005.97
8	Textile	884.09
9	Air & water transports	785.60
10	Drink & tobacco	529.52
11	Agriculture, forestry & fishing	521.11
12	Wholesale & retail	517.43
13	Other manufacturing	315.23
14	Automobiles, bicycles	225.99
15	Mechanical engineering	200.81
16	Chemicals & fertilizers	180.34
17	Rubber & plastics	176.63
18	Electrical engineering	147.99
19	Timber & its product	102.17
20	Non-metallic mineral	79.65
21	Pulp, paper & printing	77.57
22	Leather, Etc.	65.28
23	Non-ferrous metal	56.27
24	Water supply & sanitation	48.47
25	Cement	33.91
26	Iron & steel	31.40
27	Ship, train, aircraft	26.72
28	Ceramics	21.22
29	Oil & natural gas	10.36
30	Metallic mineral	9.89
31	Coal mining	9.46
32	Bricks & tiles	6.54
33	Charcoal & fuel wood	5.39
34	Gas distribution	0.03
	Overall	18,040.12

Table 3-4 Direct and indirect embodied energy (final demand) in 1985

Unit : 1,000 toe

Rank	Sectors	Direct	Indirect	Total
1	Food & allied	1,514.71	1,448.06	2,962.77
2	Electricity generation & distribution	1,275.27	286.75	1,562.02
3	Oil products	1,144.38	90.43	1,234.81
4	Land transports	484.16	2,707.49	3,191.65
5	Drink & tobacco	300.29	229.23	529.52
6	Air & water transports	170.84	614.75	785.60
7	Other manufacturing	151.64	163.59	315.23
8	Agriculture, forestry & fishing	87.25	433.86	521.11
9	Chemicals & fertilizers	69.19	111.16	180.34
10	Rubber & plastics	68.91	107.72	176.63
11	Non-metallic mineral	27.29	52.36	79.65
12	Construction	20.23	1,983.73	2,003.96
13	Textile	12.79	871.29	884.09
14	Cement	5.92	27.99	33.91
15	Ceramics	4.93	16.29	21.22
16	Pulp, paper & printing	4.66	72.91	77.57
17	Coal mining	3.02	6.43	9.46
18	Iron & steel	2.39	29.02	31.40
19	Bricks & tiles	1.84	4.71	6.54
20	Timber & its product	1.44	100.73	102.17
21	Leather, etc.	1.13	64.15	65.28
22	Metallic mineral	0.15	9.74	9.89
23	Gas distribution	0.03	0.00	0.03
24	Other services	0.00	1,005.97	1,005.97
25	Charcoal & fuel wood	0.00	5.39	5.39
26	Oil & natural gas	0.00	10.36	10.36
27	Non-ferrous metal	0.00	56.27	56.27
28	Mechanical engineering	0.00	200.81	200.81
29	Electrical engineering	0.00	147.99	147.99
30	Ship, train, aircraft	0.00	26.72	26.72
31	Automobiles, bicycles	0.00	225.99	225.99
32	Water supply & sanitation	0.00	48.47	48.47
33	Wholesale & retail	0.00	517.43	517.43
34	Hotel & restaurant	0.00	1,009.85	1,009.85
	Overall	5,352.45	12,687.68	18,040.12
	%	29.67	70.33	100.00

2. Energy Intensities and Embodied Energy in 1995

2.1 Total Energy Intensities

Table 3-5 illustrates the total energy intensities (toe/US$ 1,000) of various economic sectors for the year 1995. The ranked top 10 economic sectors with high total energy intensities were electricity generation & distribution (3.46) , oil products (2.41), gas distribution (1.08), land transports (0.74), cement (0.74), bricks & tiles, non-metallic mineral, air & water transport, ceramics, and food & allied, respectively. While the 5 economic sectors with lowest total energy intensities were mechanical engineering (0.05), electrical engineering (0.05), non-ferrous metal (0.02), charcoal & fuel wood (0.02), and ship, train, aircraft (0.02), respectively. In 1995, the majority of the 34 economic sectors were much more responsible for indirect energy consumption than direct consumption to produce their goods and services as shown in Table 3-6.

2.2 Direct Energy Intensities

Table 3-6 shows the ranked sector-wise direct energy intensities in terms of toe/US$ 1,000 of 34 economic sectors in the year 1995. It is notable that out of the top 10 economic sectors with high direct energy intensities, 8 were among the top 10 economic sectors with high total energy intensities, excluded other manufacturing and drink & tobacco sectors. Electricity generation & distribution, gas distribution, and oil products were top 3 sectors in both total energy intensities and direct energy intensity rankings. Direct energy intensities took a share of 30.95 % in total energy intensities and the majority of 68.76 % was taken by indirect energy intensities.

2.3 Embodied Energy (Final Demand)

Table 3-7 represents the embodied energy (final demand) in the year 1995 (excluding residential sector) which was in the sum of 54,968 thousand toe. The top 10 economic sectors with substantial high embodied energy (final demand) in the unit of 1,000 toe in 1995 were construction (7,067), oil products (6,363), land transports (5,960), food & allied (5,458), electricity generation & distribution (5,101) hotel & restaurant, textile, other services, other manufacturing, and air & water transports. The bottom 5 economic sectors were bricks & tiles (9.1), oil & natural gas (3.8), coal mining (2.1), charcoal & fuel wood (2.0), and metallic mineral (1.3), respectively. It is interesting to note that 5 of the 10 economic sectors with high total energy intensities were

among top 10 economic sectors with high embodied energy (final demand) in the same year. These economic sectors included were electricity generation & distribution, oil products, land transports, air & water transports, and food & allied. It can be noticed in Table 3-8 that in the year 1995, the overall indirect embodied energy (final demand) had a large share of 69.05% in the overall embodied energy in the final demand.

2.4 Direct Embodied Energy (Final Demand)

Table 3-8 shows the ranked direct embodied energy (final demand) of 34 Thai economic sectors in the year 1995. It is noticeable that 6 of the top 10 economic sectors with high embodied energy (final demand) were among top 10 economic sector with high direct embodied energy. This indicates a relationship between embodied energy (final demand) and direct embodied energy (final demand) in economic sectors.

2.5 Energy Intensities in 1995 with Modification

In this study, the monetary units in the input-output table for the year 1995 were modified to the 1985 constant prices using the annual customer price indices of Thailand (Bank of Thailand [BOT], 2000]. A single value 0.638 (67.5/105.8) was applied to total energy intensities of 1995 current market price for all economic sectors since the sector-wise information was not available.

Table 3-9 represents modified total energy intensities (toe/US$ 1,000 at 1985 constant price) for the year 1995. There is no change in the rankings of all the 34 sectors and energy intensities were changed uniformly for all sectors. In this way, the average total energy intensities was shifted from 0.21 toe/US$ 1,000 to 0.33 toe/US$ 1,000. Note that the shares of direct and indirect energy intensities in total energy intensities were not changed.

Table 3-5 Total energy intensities in 1995

Unit : toe/US$ 1,000

Rank	Sectors	Intensities
1	Electricity generation & distribution	3.46
2	Oil products	2.41
3	Gas distribution	1.08
4	Land transports	0.75
5	Cement	0.74
6	Bricks & tiles	0.55
7	Non-metallic mineral	0.48
8	Air & water transports	0.48
9	Ceramics	0.38
10	Food & allied	0.31
11	Water supply & sanitation	0.27
12	Rubber & plastics	0.25
13	Coal mining	0.24
14	Hotel & restaurant	0.24
15	Construction	0.22
16	Textile	0.21
17	Other manufacturing	0.18
18	Drink & tobacco	0.17
19	Agriculture, forestry & fishing	0.17
20	Chemicals & fertilizers	0.14
21	Timber & its product	0.14
22	Iron & steel	0.13
23	Leather, etc.	0.11
24	Pulp, paper & printing	0.11
25	Metallic mineral	0.09
26	Wholesale & retail	0.09
27	Automobiles, bicycles	0.08
28	Oil & natural gas	0.08
29	Other services	0.07
30	Mechanical engineering	0.05
31	Electrical engineering	0.05
32	Non-ferrous metal	0.02
33	Charcoal & fuel wood	0.02
34	Ship, train, aircraft	0.02
	Average	0.21

Table 3-6 Direct and indirect energy intensities in 1995

Unit : toe/US$ 1,000

Rank	Sectors	Direct	Indirect	Total
1	Electricity generation & distribution	2.80	0.67	3.46
2	Oil products	2.34	0.08	2.41
3	Gas distribution	0.91	0.17	1.08
4	Bricks & tiles	0.17	0.37	0.55
5	Cement	0.17	0.57	0.74
6	Non-metallic mineral	0.16	0.32	0.48
7	Land transports	0.16	0.58	0.75
8	Food & allied	0.13	0.17	0.31
9	Other manufacturing	0.09	0.09	0.18
10	Drink & tobacco	0.09	0.09	0.17
11	Rubber & plastics	0.08	0.16	0.25
12	Ceramics	0.07	0.31	0.38
13	Air & water transports	0.07	0.42	0.48
14	Chemicals & fertilizers	0.06	0.08	0.14
15	Agriculture, forestry & fishing	0.01	0.16	0.17
16	Iron & steel	0.01	0.12	0.13
17	Pulp, paper & printing	0.00	0.10	0.11
18	Textile	0.00	0.21	0.21
19	Leather, etc.	0.00	0.11	0.11
20	Construction	0.00	0.21	0.22
21	Timber & its product	0.00	0.14	0.14
22	Mechanical engineering	0.00	0.05	0.05
23	Electrical engineering	0.00	0.05	0.05
24	Charcoal & fuel wood	0.00	0.02	0.02
25	Coal mining	0.00	0.24	0.24
26	Oil & natural gas	0.00	0.08	0.08
27	Metallic mineral	0.00	0.09	0.09
28	Non-ferrous metal	0.00	0.02	0.02
29	Ship, train, aircraft	0.00	0.02	0.02
30	Automobiles, bicycles	0.00	0.08	0.08
31	Water supply & sanitation	0.00	0.27	0.27
32	Wholesale & retail	0.00	0.09	0.09
33	Hotel & restaurant	0.00	0.24	0.24
34	Other services	0.00	0.07	0.07
	Average	0.06	0.14	0.21
	%	30.95	69.05	100.00

Table 3-7 Embodied energy (final demand) in 1995

Unit : 1,000 toe

Rank	Sectors	Energy
1	Construction	7,067.52
2	Oil products	6,362.86
3	Land transports	5,960.11
4	Food & allied	5,458.10
5	Electricity generation & distribution	5,100.64
6	Hotel & restaurant	3,465.65
7	Textile	3,442.88
8	Other services	2,480.85
9	Other manufacturing	2,200.05
10	Air & water transports	2,079.17
11	Wholesale & retail	2,071.40
12	Automobiles, bicycles	1,432.26
13	Rubber & plastics	1,234.83
14	Agriculture, forestry & fishing	1,052.39
15	Mechanical engineering	1,027.84
16	Drink & tobacco	1,020.62
17	Electrical engineering	842.43
18	Leather, etc.	617.65
19	Chemicals & fertilizers	497.51
20	Timber & its product	448.53
21	Gas distribution	317.19
22	Pulp, paper & printing	203.22
23	Ceramics	117.14
24	Non-metallic mineral	95.66
25	Cement	93.29
26	Ship, train, aircraft	87.79
27	Water supply & sanitation	87.46
28	Iron & steel	75.81
29	Non ferrous metal	9.18
30	Bricks & tiles	9.08
31	Oil & natural gas	3.76
32	Coal mining	2.15
33	Charcoal & fuel wood	2.04
34	Metallic mineral	1.33
	Overall	54,968.36

Table 3-8 Direct and indirect embodied energy (final demand) in 1995

Unit : 1,000 toe

Rank	Sectors	Direct	Indirect	Total
1	Oil products	6,162.67	200.19	6,362.86
2	Electricity generation & distribution	4,116.50	984.14	5,100.64
3	Food & allied	2,378.49	3,079.61	5,458.10
4	Land transports	1,303.94	4,656.17	5,960.11
5	Other manufacturing	1,127.35	1,072.70	2,200.05
6	Drink & tobacco	512.18	508.44	1,020.62
7	Rubber & plastics	423.19	811.64	1,234.83
8	Air & water transports	284.99	1,794.18	2,079.17
9	Gas distribution	267.49	49.70	317.19
10	Chemicals & fertilizers	221.67	275.85	497.51
11	Agriculture, forestry & fishing	66.20	986.19	1,052.39
12	Non-metallic mineral	32.52	63.13	95.66
13	Construction	29.06	7,038.47	7,067.52
14	Ceramics	22.35	94.79	117.14
15	Cement	21.29	72.00	93.29
16	Textile	20.58	3,422.31	3,442.88
17	Leather, etc.	7.28	610.37	617.65
18	Pulp, paper & printing	6.23	196.99	203.22
19	Iron & steel	3.20	72.61	75.81
20	Bricks & tiles	2.90	6.17	9.08
21	Mechanical engineering	1.43	1,026.41	1,027.84
22	Timber & its product	0.98	447.54	448.53
23	Electrical engineering	0.41	842.02	842.43
24	Charcoal & fuel wood	0.00	2.04	2.04
25	Coal mining	0.00	2.15	2.15
26	Oil & natural gas	0.00	3.76	3.76
27	Metallic mineral	0.00	1.33	1.33
28	Non-ferrous metal	0.00	9.18	9.18
29	Ship, train, aircraft	0.00	87.79	87.79
30	Automobiles, bicycles	0.00	1,432.26	1,432.26
31	Water supply & sanitation	0.00	87.46	87.46
32	Wholesale & retail	0.00	2,071.40	2,071.40
33	Hotel & restaurant	0.00	3,465.65	3,465.65
34	Other services	0.00	2,480.85	2,480.85
	Overall	17,012.88	37,955.48	54,968.36
	%	30.95	69.05	100.00

Table 3-9 Total Energy Intensities in 1995 (modified)

Unit : toe/US$ 1,000

Rank	Sectors	Intensities
1	Electricity generation & distribution	5.43
2	Oil products	3.78
3	Gas distribution	1.70
4	Land transports	1.17
5	Cement	1.16
6	Bricks & tiles	0.86
7	Non-metallic mineral	0.76
8	Air & water transports	0.75
9	Ceramics	0.59
10	Food & allied	0.49
11	Water supply & sanitation	0.43
12	Rubber & plastics	0.39
13	Coal mining	0.38
14	Hotel & restaurant	0.37
15	Construction	0.34
16	Textile	0.33
17	Other manufacturing	0.29
18	Drink & tobacco	0.27
19	Agriculture, forestry & fishing	0.27
20	Chemicals & fertilizers	0.22
21	Timber & its product	0.21
22	Iron & steel	0.20
23	Leather, etc.	0.17
24	Pulp, paper & printing	0.17
25	Metallic mineral	0.14
26	Wholesale & retail	0.13
27	Automobiles, bicycles	0.13
28	Oil & natural gas	0.13
29	Other services	0.12
30	Mechanical engineering	0.08
31	Electrical engineering	0.08
32	Non-ferrous metal	0.04
33	Charcoal & fuel wood	0.03
34	Ship, train, aircraft	0.03
	Average	0.33

3. Comparison between the Years 1985 and 1995 for Energy Intensity and Embodied Energy

3.1 Total Energy Intensities

Table 3-10 and Figure 3-1 illustrate the total energy intensities (toe/US$ 1,000) of all 34 Thai economic sectors for the years 1985 and 1995. It is notable that 9 of the top 10 economic sectors with high total energy intensities in 1995 were among top 10 economic sectors with high total energy intensities in 1985. The economic sector not included was coal mining that ranked 10^{th} in 1985 but fell to 13^{th} position in 1995 with large reduction in total energy intensity.

The average total energy intensity as well as total energy intensities of most of the economic sectors were decreased. However, there was an increase of the same in some sectors such as oil products sector in 1995 compared to 1985 due to the increase in direct energy intensities in this sector. It's direct energy intensity share increased from 92.68 % of total energy intensity in 1985 to 96.85 % in 1995.

3.2 Direct Energy Intensities

Table 3-11 represents direct energy intensities of 34 economic sectors for the years 1985 and 1995. It can be noticed that 9 of the top 10 economic sectors with high direct energy intensities in 1995 were in the top 10 economic sectors with high direct energy intensities in 1985. The sectors not included were coal mining that ranked 10^{th} position in 1985 but fell to 25^{th} positions in 1995 with substantial reduction in their direct energy intensities.

Although there was a decrease in the average direct energy intensity as well as in direct energy intensities of many individual economic sectors, increase of the same for some sectors such as oil products is notable in 1995 compared to 1985. At the same time, it is noteworthy that for both years, the majority of the 34 economic sectors were responsible for much more energy consumption indirectly than directly to produce their outputs.

In case of the year 1995 with modified monetary units, the average total energy intensity was still lower compared to the same in 1995 although there were 16 out of 34 economic sectors with increased total energy intensities.

Table 3-10 Total energy intensities in 1985 & 1995

Unit : toe/US$ 1,000

Sectors	1995		1985	
	Intensities	Rank	Intensities	Rank
Electricity generation & distribution	3.46	1	4.08	1
Oil products	2.41	2	2.32	2
Gas distribution	1.08	3	1.44	3
Land transports	0.75	4	1.08	5
Cement	0.74	5	1.15	4
Bricks & tiles	0.55	6	0.66	6
Non-metallic mineral	0.48	7	0.59	8
Air & water transports	0.48	8	0.54	9
Ceramics	0.38	9	0.61	7
Food & allied	0.31	10	0.46	11
Water supply & sanitation	0.27	11	0.45	12
Rubber & plastics	0.25	12	0.27	17
Coal mining	0.24	13	0.47	10
Hotel & restaurant	0.24	14	0.31	15
Construction	0.22	15	0.40	13
Textile	0.21	16	0.27	18
Other manufacturing	0.18	17	0.30	16
Drink & tobacco	0.17	18	0.35	14
Agriculture, forestry & fishing	0.17	19	0.27	19
Chemicals & fertilizers	0.14	20	0.20	25
Timber & its product	0.14	21	0.22	24
Iron & steel	0.13	22	0.26	20
Leather, etc.	0.11	23	0.20	26
Pulp, paper & printing	0.11	24	0.24	23
Metallic mineral	0.09	25	0.25	22
Wholesale & retail	0.09	26	0.11	30
Automobiles, bicycles	0.08	27	0.16	27
Oil & natural gas	0.08	28	0.05	33
Other services	0.07	29	0.12	28
Mechanical engineering	0.05	30	0.10	31
Electrical engineering	0.05	31	0.12	29
Non-ferrous metal	0.02	32	0.26	21
Charcoal & fuel wood	0.02	33	0.04	34
Ship, train, aircraft	0.02	34	0.07	32
Average	0.21		0.36	

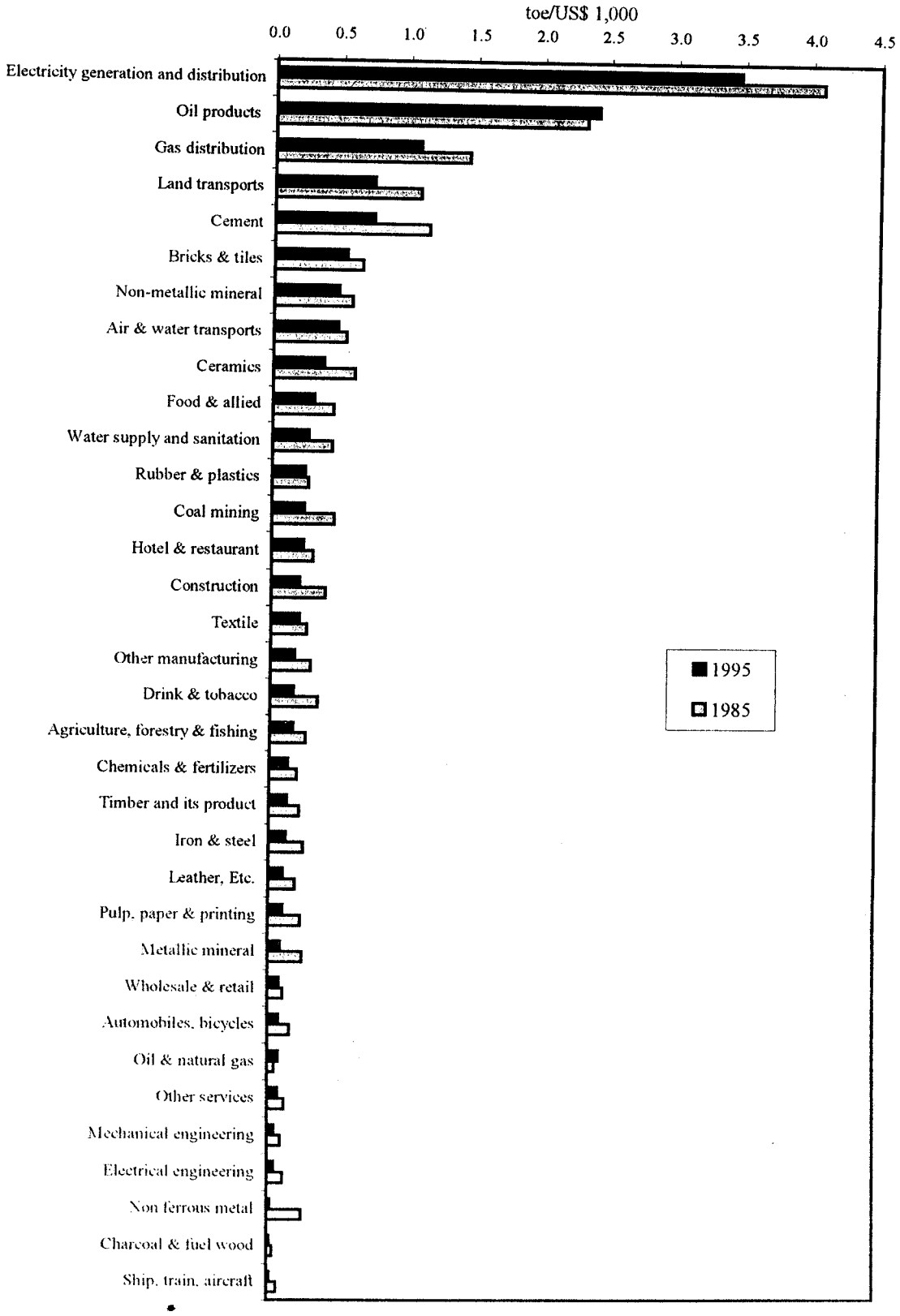

Figure 3-1 Total energy intensities in 1985 & 1995

Table 3-11 Direct energy intensities in 1985 & 1995

Unit : toe/US$ 1,000

Sectors	1995		1985	
	Intensities	Rank	Intensities	Rank
Electricity generation & distribution	2.80	1	3.33	1
Oil products	2.34	2	2.15	2
Gas distribution	0.91	3	1.27	3
Bricks & tiles	0.17	4	0.19	8
Cement	0.17	5	0.20	5
Non-metallic mineral	0.16	6	0.20	6
Land transports	0.16	7	0.16	9
Food & allied	0.13	8	0.23	4
Other manufacturing	0.09	9	0.14	11
Drink & tobacco	0.09	10	0.20	7
Rubber & plastics	0.08	11	0.11	14
Ceramics	0.07	12	0.14	12
Air & water transports	0.07	13	0.12	13
Chemicals & fertilizers	0.06	14	0.08	15
Agriculture, forestry & fishing	0.01	15	0.04	16
Iron & steel	0.01	16	0.02	17
Pulp, paper & printing	0.00	17	0.01	18
Textile	0.00	18	0.00	20
Leather, etc.	0.00	19	0.00	22
Construction	0.00	20	0.00	19
Timber & its product	0.00	21	0.00	23
Mechanical engineering	0.00	22	0.00	28
Electrical engineering	0.00	23	0.00	29
Charcoal & fuel wood	0.00	24	0.00	25
Coal mining	0.00	25	0.15	10
Oil & natural gas	0.00	26	0.00	26
Metallic mineral	0.00	27	0.00	21
Non-ferrous metal	0.00	28	0.00	27
Ship, train, aircraft	0.00	29	0.00	30
Automobiles, bicycles	0.00	30	0.00	31
Water supply & sanitation	0.00	31	0.00	32
Wholesale & retail	0.00	32	0.00	33
Hotel & restaurant	0.00	33	0.00	34
Other services	0.00	34	0.00	24
Average	0.06		0.11	

Table 3 -12 Total energy intensities in 1985 & 1995 (modified)

Unit : toe/US$ 1,000

Sectors	1995 (modified)		1985	
	Intensities	Rank	Intensities	Rank
Electricity generation & distribution	5.43	1	4.08	1
Oil products	3.78	2	2.32	2
Gas distribution	1.70	3	1.44	3
Land transports	1.17	4	1.08	5
Cement	1.16	5	1.15	4
Bricks & tiles	0.86	6	0.66	6
Non-metallic mineral	0.76	7	0.59	8
Air & water transports	0.75	8	0.54	9
Ceramics	0.59	9	0.61	7
Food & allied	0.49	10	0.46	11
Water supply & sanitation	0.43	11	0.45	12
Rubber & plastics	0.39	12	0.27	17
Coal mining	0.38	13	0.47	10
Hotel & restaurant	0.37	14	0.31	15
Construction	0.34	15	0.40	13
Textile	0.33	16	0.27	18
Other manufacturing	0.29	17	0.30	16
Drink & tobacco	0.27	18	0.35	14
Agriculture, forestry & fishing	0.27	19	0.27	19
Chemicals & fertilizers	0.22	20	0.20	25
Timber & its product	0.21	21	0.22	24
Iron & steel	0.20	22	0.26	20
Leather, etc.	0.17	23	0.20	26
Pulp, paper & printing	0.17	24	0.24	23
Metallic mineral	0.14	25	0.25	22
Wholesale & retail	0.13	26	0.11	30
Automobiles, bicycles	0.13	27	0.16	27
Oil & natural gas	0.13	28	0.05	33
Other services	0.12	29	0.12	28
Mechanical engineering	0.08	30	0.10	31
Electrical engineering	0.08	31	0.12	29
Non-ferrous metal	0.04	32	0.26	21
Charcoal & fuel wood	0.03	33	0.04	34
Ship, train, aircraft	0.03	34	0.07	32
Average	0.33		0.36	

3.3 Embodied Energy (Final Demand)

The embodied energy (final demand) for the years 1985 and 1995 (excluding residential sector) are shown in Table 3-13 and Figure 3-2 in terms of 1,000 toe. It is noticeable that the top 8 economic sectors with high embodied energy (final demand) were the same in both years. Although most of the economic sectors had a large increase in their embodied energy (final demand) due to the economic growth during the ten-year period, some economic sectors such as non ferrous metal, oil & natural gas, coal mining, charcoal & fuel wood, and metallic mineral sectors decreased their embodied energy.

3.4 Direct Embodied Energy (Final Demand)

Table 3-14 represents direct embodied energy in the final demand of 34 economic sectors for the years 1985 and 1995. Oil products, electricity generation & distribution, food & allied, and land transport were top 4 sectors with high direct embodied energy (final demand) in both years. It can be observed that most of the economic sectors had increased their direct embodied energy (final demand) except for some sectors such as agriculture, forestry, fishing; timber & its product; and metallic mineral sectors. Although the share of the overall direct embodied energy (final demand) increased from 29.67% in 1985 to 30.95% in 1995, the overall indirect embodied energy of Thai economy had still large share in 1995 (69.05%) as in 1985 (70.33%). This indicated the strong environmental and economic interdependency between different economic sectors of Thai economy.

Table 3-13 Total embodied energy (final demand) in 1985 & 1995

Unit : 1,000 toe

Sectors	1995		1985	
	Energy	Rank	Energy	Rank
Construction	7,067.52	1	2,003.96	3
Oil products	6,362.86	2	1,234.81	5
Land transports	5,960.11	3	3,191.65	1
Food & allied	5,458.10	4	2,962.77	2
Electricity generation & distribution	5,100.64	5	1,562.02	4
Hotel & restaurant	3,465.65	6	1,009.85	6
Textile	3,442.88	7	884.09	8
Other services	2,480.85	8	1,005.97	7
Other manufacturing	2,200.05	9	315.23	13
Air & water transports	2,079.17	10	785.60	9
Wholesale & retail	2,071.40	11	517.43	12
Automobiles, bicycles	1,432.26	12	225.99	14
Rubber & plastics	1,234.83	13	176.63	17
Agriculture, forestry & fishing	1,052.39	14	521.11	11
Mechanical engineering	1,027.84	15	200.81	15
Drink & tobacco	1,020.62	16	529.52	10
Electrical engineering	842.43	17	147.99	18
Leather, etc.	617.65	18	65.28	22
Chemicals & fertilizers	497.51	19	180.34	16
Timber & its product	448.53	20	102.17	19
Gas distribution	317.19	21	0.03	34
Pulp, paper & printing	203.22	22	77.57	21
Ceramics	117.14	23	21.22	28
Non-metallic mineral	95.66	24	79.65	20
Cement	93.29	25	33.91	25
Ship, train, aircraft	87.79	26	26.72	27
Water supply & sanitation	87.46	27	48.47	24
Iron & steel	75.81	28	31.40	26
Non-ferrous metal	9.18	29	56.27	23
Bricks & tiles	9.08	30	6.54	32
Oil & natural gas	3.76	31	10.36	29
Coal mining	2.15	32	9.46	31
Charcoal & fuel wood	2.04	33	5.39	33
Metallic mineral	1.33	34	9.89	30
Overall	54,968.36		18,040.12	

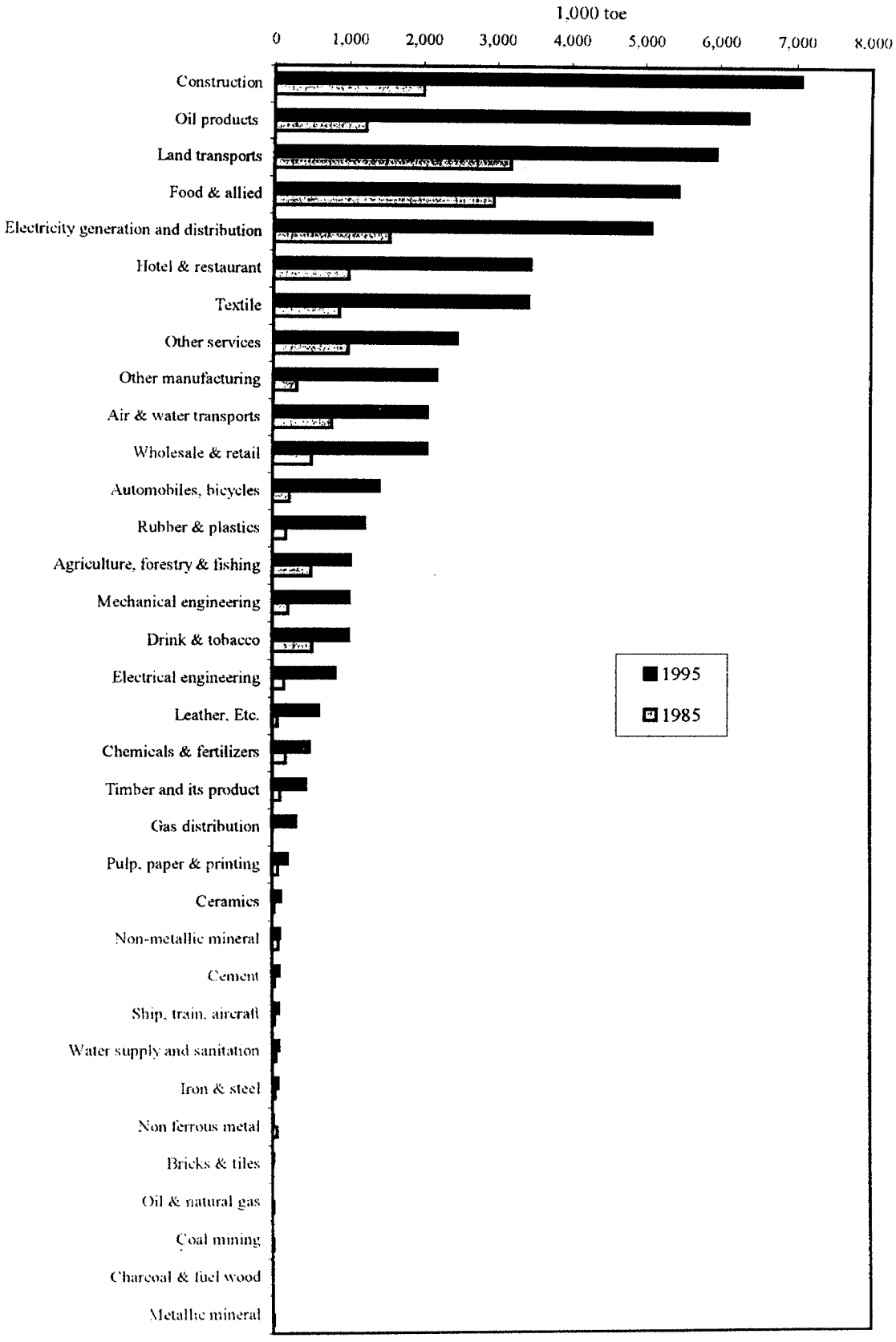

Figure 3-2 Embodied energy (final demand) in 1985 & 1995

Table 3-14 Direct embodied energy (final demand) in 1985 & 1995

Unit : 1,000 toe

Sectors	1995		1985	
	Energy	Rank	Energy	Rank
Oil products	6,162.67	1	1,144.38	3
Electricity generation & distribution	4,116.50	2	1,275.27	2
Food & allied	2,378.49	3	1,514.71	1
Land transports	1,303.94	4	484.16	4
Other manufacturing	1,127.35	5	151.64	7
Drink & tobacco	512.18	6	300.29	5
Rubber & plastics	423.19	7	68.91	10
Air & water transports	284.99	8	170.84	6
Gas distribution	267.49	9	0.03	23
Chemicals & fertilizers	221.67	10	69.19	9
Agriculture, forestry & fishing	66.20	11	87.25	8
Non-metallic mineral	32.52	12	27.29	11
Construction	29.06	13	20.23	12
Ceramics	22.35	14	4.93	15
Cement	21.29	15	5.92	14
Textile	20.58	16	12.79	13
Leather, etc.	7.28	17	1.13	21
Pulp, paper & printing	6.23	18	4.66	16
Iron & steel	3.20	19	2.39	18
Bricks & tiles	2.90	20	1.84	19
Mechanical engineering	1.43	21	0.00	28
Timber & its product	0.98	22	1.44	20
Electrical engineering	0.41	23	0.00	29
Charcoal & fuel wood	0.00	24	0.00	25
Coal mining	0.00	25	3.02	17
Oil & natural gas	0.00	26	0.00	26
Metallic mineral	0.00	27	0.15	22
Non-ferrous metal	0.00	28	0.00	27
Ship, train, aircraft	0.00	29	0.00	30
Automobiles, bicycles	0.00	30	0.00	31
Water supply & sanitation	0.00	31	0.00	32
Wholesale & retail	0.00	32	0.00	33
Hotel & restaurant	0.00	33	0.00	34
Other services	0.00	34	0.00	24
Overall	17,012.88		5,352.45	

4. CO_2 Intensities and Embodied CO_2 in 1985

4.1 Total CO_2 Intensities

Table 3-15 illustrates the total (direct plus indirect) CO_2 intensities (tCO_2/US$ 1,000) of various Thai economic sectors for the year 1985. The ranked top 10 economic sectors with high total CO_2 emission were electricity generation & distribution (11.26), land transports (3.27), gas distribution (3.23), cement (2.29), non-metallic mineral (1.88), bricks & tiles, ceramics, food & allied, agriculture & forestry & fishing, and other manufacturing. At the same time, the bottom 5 economic sectors with low CO_2 intensities were wholesale & retail (0.26), mechanical engineering (0.22), ship & train & aircraft (0.14), charcoal & fuel wood (0.08), and oil & natural gas(0.03), respectively. It can be noticed from Table 3-16 that the majority of the 35 economic sectors took much responsibility for CO_2 emission indirectly, compared to the same directly in producing a monetary unit of goods and services.

4.2 Direct CO_2 Intensities

Table 3-16 shows the ranked sector-wise direct CO_2 intensities (tCO_2/US$ 1,000) of 34 economic sectors. It is notable that 9 of the top 10 economic sectors with high direct CO_2 intensities were among top 10 economic sectors with high total CO_2 intensities. The sector not included was drink & tobacco. Electricity generation & distribution, land transports, gas distribution, cement, non-metallic mineral, and bricks & tiles were top 6 sectors in both direct and total CO_2 intensities rankings. The share of direct CO_2 intensities in 1985 was 47.52 % and the indirect one was 52.48 %.

4.3 Ratio of Embodied CO_2 to Embodied Energy (Final Demand)

The embodied CO_2 to embodied energy (final demand) ratio indicates the amount of CO_2 emitted from an economic sector in the consumption of one unit of energy. The ratio can be obtained by dividing the CO_2 intensity by the energy intensity of the same economic sector.

Table 3-17 illustrates the ranked ratio of embodied CO_2 to embodied energy (final demand)(tCO_2/toe) for different economic sectors for the year 1985. The top 10 economic sectors with high ratio were agriculture & forestry & fishing (4.71), other manufacturing (4.04), chemicals & fertilizers (3.96), leather & etc. (3.65), rubber & plastics (3.57), pulp & paper & printing, food

& allied, iron & steel, drink & tobacco, and non-metallic mineral, respectively. The bottom 5 sectors with low ratio were non-ferrous metal (1.27), metallic mineral (1.22), coal mining (0.90), oil & natural gas (0.61), and oil products (0.13). It is noticeable that 4 of the top 10 economic sectors with high ratio were among top 10 sectors with high total CO_2 intensities which were agriculture & forestry & fishing, other manufacturing, food & allied, and non-metallic mineral. The overall ratio in this year was 2.76 tCO_2/toe.

4.4 Embodied CO_2 (Final Demand)

Table 3-18 illustrates total embodied CO_2 in final demand (1,000 tCO_2) from various economic sectors in Thailand for the year 1985 (excluding residential sectors). The top 10 economic sectors with high total embodied CO_2 (final demand) were food & allied (10,087), land transport (9,616), construction (5,430), electricity generation & distribution (4,314), hotel & restaurant (3,072), textile, agriculture & forestry & fishing, other services, drink & tobacco, and other manufacturing, respectively. At the same time, 5 sectors with the lowest values were metallic mineral (12.0), charcoal & fuel wood (11.6), coal mining (8.5), oil & natural gas (6.3), and gas distribution (0.1), respectively. It is notable that the positions of economic sectors in the embodied CO_2 (final demand) ranking were almost same as in the embodied energy (final demand) ranking except for a minor change. This has indicated a strong interdependence of embodied energy (final demand) and the corresponding CO_2 in economic sectors. It is also interesting to note that 5 of the top 10 economic sectors with high embodied CO_2 (final demand) were among the top 10 sectors with high total CO_2 intensities in the same year.

The overall embodied CO_2 (final demand) in the year 1985, excluding residential sector, was 49,875 thousand tonnes while the overall emission including residential sector was summed to 85,614 thousand tonnes.

4.5 Direct Embodied CO_2 (Final Demand)

Table 3-19 exhibits direct and indirect embodied CO_2 (final demand) for 1985. It is notable that 7 of top 10 sectors with high direct embodied CO_2 (final demand) were also among top 10 sectors with high total embodied CO_2 (final demand). It is also noteworthy that most of the economic sectors were responsible for more CO_2 emission indirectly than directly. Indirect emissions shared 52.48% of total emissions compared to 47.52% shared by direct emissions.

Table 3-15 Total CO_2 intensities in 1985

Unit : tCO_2/US$ 1,000

Rank	Sectors	Intensities
1	Electricity generation & distribution	11.26
2	Land transports	3.27
3	Gas distribution	3.24
4	Cement	2.29
5	Non-metallic mineral	1.88
6	Bricks & tiles	1.84
7	Ceramics	1.56
8	Food & allied	1.55
9	Agriculture, forestry & fishing	1.25
10	Other manufacturing	1.20
11	Drink & tobacco	1.20
12	Construction	1.10
13	Water supply & sanitation	1.08
14	Rubber & plastics	0.96
15	Hotel & restaurant	0.93
16	Iron & steel	0.87
17	Pulp, paper & printing	0.85
18	Textile	0.81
19	Chemicals & fertilizers	0.81
20	Air & water transports	0.81
21	Leather, etc.	0.72
22	Timber & its product	0.58
23	Coal mining	0.42
24	Automobiles, bicycles	0.39
25	Non-ferrous metal	0.32
26	Metallic mineral	0.30
27	Oil products	0.30
28	Electrical engineering	0.29
29	Other services	0.29
30	Wholesale & retail	0.26
31	Mechanical engineering	0.22
32	Ship, train, aircraft	0.14
33	Charcoal & fuel wood	0.08
34	Oil & natural gas	0.03
	Average	1.01

Table 3-16 Direct and indirect CO_2 intensities in 1985

Unit : tCO_2/US$ 1,000

Rank	Sectors	Direct	Indirect	Total
1	Electricity generation & distribution	10.06	1.20	11.26
2	Land transports	2.95	0.32	3.27
3	Gas distribution	2.90	0.33	3.24
4	Cement	1.19	1.10	2.29
5	Non-metallic mineral	1.17	0.71	1.88
6	Bricks & tiles	1.08	0.77	1.84
7	Agriculture, forestry & fishing	0.83	0.42	1.25
8	Ceramics	0.83	0.73	1.56
9	Drink & tobacco	0.82	0.38	1.20
10	Food & allied	0.75	0.80	1.55
11	Other manufacturing	0.75	0.46	1.20
12	Air & water transports	0.58	0.23	0.81
13	Rubber & plastics	0.53	0.44	0.96
14	Chemicals & fertilizers	0.41	0.40	0.81
15	Iron & steel	0.40	0.47	0.87
16	Pulp, paper & printing	0.29	0.56	0.85
17	Oil products	0.11	0.19	0.30
18	Textile	0.08	0.73	0.81
19	Leather, etc.	0.07	0.65	0.72
20	Construction	0.07	1.02	1.10
21	Metallic mineral	0.06	0.24	0.30
22	Timber & its product	0.04	0.54	0.58
23	Automobiles, bicycles	0.01	0.39	0.39
24	Ship, train, aircraft	0.00	0.14	0.14
25	Mechanical engineering	0.00	0.22	0.22
26	Electrical engineering	0.00	0.29	0.29
27	Charcoal & fuel wood	0.00	0.08	0.08
28	Coal mining	0.00	0.42	0.42
29	Oil & natural gas	0.00	0.03	0.03
30	Non ferrous metal	0.00	0.32	0.32
31	Water supply & sanitation	0.00	1.08	1.08
32	Wholesale & retail	0.00	0.26	0.26
33	Hotel & restaurant	0.00	0.93	0.93
34	Other services	0.00	0.29	0.29
	Average	0.48	0.53	1.01
	%	47.52	52.48	100.00

Table 3-17 Ratio of embodied CO_2 to embodied energy (final demand) in 1985

Unit : tCO_2 / toe

Rank	Sectors	Ratio
1	Agriculture, forestry & fishing	4.71
2	Other manufacturing	4.04
3	Chemicals & fertilizers	3.96
4	Leather, etc.	3.65
5	Rubber & plastics	3.57
6	Pulp, paper & printing	3.56
7	Food & allied	3.40
8	Iron & steel	3.39
9	Drink & tobacco	3.39
10	Non-metallic mineral	3.20
11	Hotel & restaurant	3.04
12	Textile	3.03
13	Land transports	3.01
14	Bricks & tiles	2.80
15	Electricity generation & distribution	2.76
16	Construction	2.71
17	Timber & its product	2.57
18	Ceramics	2.55
19	Electrical engineering	2.47
20	Automobiles, bicycles	2.42
21	Water supply & sanitation	2.41
22	Other services	2.35
23	Mechanical engineering	2.31
24	Wholesale & retail	2.30
25	Gas distribution	2.24
26	Charcoal & fuel wood	2.15
27	Ship, train, aircraft	2.08
28	Cement	1.99
29	Air & water transports	1.48
30	Non-ferrous metal	1.27
31	Metallic mineral	1.22
32	Coal mining	0.90
33	Oil & natural gas	0.61
34	Oil products	0.13
	Overall	2.76

Table 3-18 Embodied CO_2 (final demand) in 1985

Unit : 1,000 tCO_2

Rank	Sectors	Emb. CO_2
1	Food & allied	10,087.14
2	Land transports	9,615.56
3	Construction	5,429.86
4	Electricity generation & distribution	4,313.81
5	Hotel & restaurant	3,071.65
6	Textile	2,675.42
7	Agriculture, forestry & fishing	2,454.52
8	Other services	2,364.84
9	Drink & tobacco	1,794.78
10	Other manufacturing	1,272.24
11	Wholesale & retail	1,191.42
12	Air & water transports	1,162.79
13	Chemicals & fertilizers	714.89
14	Rubber & plastics	630.34
15	Automobiles, bicycles	547.00
16	Mechanical engineering	464.60
17	Electrical engineering	364.81
18	Pulp, paper & printing	275.77
19	Timber & its product	262.12
20	Non-metallic mineral	254.96
21	Leather, etc.	238.36
22	Oil products	159.07
23	Water supply & sanitation	116.89
24	Iron & steel	106.47
25	Non-ferrous metal	71.23
26	Cement	67.41
27	Ship, train, aircraft	55.65
28	Ceramics	54.18
29	Bricks & tiles	18.34
30	Metallic mineral	12.01
31	Charcoal & fuel wood	11.62
32	Coal mining	8.52
33	Oil & natural gas	6.33
34	Gas distribution	0.07
	Overall	49,874.68

Table 3-19 Direct and indirect embodied CO_2 (final demand) in 1985

Unit : 1,000 tCO_2

Rank	Sectors	Direct	Indirect	Total
1	Land transports	8,675.57	940.00	9,615.56
2	Food & allied	4,871.92	5,215.22	10,087.14
3	Electricity generation & distribution	3,853.96	459.85	4,313.81
4	Agriculture, forestry & fishing	1,626.48	828.04	2,454.52
5	Drink & tobacco	1,227.59	567.19	1,794.78
6	Air & water transports	837.47	325.32	1,162.79
7	Other manufacturing	787.93	484.31	1,272.24
8	Chemicals & fertilizers	363.08	351.81	714.89
9	Construction	361.77	5,068.09	5,429.86
10	Rubber & plastics	345.14	285.20	630.34
11	Textile	252.30	2,423.12	2,675.42
12	Non-metallic mineral	158.29	96.67	254.96
13	Pulp, paper & printing	92.67	183.10	275.77
14	Oil products	60.26	98.80	159.07
15	Iron & steel	49.21	57.26	106.47
16	Cement	34.95	32.47	67.41
17	Ceramics	28.89	25.29	54.18
18	Leather, etc.	24.46	213.90	238.36
19	Timber & its product	16.67	245.45	262.12
20	Bricks & tiles	10.71	7.63	18.34
21	Mechanical engineering	7.66	456.94	464.60
22	Automobiles, bicycles	7.57	539.43	547.00
23	Electrical engineering	3.00	361.81	364.81
24	Metallic mineral	2.50	9.51	12.01
25	Ship, train, aircraft	1.49	54.17	55.65
26	Gas distribution	0.06	0.01	0.07
27	Charcoal & fuel wood	0.00	11.62	11.62
28	Coal mining	0.00	8.52	8.52
29	Oil & natural gas	0.00	6.33	6.33
30	Non ferrous metal	0.00	71.23	71.23
31	Water supply & sanitation	0.00	116.89	116.89
32	Wholesale & retail	0.00	1,191.42	1,191.42
33	Hotel & restaurant	0.00	3,071.65	3,071.65
34	Other services	0.00	2,364.84	2,364.84
	Overall	23,701.61	26,173.07	49,874.68
	%	47.52	52.48	100.00

5. CO_2 Intensities and Embodied CO_2 in 1995

5.1 Total CO_2 Intensities

Table 3-20 demonstrates the total CO_2 intensities in terms of tCO_2/US$ 1,000 of Thai economic sectors for the year 1995. The top 10 economic sectors with high total CO_2 intensities were electricity generation & distribution (9.89), land transport (3.68), gas distribution (2.38), cement (1.97), bricks and tiles (1.41), non-metallic mineral, ceramics, food & allied, other manufacturing, and rubber & plastics, respectively. On the other hand, the bottom 5 sectors with low intensities were metallic mineral (0.07), charcoal & fuel wood (0.05), oil & natural gas (0.04), non-ferrous metal (0.04), and ship & train & aircraft (0.03), respectively. Table 3-21 reveals that a majority of the 34 economic sectors were responsible for indirect embodied CO_2 more than direct embodied CO_2 in producing their products.

5.2 Direct CO_2 Intensities

Referred to Table 3-21, it can be seen that 9 of the top 10 sectors with high direct CO_2 intensities were among the top 10 sectors with high total CO_2 intensities except drink & tobacco sector. Electricity generation & distribution , land transports, and gas distribution were in the top three positions in both intensity rankings. In 1995, the shares of direct and indirect CO_2 intensities were 41.17 % and 58.83 % of total intensities, respectively.

5.3 Embodied CO_2 to Embodied Energy Ratio

Table 3-22 illustrates the embodied CO_2 to embodied energy (final demand) ratio (tCO_2/toe) for the year 1995. The top 10 economic sectors with high ratio were land transports (4.94), other manufacturing (4.80), leather & etc. (3.80), automobile & bicycles (3.54), chemical & fertilizers (3.52), construction, pulp & paper & printing, drink & tobacco, rubber & plastics, and textile, respectively. It is notable that 3 of the top 10 sectors with high ratio were in the top 10 sectors with high total CO_2 intensities as well. These sectors were land transports, other manufacturing, and rubber & plastics. The overall ratio for the year 1995 was 2.88 tCO_2/toe. It is also notable that agriculture & forestry & fishing sector that ranked 1st in 1985 fell to 19th position in 1995. This sector had a large decrease in the total CO_2 intensity in 1995 compared to 1985.

Table 3-20 Total CO_2 intensities in 1995

Unit : tCO_2/US$ 1,000

Rank	Sectors	Intensities
1	Electricity generation & distribution	9.89
2	Land transports	3.68
3	Gas distribution	2.38
4	Cement	1.97
5	Bricks & tiles	1.41
6	Non-metallic mineral	1.39
7	Ceramics	1.01
8	Food & allied	0.89
9	Other manufacturing	0.88
10	Rubber & plastics	0.83
11	Construction	0.74
12	Textile	0.70
13	Water supply & sanitation	0.69
14	Hotel & restaurant	0.69
15	Drink & tobacco	0.59
16	Coal mining	0.49
17	Chemicals & fertilizers	0.49
18	Agriculture, forestry & fishing	0.46
19	Timber & its product	0.41
20	Leather, etc.	0.40
21	Iron & steel	0.40
22	Pulp, paper & printing	0.36
23	Air & water transports	0.31
24	Automobiles, bicycles	0.29
25	Wholesale & retail	0.21
26	Other services	0.19
27	Electrical engineering	0.15
28	Oil products	0.13
29	Mechanical engineering	0.13
30	Metallic mineral	0.07
31	Charcoal & fuel wood	0.05
32	Oil & natural gas	0.04
33	Non-ferrous metal	0.04
34	Ship, train, aircraft	0.03
	Average	0.60

Table 3-21 Direct and indirect CO_2 intensities in 1995

Unit : tCO_2/US$ 1,000

Rank	Sectors	Direct	Indirect	Total
1	Electricity generation & distribution	9.03	0.86	9.89
2	Land transports	3.46	0.22	3.68
3	Gas distribution	2.09	0.29	2.38
4	Bricks & tiles	0.82	0.59	1.41
5	Cement	0.79	1.17	1.97
6	Non-metallic mineral	0.71	0.68	1.39
7	Other manufacturing	0.58	0.29	0.88
8	Food & allied	0.38	0.51	0.89
9	Rubber & plastics	0.36	0.46	0.83
10	Drink & tobacco	0.35	0.24	0.59
11	Ceramics	0.34	0.67	1.01
12	Chemicals & fertilizers	0.27	0.22	0.49
13	Agriculture, forestry & fishing	0.24	0.22	0.46
14	Air & water transports	0.15	0.16	0.31
15	Iron & steel	0.10	0.30	0.40
16	Oil products	0.07	0.06	0.13
17	Pulp, paper & printing	0.06	0.31	0.36
18	Textile	0.04	0.66	0.70
19	Leather, etc.	0.03	0.37	0.40
20	Construction	0.03	0.71	0.74
21	Timber & its product	0.01	0.39	0.41
22	Metallic mineral	0.01	0.07	0.07
23	Mechanical engineering	0.01	0.13	0.13
24	Electrical engineering	0.01	0.14	0.15
25	Automobiles, bicycles	0.00	0.28	0.29
26	Ship, train, aircraft	0.00	0.03	0.03
27	Charcoal & fuel wood	0.00	0.05	0.05
28	Coal mining	0.00	0.49	0.49
29	Oil & natural gas	0.00	0.04	0.04
30	Non-ferrous metal	0.00	0.04	0.04
31	Water supply & sanitation	0.00	0.69	0.69
32	Wholesale & retail	0.00	0.21	0.21
33	Hotel & restaurant	0.00	0.69	0.69
34	Other services	0.00	0.19	0.19
	Average	0.25	0.35	0.60
	%	41.17	58.83	100.00

Table 3-22 Ratio of embodied CO_2 to embodied energy (final demand) in 1995

Unit : tCO_2/toe

Rank	Sectors	Ratio
1	Land transports	4.94
2	Other manufacturing	4.80
3	Leather, etc.	3.80
4	Automobiles, bicycles	3.54
5	Chemicals & fertilizers	3.52
6	Construction	3.42
7	Pulp, paper & printing	3.42
8	Drink & tobacco	3.38
9	Rubber & plastics	3.35
10	Textile	3.31
11	Iron & steel	3.19
12	Electrical engineering	3.09
13	Timber & its product	2.97
14	Food & allied	2.89
15	Hotel & restaurant	2.87
16	Non-metallic mineral	2.87
17	Electricity generation & distribution	2.86
18	Mechanical engineering	2.72
19	Agriculture, forestry & fishing	2.69
20	Ceramics	2.67
21	Cement	2.65
22	Bricks & tiles	2.58
23	Other services	2.56
24	Water supply & sanitation	2.55
25	Wholesale & retail	2.41
26	Charcoal & fuel wood	2.38
27	Gas distribution	2.20
28	Coal mining	2.00
29	Non-ferrous metal	1.89
30	Ship, train, aircraft	1.88
31	Metallic mineral	0.80
32	Air & water transports	0.64
33	Oil & natural gas	0.53
34	Oil products	0.06
	Overall	2.88

5.4 Embodied CO_2 (Final Demand)

Referred to Table 3-23, the top 10 economic sectors with high embodied CO_2 emission (1,000 tCO_2) in 1995 were land transport (29,445), construction (24,177), food and allied (15,765), electricity generation & distribution (14,567), textile (11,395), other manufacturing, hotel & restaurant, other services, automobiles & bicycles, and wholesale & retail, respectively. It is notable that there was a strong relationship between energy consumption and CO_2 emission as the positions of economic sectors in total embodied energy (final demand) ranking and embodied CO_2 ranking were almost the same, except some minor changes. It is interesting to note that among top 10 sectors with high CO_2 intensities, 4 sectors were also in the top 10 positions with high embodied CO_2 (final demand).

The overall total embodied CO_2 (final demand) in Thai economic sectors in 1995 (excluding residential sectors) was 158,088 thousand tonnes. The overall amount including residential sector was 202,275 thousand tonnes.

5.5 Direct Embodied CO_2 (Final demand)

Table 3-24 demonstrates direct and indirect embodied CO_2 in the final demand of 34 economic sectors in 1995. It is notable that 6 out of top 10 sectors with high direct embodied CO_2 were among top 10 sectors with high total embodied CO_2. The sectors not included were drink & tobacco, rubber & plastics, agriculture & forestry & fishing, and chemicals & fertilizers. It is also interesting to note that in a majority of the 34 economic sectors were responsible for more embodied CO_2 indirectly than directly. The shares of indirect and direct embodied CO_2 were in percentages of 58.83 % and 41.17 %, respectively.

5.6 CO_2 Intensities in 1995 with Modification

Table 3-25 represents the modified total CO_2 intensities for the year 1995, based on 1985 constant price. The total intensity of each economic sector was changed uniformly according to the difference in the customer price indices as well as the overall values. Thus, the position of each sector in the rankings, and the shares of direct and indirect CO_2 intensities were still the same.

Table 3-23 Embodied CO_2 (final demand) in 1995

Unit : 1,000 tCO_2

Rank	Sector Description	Embodied
1	Land transports	29,444.94
2	Construction	24,177.02
3	Food & allied	15,765.25
4	Electricity generation & distribution	14,567.48
5	Textile	11,394.97
6	Other manufacturing	10,554.70
7	Hotel & restaurant	9,943.03
8	Other services	6,342.37
9	Automobiles, bicycles	5,074.03
10	Wholesale & retail	4,989.30
11	Rubber & plastics	4,139.56
12	Drink & tobacco	3,447.95
13	Agriculture, forestry & fishing	2,827.28
14	Mechanical engineering	2,798.94
15	Electrical engineering	2,605.41
16	Leather, etc.	2,348.68
17	Chemicals & fertilizers	1,748.87
18	Timber & its product	1,331.32
19	Air & water transports	1,324.96
20	Gas distribution	697.22
21	Pulp, paper & printing	694.28
22	Oil products	354.05
23	Ceramics	312.88
24	Non-metallic mineral	274.12
25	Cement	246.99
26	Iron & steel	242.15
27	Water supply & sanitation	222.63
28	Ship, train, aircraft	165.01
29	Bricks & tiles	23.46
30	Non-ferrous metal	17.33
31	Charcoal & fuel wood	4.84
32	Coal mining	4.31
33	Oil & natural gas	2.00
34	Metallic mineral	1.07
	Overall	158,088.41

Table 3-24 Direct and indirect embodied CO_2 (final demand) in 1995

Unit : 1,000 tCO_2

Rank	Sectors	Direct	Indirect	Total
1	Land transports	27,696.19	1,748.75	29,444.94
2	Electricity generation & distribution	13,296.91	1,270.57	14,567.48
3	Other manufacturing	7,027.60	3,527.10	10,554.70
4	Food & allied	6,763.71	9,001.53	15,765.25
5	Drink & tobacco	2,061.94	1,386.01	3,447.95
6	Rubber & plastics	1,821.22	2,318.35	4,139.56
7	Agriculture, forestry & fishing	1,456.97	1,370.31	2,827.28
8	Chemicals & fertilizers	953.94	794.93	1,748.87
9	Construction	836.69	23,340.33	24,177.02
10	Textile	670.84	10,724.13	11,394.97
11	Air & water transports	639.56	685.40	1,324.96
12	Gas distribution	611.72	85.51	697.22
13	Leather, etc.	196.12	2,152.56	2,348.68
14	Oil products	184.80	169.25	354.05
15	Non-metallic mineral	140.55	133.56	274.12
16	Mechanical engineering	110.57	2,688.37	2,798.94
17	Pulp, paper & printing	106.11	588.17	694.28
18	Ceramics	104.81	208.07	312.88
19	Cement	99.55	147.44	246.99
20	Electrical engineering	89.23	2,516.18	2,605.41
21	Automobiles, bicycles	76.05	4,997.98	5,074.03
22	Iron & steel	63.10	179.05	242.15
23	Timber & its product	47.88	1,283.44	1,331.32
24	Bricks & tiles	13.68	9.78	23.46
25	Ship, train, aircraft	11.94	153.07	165.01
26	Metallic mineral	0.11	0.96	1.07
27	Charcoal & fuel wood	0.00	4.84	4.84
28	Coal mining	0.00	4.31	4.31
29	Oil & natural gas	0.00	2.00	2.00
30	Non ferrous metal	0.00	17.33	17.33
31	Water supply & sanitation	0.00	222.63	222.63
32	Wholesale & retail	0.00	4,989.30	4,989.30
33	Hotel & restaurant	0.00	9,943.03	9,943.03
34	Other services	0.00	6,342.37	6,342.37
	Overall	65,081.79	93,006.62	158,088.41
	%	41.17	58.83	100.00

Table 3-25 Total CO_2 intensities in 1995 (modified)

Unit : tCO_2/US$ 1,000

Rank	Sectors	Intensities
1	Electricity generation & distribution	15.51
2	Land transports	5.77
3	Gas distribution	3.73
4	Cement	3.08
5	Bricks & tiles	2.21
6	Non-metallic mineral	2.17
7	Ceramics	1.59
8	Food & allied	1.40
9	Other manufacturing	1.37
10	Rubber & plastics	1.30
11	Construction	1.16
12	Textile	1.10
13	Water supply & sanitation	1.09
14	Hotel & restaurant	1.07
15	Drink & tobacco	0.93
16	Coal mining	0.77
17	Chemicals & fertilizers	0.77
18	Agriculture, forestry & fishing	0.73
19	Timber & its product	0.64
20	Leather, etc.	0.63
21	Iron & steel	0.63
22	Pulp, paper & printing	0.57
23	Air & water transports	0.48
24	Automobiles, bicycles	0.45
25	Wholesale & retail	0.32
26	Other services	0.30
27	Electrical engineering	0.23
28	Oil products	0.21
29	Mechanical engineering	0.21
30	Metallic mineral	0.12
31	Charcoal & fuel wood	0.07
32	Oil & natural gas	0.07
33	Non-ferrous metal	0.07
34	Ship, train, aircraft	0.05
	Average	0.94

6. Comparison of CO_2 Intensities and Embodied CO_2 between the Years 1985 and 1995

6.1 Total CO_2 Intensities

Table 3-26 and Figure 3-3 illustrate the comparison of total CO_2 intensities of 34 economic sectors for the years 1985 and 1995. It is noticeable that 9 of the top 10 sectors with high total CO_2 intensities in 1995 were among top 10 sectors of the same in 1985. The economic sector excluded was agriculture & forestry & fishing. This sector ranked 9th in 1985 and fell to 18th position in 1995 with large reduction in the total CO_2 intensity.

Despite a decrease in overall total CO_2 intensities as well as intensities of many economic sectors, increase for some sectors such as land transports is notable for the year 1995. The main cause was due to the increase in direct CO_2 intensity of this sector. Among the sectors with high total CO_2 intensities in 1995 and 1985, electricity generation & distribution sector's CO_2 intensity is remarkably high and it's total CO_2 intensity ranked first for both years.

6.2 Direct Carbon-dioxide Intensities

With reference to Table 3-27, it can be observed that among top 10 economic sectors with high direct CO_2 intensities in 1985, 8 sectors were in top 10 positions in 1995. While some sectors such as food & allied, drink & tobacco, ceramics, and agriculture & forestry & fishing had a substantial reduction in their direct CO_2 intensities. A decrease in average direct intensities as well as in direct intensities of many sectors can be observed. However, an increase in some sectors is noticeable such as land transports. At the same time, it is worthy to note that the share of direct CO_2 intensities decreased in 1995 compared to 1985, and the average indirect intensities had a large share of 58.80% in 1995 as of 52.49% in 1985.

6.3 Ratio of Embodied Carbon-dioxide to Embodied Energy

Due to increase in consumption of carbon-intensive fuels in economic sectors, the overall embodied CO_2 to embodied energy (final demand) ratio increased from 2.76 tCO_2/toe in 1985 to 2.88 tCO_2/toe in 1995 as well as the ratios for many economic sectors, as shown in Table 3-28. This was the reflection of changes in fuel mix ratios or embodied CO_2 to embodied energy (final demand) ratios in those sectors.

Table 3-26 Total CO_2 intensities in 1985 & 1995

Unit : $tCO_2/US\$\ 1,000$

Sectors	1995		1985	
	Intensities	Rank	Intensities	Rank
Electricity generation & distribution	9.89	1	11.26	1
Land transports	3.68	2	3.27	2
Gas distribution	2.38	3	3.24	3
Cement	1.97	4	2.29	4
Bricks & tiles	1.41	5	1.84	6
Non-metallic mineral	1.39	6	1.88	5
Ceramics	1.01	7	1.56	7
Food & allied	0.89	8	1.55	8
Other manufacturing	0.88	9	1.20	10
Rubber & plastics	0.83	10	0.96	14
Construction	0.74	11	1.10	12
Textile	0.70	12	0.81	18
Water supply & sanitation	0.69	13	1.08	13
Hotel & restaurant	0.69	14	0.93	15
Drink & tobacco	0.59	15	1.20	11
Coal mining	0.49	16	0.42	23
Chemicals & fertilizers	0.49	17	0.81	19
Agriculture, forestry & fishing	0.46	18	1.25	9
Timber & its product	0.41	19	0.58	22
Leather, etc.	0.40	20	0.72	21
Iron & steel	0.40	21	0.87	16
Pulp, paper & printing	0.36	22	0.85	17
Air & water transports	0.31	23	0.81	20
Automobiles, bicycles	0.29	24	0.39	24
Wholesale & retail	0.21	25	0.26	30
Other services	0.19	26	0.29	29
Electrical engineering	0.15	27	0.29	28
Oil products	0.13	28	0.30	27
Mechanical engineering	0.13	29	0.22	31
Metallic mineral	0.07	30	0.30	26
Charcoal & fuel wood	0.05	31	0.08	33
Oil & natural gas	0.04	32	0.03	34
Non-ferrous metal	0.04	33	0.32	25
Ship, train, aircraft	0.03	34	0.14	32
Average	0.60		1.01	

Figure 3-3 Total CO_2 intensities in 1985 & 1995

Table 3-27 Direct CO_2 intensities in 1985 & 1995

Unit : tCO_2/US$ 1,000

Sectors	1995		1985	
	Intensities	Rank	Intensities	Rank
Electricity generation & distribution	9.03	1	10.06	1
Land transports	3.46	2	2.95	2
Gas distribution	2.09	3	2.90	3
Bricks & tiles	0.82	4	1.08	6
Cement	0.79	5	1.19	4
Non-metallic mineral	0.71	6	1.17	5
Other manufacturing	0.58	7	0.75	11
Food & allied	0.38	8	0.75	10
Rubber & plastics	0.36	9	0.53	13
Drink & tobacco	0.35	10	0.82	9
Ceramics	0.34	11	0.83	8
Chemicals & fertilizers	0.27	12	0.41	14
Agriculture, forestry & fishing	0.24	13	0.83	7
Air & water transports	0.15	14	0.58	12
Iron & steel	0.10	15	0.40	15
Oil products	0.07	16	0.11	17
Pulp, paper & printing	0.06	17	0.29	16
Textile	0.04	18	0.08	18
Leather, etc.	0.03	19	0.07	19
Construction	0.03	20	0.07	20
Timber & its product	0.01	21	0.04	22
Metallic mineral	0.01	22	0.06	21
Mechanical engineering	0.01	23	0.00	25
Electrical engineering	0.01	24	0.00	26
Automobiles, bicycles	0.00	25	0.01	23
Ship, train, aircraft	0.00	26	0.00	24
Charcoal & fuel wood	0.00	27	0.00	27
Coal mining	0.00	28	0.00	28
Oil & natural gas	0.00	29	0.00	29
Non-ferrous metal	0.00	30	0.00	30
Water supply & sanitation	0.00	31	0.00	31
Wholesale & retail	0.00	32	0.00	32
Hotel & restaurant	0.00	33	0.00	33
Other services	0.00	34	0.00	34
Average	0.25		0.48	

Table 3-28 Embodied CO_2 to embodied energy (final demand) ratio in 1985 & 1995

Unit : tCO_2/toe

Sectors	1995		1985	
	Ratio	Rank	Ratio	Rank
Land transports	4.94	1	3.01	13
Other manufacturing	4.80	2	4.04	2
Leather, etc.	3.80	3	3.65	4
Automobiles, bicycles	3.54	4	2.42	20
Chemicals & fertilizers	3.52	5	3.96	3
Construction	3.42	6	2.71	16
Pulp, paper & printing	3.42	7	3.56	6
Drink & tobacco	3.38	8	3.39	9
Rubber & plastics	3.35	9	3.57	5
Textile	3.31	10	3.03	12
Iron & steel	3.19	11	3.39	8
Electrical engineering	3.09	12	2.47	19
Timber & its product	2.97	13	2.57	17
Food & allied	2.89	14	3.40	7
Hotel & restaurant	2.87	15	3.04	11
Non-metallic mineral	2.87	16	3.20	10
Electricity generation & distribution	2.86	17	2.76	15
Mechanical engineering	2.72	18	2.31	23
Agriculture, forestry & fishing	2.69	19	4.71	1
Ceramics	2.67	20	2.55	18
Cement	2.65	21	1.99	28
Bricks & tiles	2.58	22	2.80	14
Other services	2.56	23	2.35	22
Water supply & sanitation	2.55	24	2.41	21
Wholesale & retail	2.41	25	2.30	24
Charcoal & fuel wood	2.38	26	2.15	26
Gas distribution	2.20	27	2.24	25
Coal mining	2.00	28	0.90	32
Non-ferrous metal	1.89	29	1.27	30
Ship, train, aircraft	1.88	30	2.08	27
Metallic mineral	0.80	31	1.22	31
Air & water transports	0.64	32	1.48	29
Oil & natural gas	0.53	33	0.61	33
Oil products	0.06	34	0.13	34
Overall	2.88		2.76	

6.4 Embodied CO_2 (Final Demand)

Table 3-29 and Figure 3-4 illustrate embodied CO_2 (final demand) for the years 1985 and 1995. The overall embodied CO_2 as well as embodied CO_2 of each economic sectors substantially increased in 1995 compared to 1985 due to economic growth in the ten-year period. However, there were some sectors such as non-ferrous metal, charcoal & fuel wood, coal mining, oil & natural gas, and metallic mineral with decreased embodied CO_2. It is interesting to note that the top 10 sectors with high embodied CO_2 were almost the same in both years with a nominal change in ranking. Change in fuel mix ratios in those economic sectors might have increased their CO_2 to embodied energy ratios.

6.5 Direct Embodied CO_2 (Final Demand)

With reference to Table 3-30, it is notable that 9 of the top 10 economic sectors with high direct embodied CO_2 (final demand) in 1995 were among top 10 sectors with the same in 1985. The sector not included was textile. Gas distribution sector that ranked 26th in 1985 jumped up to 12th position in 1995 with a large increase in direct embodied CO_2 (final demand). It is also notable that the share of overall direct embodied CO_2 (final demand) decreased in 1995 (41.17 %) compared to 1985 (47.52%), thus, overall indirect embodied CO_2 (final demand) still had a large share in 1995 (58.83%). This indicated a strong economic and environmental interdependence among various economic sectors of the Thai economy.

Table 3-29 Embodied CO_2 (final demand) in 1985 & 1995

Unit : 1,000 tCO_2

Sectors	1995		1985	
	Emb. CO_2	Rank	Emb. CO_2	Rank
Land transports	29,444.94	1	9,615.56	2
Construction	24,177.02	2	5,429.86	3
Food & allied	15,765.25	3	10,087.14	1
Electricity generation & distribution	14,567.48	4	4,313.81	4
Textile	11,394.97	5	2,675.42	6
Other manufacturing	10,554.70	6	1,272.24	10
Hotel & restaurant	9,943.03	7	3,071.65	5
Other services	6,342.37	8	2,364.84	8
Automobiles, bicycles	5,074.03	9	547.00	15
Wholesale & retail	4,989.30	10	1,191.42	11
Rubber & plastics	4,139.56	11	630.34	14
Drink & tobacco	3,447.95	12	1,794.78	9
Agriculture, forestry & fishing	2,827.28	13	2,454.52	7
Mechanical engineering	2,798.94	14	464.60	16
Electrical engineering	2,605.41	15	364.81	17
Leather, etc.	2,348.68	16	238.36	21
Chemicals & fertilizers	1,748.87	17	714.89	13
Timber & its product	1,331.32	18	262.12	19
Air & water transports	1,324.96	19	1,162.79	12
Gas distribution	697.22	20	0.07	34
Pulp, paper & printing	694.28	21	275.77	18
Oil products	354.05	22	159.07	22
Ceramics	312.88	23	54.18	28
Non-metallic mineral	274.12	24	254.96	20
Cement	246.99	25	67.41	26
Iron & steel	242.15	26	106.47	24
Water supply & sanitation	222.63	27	116.89	23
Ship, train, aircraft	165.01	28	55.65	27
Bricks & tiles	23.46	29	18.34	29
Non-ferrous metal	17.33	30	71.23	25
Charcoal & fuel wood	4.84	31	11.62	31
Coal mining	4.31	32	8.52	32
Oil & natural gas	2.00	33	6.33	33
Metallic mineral	1.07	34	12.01	30
Overall	158,088.41		49,874.68	

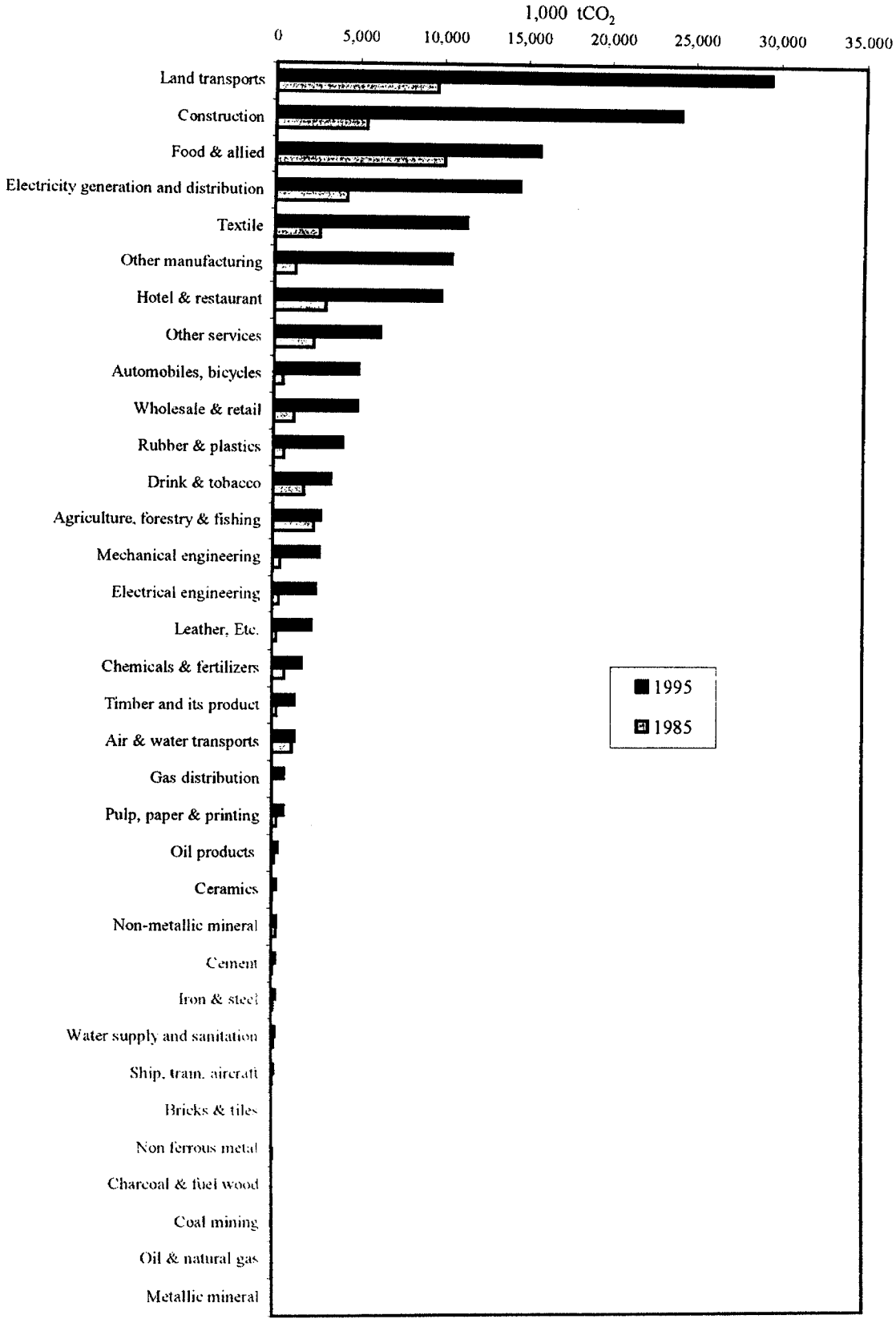

Figure 3-4 Embodied CO_2 (final demand) in 1985 & 1995

Table 3-30 Direct embodied CO_2 (final demand) in 1985 & 1995

Unit : 1,000 tCO_2

Sectors	1995		1985	
	Emb. CO_2	Rank	Emb. CO_2	Rank
Land transports	27,696.19	1	8,675.57	1
Electricity generation & distribution	13,296.91	2	3,853.96	3
Other manufacturing	7,027.60	3	787.93	7
Food & allied	6,763.71	4	4,871.92	2
Drink & tobacco	2,061.94	5	1,227.59	5
Rubber & plastics	1,821.22	6	345.14	10
Agriculture, forestry & fishing	1,456.97	7	1,626.48	4
Chemicals & fertilizers	953.94	8	363.08	8
Construction	836.69	9	361.77	9
Textile	670.84	10	252.30	11
Air & water transports	639.56	11	837.47	6
Gas distribution	611.72	12	0.06	26
Leather, etc.	196.12	13	24.46	18
Oil products	184.80	14	60.26	14
Non-metallic mineral	140.55	15	158.29	12
Mechanical engineering	110.57	16	7.66	21
Pulp, paper & printing	106.11	17	92.67	13
Ceramics	104.81	18	28.89	17
Cement	99.55	19	34.95	16
Electrical engineering	89.23	20	3.00	23
Automobiles, bicycles	76.05	21	7.57	22
Iron & steel	63.10	22	49.21	15
Timber & its product	47.88	23	16.67	19
Bricks & tiles	13.68	24	10.71	20
Ship, train, aircraft	11.94	25	1.49	25
Metallic mineral	0.11	26	2.50	24
Charcoal & fuel wood	0.00	27	0.00	27
Coal mining	0.00	28	0.00	28
Oil & natural gas	0.00	29	0.00	29
Non-ferrous metal	0.00	30	0.00	30
Water supply & sanitation	0.00	31	0.00	31
Wholesale & retail	0.00	32	0.00	32
Hotel & restaurant	0.00	33	0.00	33
Other services	0.00	34	0.00	34
Overall	65,081.79		23,701.61	

7. Notable Economic Sectors

As described in the previous sub-sections, apart from energy sectors such as oil products, electricity generation and distribution, and gas distribution, economic sectors with substantial high total energy or CO_2 intensities and/or embodied energy or corresponding CO_2 (final demand) for the year 1995 were cement, food & allied, construction, and land transports. These sectors were so-called energy intensive sectors.

7.1 Oil Products Sector

There are eleven petroleum oil refinery plants in Thailand with total refining capacity of about 900 thousand barrels per day in the year 2000 (Department of Industrial Works, 2000). Direct embodied energy in this sector in the forms of crude oil, natural gas and oil products accounted for 96.85 % of embodied energy (final demand). Indirect energy included coal, natural gas, crude oil, and oil products. The energy intensities as well as embodied energy (final demand) in the year 1995 were substantial high compared to other economic sectors. The total and direct energy intensities were 2.41 and 2.34 toe/US$ 1,000, respectively. The embodied energy (final demand) and corresponding CO_2 of this sector were 6.36 Mtoe and 0.35 $MtCO_2$, that accounted for 9.79 % and 0.18 % of overall embodied energy and corresponding CO_2 (final demand) including residential sector.

As reported by the Department of Energy Development and Promotion (2000), the energy loss in transformation process in 1999 was 13.46 % with an increase of 1.82 % from the previous year. According to Thailand Energy Development Plans, annual energy consumption demand will increase in the rate of 4.7 % during the year 2002 to 2006, and 5.3 % during the year 2007 to 2011. It is clearly seen that the amount of loss in energy transformation will be significantly increased. Hence, reduction of this loss by methods such as the use of modern technologies with less wastes and loss or application of waste recycling system would be important not only in loss reduction but also in energy conservation and corresponding CO_2 reduction.

7.2 Electricity Generation and Distribution Sector

In Thailand there are several types of electricity generation systems such as hydro power, thermal energy, co-generation, gas turbine, diesel turbine, wind power turbine, geo-

thermal energy, and solar cell. In 1999, total electricity consumption was 6,941 ktoe, an increase of 1.3 % over the previous year and accounted for 14.6 % of the final energy consumption (DEDP, 2000). In 1995 the total CO_2 intensity of this sector was extremely high (9.89 tCO_2/US$ 1,000) compared to other economic sectors and it induced embodied CO_2 (final demand) of 14.57 $MtCO_2$. Direct embodied energy (final demand) that accounted for 80.71 % of embodied energy (final demand) of the sector was in the forms of coal, natural gas, crude oil, and oil products.

The loss in energy transformation in power plant was up to 63.3 % of the energy input (DEDP, 2000), mostly in the form of heat. This problem has been partly solved by using the co-generation system, which is still not sufficient. An urgent and adequate increase in the share of co-generation system by the government as well as private power plants such as Independent Power Producers (IPP), and Small Power Producers (SPP) will directly lead to the solution. At the same time, increased use of cleaner energies in these systems such as natural gas, hydro power, wind power and solar energy will reduce CO_2 emission in the electricity generation processes as well.

Regarding energy-efficient use, special electrical equipment and machines such as electronic ballast, high-intensity discharge lamp power reduction equipment, voltage regulator, fluorescent lighting control, demand controller, variable speed motor, motor load controller, high efficiency motor, and high efficiency welding machine are now in use. Increased use of these equipment and machines in various economic sectors contributes a significant reduction in electricity consumption.

7.3 Gas Distribution Sector

At present, it is well known that natural gas is a major domestic energy source of the country. The demand for natural gas in the year 2000 was approximately 126.6 million cubic feet/day, an increase of 26.6 % from the previous year (DEDP, 2000). In the energy consumption and respective environmental deterioration point of view, this economic sector in 1995 had high total and direct energy intensities as well as high total and direct CO_2 intensities (1.08, 0.91 toe/US$ 1,000 and 2.38, 2.09 tCO_2/US$ 1,000, respectively). The sector's direct embodied energy, in the forms of natural gas and crude oil, accounted for 84.33 % of embodied energy (final demand), while indirect embodied energy included coal, natural gas, crude oil, and electricity were used as the intermediate input. The share of direct embodied CO_2 to total embodied CO_2 was 87.74

%, similar to that of energy. So, it is worthwhile to minimize the direct energy and corresponding CO_2 intensities in order to reduce the embodied energy and corresponding CO_2 in final demand of this sector.

7.4 Cement Sector

In Thailand there are approximately 350 cement factories of various sizes with total production capacity of about 265 million tonnes per year (Department of Industrial Works, 2000). From this study, it is notable that this sector had high total and direct energy intensities as well as total and direct CO_2 intensities in 1995, in the figures of 0.74, 0.17 toe/US$ 1,000, and 1.97, 0.79 tCO_2/US$ 1,000, respectively. The sector's direct embodied energy (final demand), in the forms of coal, oil products, and electricity, accounted for 22.82 %. Indirect embodied energy took a share of 77.18 % consisted of coal, natural gas, crude oil, oil products, electricity, and baggase. Embodied energy (final demand) in the year 1995 was 0.09 Mtoe, which induced corresponding embodied CO_2 of 0.25 $MtCO_2$. In this circumstance, energy-efficient technologies are needed to decrease energy intensity, such as exhausted hot air recycling system, material pre-heat system, use of high performance material for kiln wall such as ceramics fiber instead of conventional fire-brick wall. At the same time, reduction of embodied CO_2 can be conducted by means of fuel mix ratio improvement such as increasing the share of natural gas in total energy consumption, and introducing practical use of cleaner energy such as solar energy. Implementation of activities in both sides, cement production factories as well as their vendors will give a good result.

7.5 Food and Allied Sector

This sector consists of human food of all kinds, ingredients, and animal feed. In the year 1995, this sector had high embodied energy (final demand) as well as high corresponding embodied CO_2 which were 5.46 Mtoe and 15.76 $MtCO_2$, that accounted for 8.40 % and 7.79 % of the overall quantities, respectively. Direct embodied energy (final demand) in a share of 43.58 % included coal, oil products, electricity, fuel wood, paddy husk, and bagasse. Indirect embodied energy (final demand) that shared 56.42 % included coal, natural gas, crude oil, oil products, electricity, fuel wood, paddy husk, and bagasse. In this sector, reduction of indirect embodied energy (final demand) by application of energy efficient methods and energy saving practices

would be of great importance. At the same time, using less bio-mass fuels and consuming more cleaner energies will lead to further reduction of corresponding embodied CO_2 in the sector.

7.6 Construction Sector

This sector comprises private house construction, building and infrastructure construction including the construction of electrical power plants and communication systems. Despite low total energy and total CO_2 intensities in the year 1995, the embodied energy (final demand) of this sector was highest among all economic sectors due to extensive construction activities all over the country. Embodied energy (final demand) in 1995 in this sector was 7.07 Mtoe that accounted for 10.88 % of the overall embodied energy in the final demand, and induced corresponding embodied CO_2 in the amount of 24.18 $MtCO_2$. Oil products were major direct energy input for this sector and took a share of only 2.24 % of the total input, while indirect energy input with 97.76 % share included coal, natural gas, crude oil, oil products, electricity, and fuel wood. As the sector was responsible for much more embodied energy (final demand) and corresponding embodied CO_2 indirectly than directly, energy efficient production technologies and energy saving practices should be employed in economic sectors whose products are supplied to the construction sector. Those sectors are timber & its product, cement, non-metallic mineral, iron & steal, and land transports.

7.7 Land Transport Sector

This sector consists of passenger and cargo transportation of all types on land including trains. As reported by the Ministry of Communication, in the year 1999 there were 731,210 cars that had been registered all over the country. In 1995, the sector's embodied energy (final demand) was 5.96 Mtoe that accounted for 9.17 % of overall embodied energy (final demand). Direct embodied energy had a share of 21.88 % included oil products as the majority and a small amount of electricity. The indirect embodied energy in a share of 78.12 % included coal, natural gas, crude oil, oil products, electricity, and bagasse embodied in the input from oil products, rubber & plastics, automobiles & bicycle, and other services sectors. High total CO_2 intensity (3.68 tCO_2/US$ 1,000) induced the highest embodied CO_2 (final demand) up to 29.44 $MtCO_2$ or 14.56 % of overall embodied CO_2 (final demand) of the economy. In this regard, promotion of energy efficient use such as use of proper octane number gasoline oil, energy

conservation programs, and environment protection such as use of catalytic converters in automobiles, use of natural gas to replace gasoline oil for some types of cars, and etc., would be of great importance in reducing embodied energy and corresponding embodied CO_2 in this sector.

8. Thailand's Energy Consumption and CO_2 Emission Trends

8.1 Energy Consumption

From the analytical results described earlier in this report, it can be observed that the overall energy intensity for the whole economic system has been decreased in the year 1995 compared to the year 1985 (0.21 and 0.36 toe/US$ 1,000). This result indicates a downward trend of the overall total energy intensity to the future. Changes from non-commercial energy sources to commercial energy sources such as fossil fuels and electricity, and use of more-efficient production technologies have led to the decrease in energy intensity. With reference to the total primary energy supply data as shown in Appendix A, the amount of non-commercial energy had a share of 40.45 % of the total primary energy supply in 1985, where as in 1995 it accounted for 21.69 %. However, some economic sector such as oil products had an increase in total energy intensity that is mainly due to the increase in the direct energy intensity of the sector.

The upward trend of energy consumption expressed in terms of embodied energy (final demand) is notable. This is due to the increasing energy demand of the economy (from 18.04 Mtoe in 1985 to 54.97 Mtoe in 1995). At present, the energy demand increases rapidly and continuously. Hence, an urgent effective management plan for energy resources is obviously a necessity to avoid energy shortage problem in the near future.

8.2 Carbon-dioxide Emission

Based on the results of the study presented in this chapter, the overall total CO_2 intensity was decreased from 1.01 tCO_2/US$ 1,000 in the year 1985 to 0.60 tCO_2/US$ 1,000 in the year 1995, resulting in a downward trend. Although there was a decrease in overall total CO_2 intensity, increase of this intensity in some economic sectors is noticeable such as land transport and coal mining. So, it is worthwhile to reduce the CO_2 intensities in these economic sectors especially in the direct side in order to minimize the amount of CO_2 emissions.

Despite decrease in the overall total CO_2 intensity, the ratio of overall CO_2 emission to energy consumption indicated an upward trend as it was increased from 2.76 tCO_2/toe in the year 1985 to 2.88 tCO_2/toe in the year 1995. Although the difference was small, increase in the amount of CO_2 emission would be substantial in corresponding to the rising energy demand. Change in fuel mix ratio, such as increase in the share of natural gas, bio-gas, hydro-power, and solar energy in total energy consumption of the economy will decrease the ratio of CO_2 emission to energy consumption and lead to reduction of overall CO_2 emission. At the same time, enhancement of energy conservation practices and implementation of energy-efficient production technology will play an important role in the minimization of CO_2 emission.

9. Effects of Production Technology and Fuel Mix Changes

9.1 Production Technology Change

In an input-output table, the technical coefficients related to economic sectors describe the existing production technology (Miller and Blair, 1985). If 'A_c' is the existing production technology that can be replaced by the new production technology 'A_n', then the new technical coefficient 'A_{cn}', reflecting the incorporation of new technology would be

$$A_{cn} = A_c r + A_n(1-r) \qquad (3\text{-}1)$$

Where 'A_n' is the technical coefficients related to new production technology, 'r' is the percentage of old production technology to be used by production sectors (i.e., (1-r) is the percentage of new production technology that will replace the old production technology). Then calculation of A_n can be done by using the equation,

$$A_n = (e_c/e_n)A_c \qquad (3\text{-}2)$$

Where,

'e_c' and 'e_n', respectively are the average production efficiencies of existing and new technologies (Tiwaree and Imura, 1994).

For an example, if 80 % of the existing production technology is upgraded in term of energy saving and/or efficiency (say, from 75 to 85 %), then

$$A_n = 0.88A_c$$

$$A_{cn} = 0.2A_c + 0.8A_n$$

$$= 0.90A_c$$

In this case, incorporation of new technology changes the technical coefficients by 10.00 %.

Thus, upgrading of the existing production technologies employed in some economic sectors by means of energy saving practices or use of energy efficient production technology leads to the reduction of energy use (embodied energy, final demand and corresponding CO_2) while the amount of production output is maintained to be the same. If matrix A for the 7 notable economic sectors discussed in section 7 are upgraded by 20%, reductions in embodied energy (final demand) and corresponding CO_2 will be obtained, at least, by 12.29% and 7.97%, respectively for those 7 economic sectors. For the whole economic system, reductions of the same can be achieved by 6.79% and 4.30%, respectively. The above results were obtained using the calculation method as explained in Chapter 2.

9.2 Change in Fuel Mix Ratios

CO_2 emissions from energy use strongly depend on fuel mix ratios. Increase in the consumption of carbon-intensive fuels such as fossil fuels and bio-mass fuels in economic sectors yields greater CO_2 emissions and vise versa.

The phenomenon can be illustrated by changing the fuel mix ratio of the total primary energy input for 7 selected economic sectors in the year 1995. These sectors are oil products, electricity generation and distribution, gas distribution, cement, food & allied, construction, and land transports. The total primary energy input of the 7 economic sectors mentioned above was 48,887.50 ktoe (that accounted for 88.87% of the total primary energy input for all economic sectors), of which

Coal	=	4,055.30	ktoe
Natural gas	=	8,143.04	ktoe
Crude oil	=	24,315.95	ktoe
Oil products	=	8,357.32	ktoe
Electricity	=	630.73	ktoe

Solid biomass	=	3,374.16	ktoe

The total CO_2 emissions of these 7 economic sectors was 119,855.99 thousand tonnes that accounted for 59.70% of the overall CO_2 emissisons of all economic sectors. These CO_2 emissions were produced from various energy sources, of which

Coal	=	16,668.30	1,000 tCO_2
Natural gas	=	19,030.48	1,000 tCO_2
Oil products	=	71,788.56	1,000 tCO_2
Solid biomass	=	12,368.65	1,000 tCO_2
Total	=	119,855.99	1,000 tCO_2

Replacing coal and oil products consumption by the same energy amount of electricity which induces no CO_2 emissions in its use, the CO_2 emissions reduction of 88,456.86 thousand tonnes can be achieved. This accounts for 44.06% of the overall CO_2 emission from the whole economy.

10. Model Sensitivity Analysis

In an input-output analysis the aggregation of economic sectors may influence the sensitivity of the model. It is appropriate to conduct the input-output analysis without making any change in the original classification of the economic sectors. Thus, in this study the input-output analysis of all 179 economic sectors with no aggregation or disaggregation was carried out directly. However, it is not possible to make a clear and concise interpretation of the analytical results of all 179 economic sectors. Hence, it is necessary to aggregate some economic sectors into appropriate groups either before or after the analysis of the model. Table 3-31 illustrates the situation for some non-aggregated economic sectors. It is notable that the model is sensitive to the sectoral aggregation in case the aggregation is made before the input-output analysis has been done. The results of non-aggregated sectors could have some changes from their actual results. Therefore, the sectoral aggregation should be done after the input-output analysis to achieve the actual results of the non-aggregated sectors. In this study, aggregation of some of the 179 economics sectors into appropriate 34 economic sectors has been done after the analysis.

Table 3-31 Model sensitivity on sectoral aggregation

Sectors	Total energy intensities in 1995 (toe/US$ 1,000)			
	Sectoral aggregation		Differences	
	After analysis (Actual)	Before analysis	Intensities	%
Bricks & tiles	0.546	0.102	0.444	81.31
Cement	0.743	2.494	-1.751	-235.67
Ceramics	0.379	0.117	0.262	69.13
Charcoal and fuel wood	0.020	0.032	-0.012	-60.00
Coal mining	0.244	0.212	0.032	13.11
Electricity generation	3.464	3.429	0.035	1.01
Gas distribution	1.082	1.080	0.002	0.18
Non ferrous metal	0.022	0.022	0	0.00
Oil and natural gas	0.080	0.077	0.003	3.75
Overall	0.209	0.209	0.000	0.00

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

Energy is an important input (directly as well as indirectly) in an economy since there is hardly any production or consumption activity without energy input. In Thailand, energy demand is being largely met by fossil and bio-mass fuels, the major cause of large emission of CO_2 which is a major component of greenhouse gas.

In this study, a model based on the input-output analysis with some modification was used to account for embodied energy as well as corresponding CO_2 in final demand of various economic sectors in Thailand for the years 1985 and 1995. The analytical results reveal that in addition to energy sectors (such as oil products, electricity generation, and gas distribution), economic sectors such as cement, food & allied, construction, and land transport also had very high total (direct plus indirect) energy or total CO_2 intensities in both years. It can be observed that the share of carbon-intensive fuels in the fuel mix of total primary energy supply was increased in 1995 compared to 1985. It is interesting to note that although the share of the overall direct embodied energy (final demand) increased in 1995 as compared to 1985, overall indirect embodied energy (final demand) of Thai economy still had large share in 1995 (70.33 %). This indicates a strong economic and environmental interdependence among different economic sectors of Thai economy. Most of the economic sectors were fairly able to reduce their total (direct plus indirect) energy intensities or total CO_2 intensities in 1995 even though some sectors had an increase of the same compared to 1985. Accounting for total energy consumption in and corresponding CO_2 emission from various economic sectors of Thai economy for the production of goods and services establishes essential information for energy-environment policy makers. This study has clearly expressed the importance of energy saving practices, energy efficient production technologies implementation, and cleaner energies use for the reduction of energy consumption and CO_2 emission in Thailand.

2. Recommendations

Although downward trends in both average energy intensities and corresponding CO_2 intensities during the period of 1985 to 1995 have been observed, much more improvement is

urgently needed. In this regard, introduction of more energy efficient production technologies and energy conservation strategies in different economic sectors with prime consideration to those economic sectors with high total energy and corresponding CO_2 intensities (such as those seven notable economic sectors mentioned in chapter 3) should be conducted to achieve sustainable economic development in Thailand.

Despite reduction in average energy intensities and corresponding CO_2 intensities, the average CO_2 emission to energy consumption ratio has been found in an upward trend. Therefore, increase in the share of non-carbon or low-carbon intensive energy in every economic sector of Thai economy is of great importance.

The present study has few deficiencies occurring from the limitation of data availability. Firstly, Thailand has been treated as a closed economy. Calculations of energy and corresponding CO_2 embodied in the imported goods and services is neglected and export of embodied energy or CO_2 has been considered as part of the final demand within the country. Thus, any embodied energy or CO_2 in the imported goods & services has been assumed to be equal to the embodied energy or CO_2 in the exported goods & services. In reality, it could be different. To obtain more reasonable result, the future study should include the calculation of the embodied energy or CO_2 in the imported goods and services. National input-output tables of major trading partners of Thailand are necessary for such study.

Secondly, in the current input-output tables of Thailand, all the inter-industry transactions are in monetary units. At the same time, the primary energy data available does not show clearly its detail transaction between different inter-industry or economic sectors in many cases. Therefore, most of the rows of energy sectors were converted into equivalent physical units assuming that the price of the primary energy is uniform throughout the economy. In actual, energy price may differ from sector to sector depending on many factors. For improvement in future study , rows of the energy sectors in an input-output table should be available in physical units.

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APPENDICES

APPENDIX A

Total Primary Energy Supply (Excluding Residential Sector)

Primary Energy Type	Total Primary Energy Supply (ktoe)	
	1985	1995
Coal	1,583.99	7,176.52
Natural Gas	2,927.88	8,858.76
Crude Oil	8,243.76	24,418.76
Oil Products	2,654.94	9,871.59
Electricity	377.89	630.73
Solid Biomass	10,726.00	14,112.00
Sum	26,514.45	65,068.36

Source : Department of Energy Development and Promotion (1989; 1999);
International Energy Agency (2000).

APPENDIX B

Energy Consumption and CO_2 Emission in Residential Sector

Primary Energy Type	Energy Consumption (ktoe)		CO_2 Emission (1,000 tonnes)	
	1985	1995	1985	1995
Coal	0	0	0	0
Oil Products	76.20	191.81	1,231.00	3,572.00
Natural Gas	0	0	0	0
Electricity	10.40	0	0	0
Solid Biomass	8,343.44	9,819.69	34,508.30	40,614.28
Total	8,430.04	10,011.50	35,739.30	44,186.28

Source : Department of Energy Development and Promotion (1986; 1996);

International Energy Agency (2000).

APPENDIX C

Consumer Price Index (CPI) for Thailand

Year	Index
1985	67.5
1986	68.8
1987	70.5
1988	75.0
1989	79.0
1990	83.7
1991	88.5
1992	92.1
1993	95.1
1994	100.0
1995	105.8
1996	112.0
1997	118.2
1998	127.8
1999	128.2
2000[1]	131.4

[1] Estimation

Source: Bank of Thailand (2000).

APPENDIX D

Exchange Rate

Year	Baht/US$
1985	27.21
1995	24.94

Source: Bank of Thailand (2000).

APPENDIX E

Economic Sectors Aggregation

Sector No.	Sector Description	Sub-sectors
1	Agricultural, forestry & fishing	Rice plantation
		Corn plantation
		Sorghum and cereal plantation
		Tapioca plantation
		Other corps plantation
		Legumes plantation
		Vegetables plantation
		Fruit plantation
		Sugarcane plantation
		Coconut plantation
		Palm tree plantation
		Jute plantation
		Fibred plants farming
		Tobacco Plantation
		Coffee, tea and cocoa production
		Rubber tree plantation
		Other agricultural products
		Cattle farming
		Pig farming
		Livestock farming
		Poultry farming
		Poultry products
		Silk worm breeding
		Agricultural services
		Forest products & hunting

		Sea and coastal fishery
		Fresh water fishery
2	Charcoal & fuel wood	Charcoal & firewood production
3	Coal mining	Coal mining
4	Oil & natural gas	Oil and natural gas
5	Metallic mineral	Iron mining
		Tin mining
		Tungsten mining
		Other ore mining
6	Non-metallic mineral	Concrete products
		Fluorite mining
		Glass products
		Limestone mining
		Non-metallic materials production
		Ore mining for chemicals and fertilizers
		Stone mining
		Special ores mining
7	Food & allied	Salt production
		Slaughter houses
		Canned meat & other meat products
		Milk products
		Canned fruit and vegetable production
		Canned fish and seafood production
		Coconut and palm oil production
		Lard and vegetable oils production
		Rice mill
		Tapioca products
		Corn grinding
		Starch production

		Bread production
		Noodle production
		Sugar production
		Sweets, candy production
		Ice production
		Seasoning powder production
		Refreshments production
		Cooking ingredients production
		Animal feed production
8	Drink & tobacco	Liquor production
		Beer production
		Soft drinks production
		Tobacco leaves maturing
		Tobacco product
9	Textile	Natural and synthetic threads production
		Weaving
		Bleaching, dye and cloth printing
		Cloth excluding garment production
		Knitting
		Garment production
		Carpet & cover materials production
		Jute products
10	Leather, etc.	Leather preparation
		Leather products
		Shoes production
11	Timber and its product	Timber production
		Miller
		Wood products
		Wood furniture production
12	Pulp, paper & printing	Pulp and paper production

		Paper products
		Paper printing
13	Chemicals & fertilizers	Primary industrial chemicals production
		Fertilizer & pesticide production
		Paint, wax and lacquer production
		Medicine production
		Soup and detergent production
		Cosmetics production
		Match production
		Chemicals consumer products
14	Oil products	Petroleum oil refinery
		Other petroleum products
15	Rubber & plastics	Plastic, resin & synthetic rubber production
		Raw rubber production
		Vehicle tires production
		Rubber products
		Plastic products
16	Ceramics	Ceramics and pottery production
17	Bricks & tiles	Bricks and tiles production
18	Cement	Cement production
19	Iron & steel	Iron and steel industry
		Steel products
20	Non ferrous metal	Metal product excluding iron
21	Mechanical engineering	Iron and steel equipment manufacturing
		Metal furniture and fixing materials production
		Metal products for construction
		Other metal products

		Engine & turbine manufacturing
		Agricultural machine & equipment manufacturing
		Machine for woodwork and metalworking manufacturing
		Special machine and equipment manufacturing
		Office and home equipment and tool manufacturing
22	Electrical engineering	Industrial electrical M/C & equipment manufacturing
		Communication equipment manufacturing
		Electrical household products
		Metal wire and shielded cable production
		Batteries production
		Electrical appliances production
23	Ship, train , aircraft	Ship repairing and manufacturing
		Train manufacturing and maintenance
		Aircraft manufacturing
24	Automobiles, bicycle	Automobiles manufacturing
		Motorcycle & bicycle manufacturing
		Vehicle maintenance
25	Other manufacturing	Scientific and medical equipment manufacturing
		Photo and optic equipment manufacturing
		Watch production
		Ornament production

		Musical instrument and sport equipment production
		Other industrial products
26	Electricity generation and distribution	Electricity *generation*
27	Gas distribution	Gas refinery and distribution
28	Water supply and sanitation	Water supply business
		Sanitary services
29	Construction	Private house construction
		Building construction excluding residence
		Infrastructure construction for agriculture and forestry
		Other infra-structure construction
		Electricity Plant construction
		Building & communication system construction
		Other construction
30	Wholesale & retail	Wholesale
		Retail
31	Hotel & restaurant	Food and drink services
		Hotel and accommodation services
32	Land transports	Train transportation
		Land transportation
		Truck transportation
		Additional service to land transportation
33	Air & water transports	Sea transportation
		Coastal and inland water transportation
		Additional service to water transportation

34	Other services	Air transportation
		Transportation related service
		Warehouse and silo
		Post and telecommunication
		Finance
		Life insurance
		Disaster insurance
		Real estate business
		Business services
		Government affair
		Educational services
		Research institutes
		Medical and health services
		Private professional institutes
		Community services
		Movie production and distribution
		Movie theatre
		Radio and television broadcasting
		Library and museum
		Entertainment services
		Maintenance and repair services
		Personal services
		Miscellaneous activities

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