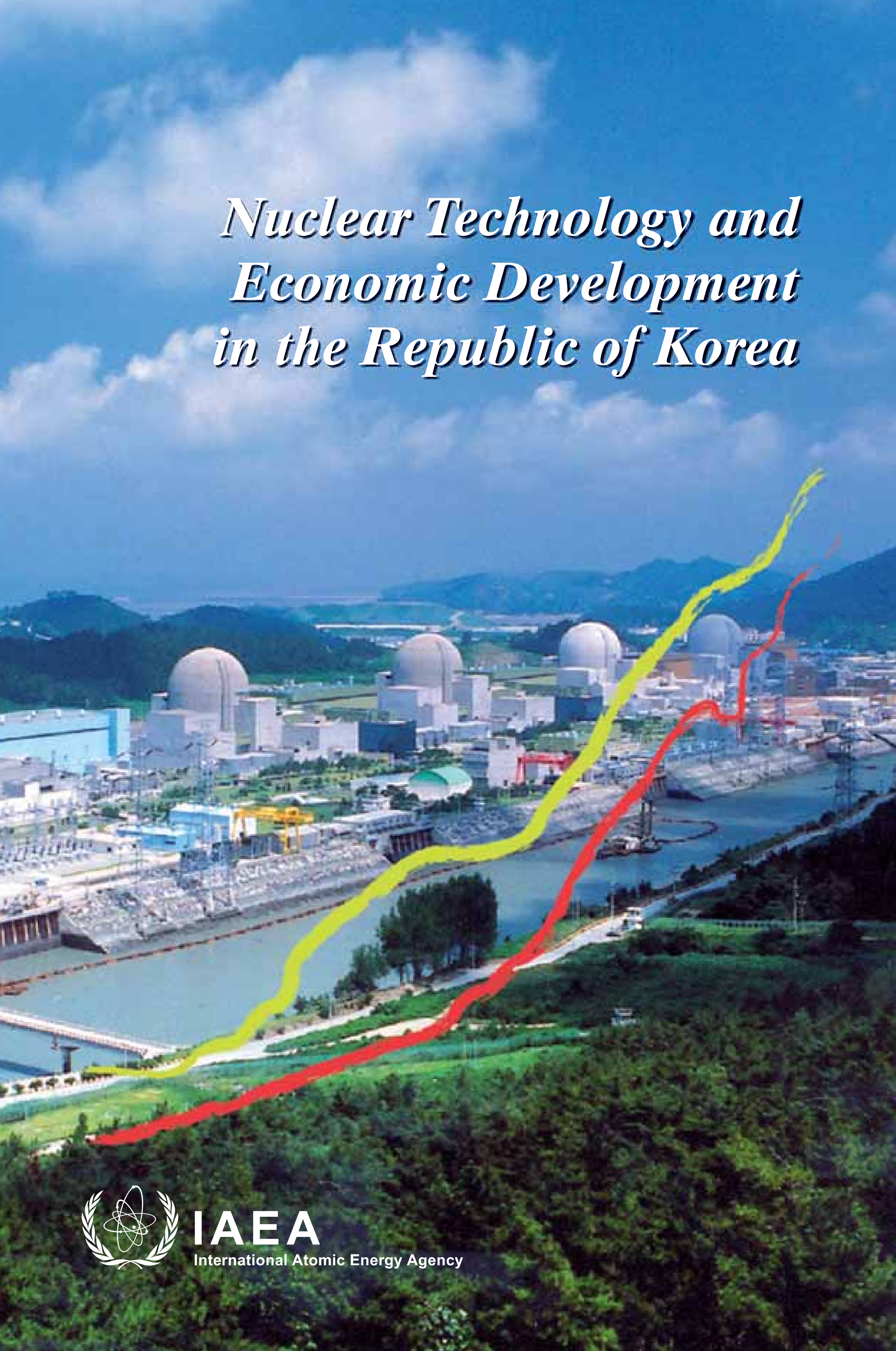
Nuclear Technology and Economic Development in the Republic of Korea



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NUCLEAR TECHNOLOGY AND ECONOMIC DEVELOPMENT IN THE REPUBLIC OF KOREA

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FOREWORD

Over the last five years, the IAEA, in cooperation with the Ministry of Science and Technology (MOST), the Ministry of Commerce, Industry and Energy (MOCIE), and the KHNP of the Republic of Korea, conducted a series of studies to quantify the benefits to date of nuclear technologies to the economy of the Republic of Korea. Working under the auspices of these agencies was a national team of experts from five different institutions, each with special areas of expertise: the Korea Atomic Energy Research Institute (KAERI); Korea Institute of Nuclear Safety (KINS); Kyungbuk National University, Korean Energy Economics Institute (KEEI), and Daegu-Gyeongbuk Development Institute.

MOST served as the focal point for the national input–put (I–O) studies, including coordination of the I–O analysis team, providing assistance in gathering official statistics from the Korean Statistical Office and providing qualitative information on nuclear policy and strategies in the Repubic of Korea. KAERI was responsible for processing and analysing the I–O data, refining the I–O methodology and carrying out the I–O analysis. The basic I–O tables restructured by KAERI were provided by the National Bank of Korea. KINS collected data on the radioisotope industries.

The regional analysis was completed under the aegis of MOCIE, in cooperation with KHNP, KEEI, KAERI and Kyungbuk National University. KHNP provided data on nuclear power plant construction and operations, on the regional costs and benefits of nuclear power plants and on KHNP's regional and social outreach programmes. KAERI and Kyungbuk National University were responsible for structuring the analytical I–O methodology for the project and adapting it for regional analysis. KAERI and Kyungbuk National University together were responsible for the I–O based economic analysis. The Daegu-Gyeongbuk Development Institute provided regional economic data for the study. KEEI provided project coordination.

The background chapters on economic history and energy sector development, and the chapters on other benefits besides contributions to gross domestic product, were written by the IAEA in cooperation with experts from the Republic of Korea.

As agreed with the sponsoring organizations, the results of these efforts are presented here as a single report summing some of the estimated incremental benefits of selected nuclear technologies and plants to the economy of the Republic of Korea.

CONTENTS

SUMMARY

Over the last five years the IAEA, in cooperation with a number of government institutions in the Republic of Korea, conducted a series of studies to quantify the benefits of nuclear technologies to the economy of the Republic of Korea. As agreed with the sponsoring ministries, these studies have now been updated and incorporated into a single study, summing a few of the estimated and quantifiable overall benefits of selected nuclear technologies to the economy of the Republic of Korea.

The study starts with a history of the evolution of the nuclear industry in the Repulic of Korea in the context of progressive industrialization, growing energy and electricity use, and increasing gross domestic product (GDP). It proceeds with a brief review of the analytical methods and presents the findings. The analysis was done primarily using an input–output (I–O) model. An I–O model measures the value added that one industry contributes to the output and hence to the value added of other industries in an economy or region. In the case of nuclear power, for example, the output effect would measure the purchases of goods and services that the nuclear power industry makes from other industries; the value added effect would measure the extent to which these purchases contributed to the final demand for the product of each of these other industries. These output and value added effects are two different ways to view an industry's place in the productive economy of a country; they are/not additive. Rather, the incremental output contribution is used to calculate incremental value added. In this study we have attempted to estimate at least part of the value added contribution of two nuclear technologies to aspects of the Korean economy at the national level, as well as the contribution of nuclear power plant construction and operation at the regional level.

Specifically, at the national level, the analysis covers two nuclear industries: nuclear power generation and radioisotope applications. For nuclear power, the analysis focuses on the incremental value of nuclear power generation to industrial value added, and hence ultimately to GDP. The incremental contribution was calculated by comparing the actual industrial value added of nuclear, with the value added that would have resulted had nuclear power not developed, using coal and gas fired electricity generation to replace nuclear. Since there is no direct substitute for radioisotopes, the value added as calculated was taken directly as the incremental contribution of radioisotopes to industrial value added and hence to GDP. At the regional level, the analysis used the case of a single nuclear plant, the Ulchin power

plant, to illustrate at least some of the regional income and output effects of plant expenditures and wages on the local economy.

No attempt was made to include exhaustively in the I–O analysis all of the contributions that might accrue to the Republic of Korea's GDP from the use of nuclear technologies. The benefits presented here are therefore only partial benefits. For example, because the I–O analysis calculated only industrial value added, any benefit from lower electricity prices that might accrue are not reflected in the calculation. In the industrial sector, electricity sales are not included in the I–O analysis. Electricity is considered an input to manufacturing; the value of any input is used only to calculate the value added of the manufacturing process. By contrast, in the residential sector, where electricity is an end use product, a reduction in the cost of electricity would be reflected in the calculation of the value added of consumption. In the regional analysis in this study, such changes are partially captured as increased household income, calculated herein as the result of subsidized electricity in the Ulchin region. This same approach could also be used to estimate the benefits of the relatively low nuclear generating costs at the national level, if households were incorporated, as they are in this analysis, as a productive sector in the national I–O tables. There are moreover, a number of external benefits not covered in this analysis. Some of these additional benefits are noted in the concluding chapter of this report. Thus the total contribution of nuclear technologies is not captured here and the total value added from these industries as given is therefore understated.

VALUE ADDED BENEFITS OF NUCLEAR POWER

The nuclear industry has been an integral part of the country's economic development, evolving from an import to an export oriented industry, providing a certain impetus to technological innovation as well as to socio-economic development such as infrastructure and education. The Republic of Korea has accumulated extensive experience in nuclear technology development and nuclear power plant construction and operation. Over the past four decades, the Republic of Korea has become one of the world's leading nuclear power countries, with 20 nuclear power plants in commercial operation at the end of 2005, comprising a total generating capacity of 17.5 GW(e). Increasing national participation in the nuclear industry has meant the steadily increased use of locally produced material and domestic staff resources. Meaningful national participation in nuclear power plant construction requires the existence of a capable construction industry; medium and heavy manufacturing including cement, steel, machinery and equipment and chemicals; as well as competency in other services such as civil engineering, quality assurance control and testing; and specialized manpower training including engineering and managerial skills. Domestic industries gradually became the main suppliers to and main contractors for the nuclear power programme. The I–O analysis in this study is an attempt to capture and quantify at least some of these benefits.

The industrial sectors that benefited from nuclear power plant construction changed over time as the commercial nature of the construction evolved from imported turn-key plants to greater technological self-sufficiency. For example, before 1990, only two major industrial sectors received significant value added from nuclear power: electric power plant construction, and finance and insurance. After 1990, as the Republic of Korea approached technological self-sufficiency in nuclear power plant construction, the number of sectors affected increased to include primary metal products, general machinery and equipment, electronic and other electric equipment, and business services. The general machinery and equipment sector was the most affected for the years 1990 and 1995, reflecting large expenditures in this sector for new plants.

Moreover, local manufacturers extended their normal product lines to incorporate nuclear designs and standards, and special factories were set up locally to manufacture heavy and specialized nuclear components, often under licensing arrangements with foreign suppliers. The most important spin-off effects of localising plant construction activities have been in the primary metal products sector.

The economic value added during nuclear power plant operations shows the same kind of evolution as in the construction phase, namely a shift in affected sectors as the number of plants and their degree of localization increased. Finance, insurance and inorganic basic chemical products are the sectors that have seen the most value added from the operation of nuclear power plants, primarily through expenditures for nuclear fuel and interest payments.

Nonetheless, had there been no nuclear power development in the Republic of Korea, electricity would still have been generated, probably by coal and LNG. We therefore did two parallel assessments of industrial value added over the study period: one using actual historical data, and one assuming that the nuclear power sector had not been developed in the Republic of Korea, in order to estimate roughly the incremental contribution of nuclear power to value added. When the total value added of plant construction and operation in the alternative thermal power scenario is subtracted from the total value actually added by nuclear power development, the result is the incremental value added to the economy of the Republic of Korea by nuclear power. This incremental contribution was actually positive throughout all periods. Value added under the thermal scenario was estimated as being some 92–160 billion Won lower than nuclear power's actual value added in 1980, and some 298–243 billion Won lower in 2005, in current prices.

The actual value added contribution of nuclear power to the GDP of the Republic of Korea in 2005 was calculated here to be, at a minimum, around 1.3%[1]; nuclear power's incremental value added contribution, which is more economically relevant, is calculated to be, at a minimum, around 0.4%. This contribution can be expected to grow over time as demand for electricity grows in the Republic of Korea. The results of this comparison are shown in Fig. 1[2].

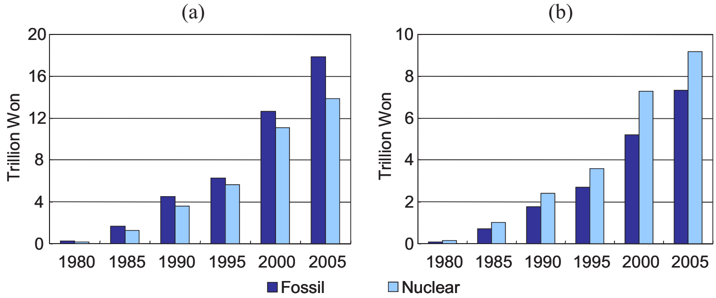

FIG. 1. Comparison of (a) total output (left) and (b) total value added (right) contribution from nuclear and alternative fossil power plant operation.

RADIOISOTOPE INDUSTRY BENEFITS

Both demand for and production of radioisotopes in the Republic of Korea are growing, but demand still exceeds domestic supply. Thus, for now, the industrial value added contribution of radioisotopes stems largely from their use: this is the contribution estimated here. The use of radioisotopes in the Republic of Korea has grown rapidly, especially in manufacturing (largely for quality control and non-destructive testing) and in medicine. The I–O assessment of this industry's contribution to industrial value added focuses on these two applications. The total value added contribution of the RI industry to GDP is therefore understated, since, for example, agricultural uses and radioisotope production are not considered.

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[1] By comparison, the four major industries in the Republic of Korea – primary iron and steel products, semiconductors and related devices, motor vehicles, petroleum refinery products, contributed 1.3%, 2.1%, 2.2%, and 2.9%, respectively to GDP in 2003.

[2] Note that output for thermal is greater than nuclear while value added is greater for nuclear. This reflects the fact that fuel imports are included in output but do not contribute to value added for domestic industries as calculated here.

The actual value added to GDP attributable to radioisotopes is estimated in this study to have grown from some 0.3% of GDP in 1980, to 0.67% in 2005. Manufacturing applications account for more than half of all total radioisotope value added in that year, but the most rapid increase in value added from radioisotope applications has been in the medical sector. Unlike the case of nuclear power, we did not estimate an incremental contribution of the radioisotope industries to value added in GDP. Whereas the electricity sector would have evolved using alternate fuels, there is really no ready and comparable substitute that could be used to make this calculation for the radioisotope services considered here.

REGIONAL BENEFITS

There are four nuclear power plant sites in Republc of Korea. Each of the host communities has benefited from the construction and operation of these plants. These benefits include tax revenues, financial contributions in terms of local expenditures by the plant for salaries, social contributions and investments, and infrastructure development. Using the Ulchin nuclear power plant and the Ulchin region as a case study, our I–O analysis has estimated for illustrative purposes some of the benefits that accrue to a Kun (local government) from hosting a nuclear power plant. These benefits flow from local taxes, wages, plant expenditures, and supporting projects (amounting to some 5.3 billion Won in 2005) financed by the government and by KHNP. The anticipated downside of nuclear power plant construction could include uneven demands on infrastructure and fluctuating property values, reflecting the boom and bust cycle typical of large construction projects. However, the data on employment for the Ulchin plants indicate a surprising continuity and balance between the labour force used for construction and for operation.

Our estimate of regional benefits for 2005 shows expenditures, contributions and other outlays from the Ulchin plant accounting for some 70% of total regional output (230 billion Won out of 3300 billion Won), not including revenues from power generation, which flow to corporate headquarters. On top of this, the plant has contributed salaries and other labour income in the Kun of some 90 billion won, about 20% of total regional labour income (460 billion Won). A brief summary of the I–O results for this regional study for the year 2005 are shown in Tables 1 and 2.

Additional social contributions not quantified include school construction, training and scholarships, marketing and support for regional products and industries, contributions to infrastructure improvements, provisions of childcare and sports facilities, and support for local cultural events.

TABLE 1. TOTAL REGIONAL OUTPUT EFFECTS OF THE ULCHIN NUCLEAR POWER PLANT (IN BILLIONS OF WON).

	Nuclear Power		NPP Areas Regional Project	Local Taxes	Total	Shares to Total Regional Output
	Construction	Operation				
1990	n.a.	581.7	2.2	-	583.9	-
1995	n.a.	605.6	4.8	8.4	618.9	48%
2000	n.a.	1 559.8	10.1	26.2	1 596.1	69%
2001	n.a.	1 615.2	10.3	10.6	1 636.0	66%
2002	n.a.	1 445.4	9.8	17.9	1 473.1	60%
2003	n.a.	1 612.0	18.4	22.9	1 653.3	62%
2004	n.a.	1 835.2	11.4	25.9	1 872.5	72%
2005	n.a.	2 240.1	9.1	56.6	2 305.8	70%

TABLE 2. TOTAL REGIONAL INCOME EFFECTS OF THE ULCHIN NUCLEAR POWER PLANT (IN BILLIONS OF WON).

	Nuclear Power		NPP Areas Regional Project	Local Taxes	Total	Shares to Total Regional Income
	Construction	Operation				
1990	-	20.0	0.6	-	20.5	-
1995	65.1	23.1	1.4	2.4	92.1	39%
2000	67.2	44.8	3.5	6.4	121.9	43%
2001	65.7	55.3	5.0	2.4	128.4	43%
2002	74.5	50.9	4.2	3.9	133.6	40%
2003	68.7	81.4	6.0	4.8	160.9	44%
2004	36.1	74.0	4.3	5.2	119.6	26%
2005	-	75.5	3.2	10.9	89.7	20%

EXTERNAL BENEFITS

As the drive intensifies to reduce greenhouse gas emissions from its to the national electricity system, nuclear's contribution to greenhouse gas (GHG) reduction will become more important. For example, the Republc of Korea has imposed a carbon dioxide emission intensity target of 110 gC/kW·h. Conventional nuclear power stations are a more cost effective GHG mitigation option than coal fired plants with carbon capture and storage. From an air pollution and environmental health point of view case studies show that nuclear power also has a lower detrimental effect than coal or natural gas.

Energy supply security concerns include sufficiency of supply and vulnerability to price volatility. Nuclear fuel price stability, the long refuelling cycle for nuclear power plants, and the small share of nuclear fuel costs in total generating costs, offer an important buffer against fuel price instability, leading to more stable and predictable electricity prices. Growing competition for fossil fuels in world markets may also be a concern. Nuclear power has already played a role in reducing fuel import requirements in the Republic of Korea.

INTRODUCTION

Nuclear technology development can be a means to economic development as well as improved environmental quality. These qualitative and quantitative development benefits can be significant. However, there have been few attempts to document this proposition by quantifying the value added contribution that nuclear technology development makes to a country's overall GDP, and hence to its economic growth. This study is an attempt to quantify at least partially some of the contributions accruing to the economy of the Republic of Korea from the development of selected nuclear technologies.

These are compelling reasons for undertaking this study, and there are several reasons for doing it in the Republic of Korea. First, this country has a thriving nuclear sector: nuclear power provided about 40% of the country's electricity needs by 2005. Second, experienced analysts with relevant expertise and access to historical data series, are interested in pursuing this project. Third, there is a national interest in quantifying the role of the nuclear sector in national development. In the context of increasing privatization and competition in the electricity sector, the long standing national utility the Korea Electric Power Company (KEPCO), a wholly government owned corporation, was divided into several private sector entities, and a government-held subsidiary, Korea Hydro & Nuclear Power Co. (KHNP) given the responsibility for nuclear power. This nuclear entity will have to compete directly with other baseload electricity generation — particularly coal and natural gas. Since public and political support is deemed essential for new nuclear build, there was strong interest in an objective and transparent analysis of the competitiveness and potential benefits of nuclear power. Finally, there is growing interest in the external benefits of nuclear power, stemming, for example, from the growing challenge to reduce GHG emissions consistent with the goals of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), adopted in 1997 and in effect since 16 February 2005, or reflecting a growing emphasis on sustainable development, and its multiple goals for improving social and economic well-being in an environmentally acceptable way, with energy and energy supply security being key components.

Chapter 1 describes the general economic and institutional background for the development of the Republic of Korea's electricity and manufacturing industries. Chapter 2 provides a detailed description of the Republic of Korea's energy balances and trends, while Chapter 3 provides more specific detail on the development of nuclear power. These chapters set the stage for the input–output (I–O) analysis and assessment of the value added contributions that the nuclear power and radioisotope industries have made to industrial value added and hence to the economy of the Republic of Korea over the period 1908–2005 (Chapters 4–7). Specifically, Chapters 4 and 5 culminate in an estimate of the incremental value added of nuclear power to GDP. Chapter 7 estimates the incremental value added contribution of the domestic radioisotope industry. Chapter 7 estimates the contribution of nuclear power plant construction and operation to regional GDP. Finally, Chapter 8 provides some conclusions and a brief discussion of various external benefits of nuclear power.

This study required extensive efforts, both statistical and methodological. The gathering, and analysis of statistical data and their structuring in a consistent and cohesive manner, have necessarily been a major substantive contribution of the Republic of Korea to this project. This work comprises the backbone and foundation of this study. A second major contribution has been the development and adaptation of the national and regional I–O tables for the Republic of Korea that are the basis for quantifying some of the actual contributions of nuclear technologies to the economy of the Republic of Korea. The groundbreaking and innovative work done to develop these national and regional I–O models is documented in Annexes I and II. A concerted effort has been made throughout the study to provide sufficient statistical and methodological information to permit emulation by other parties interested in conducting similar national and/or regional analyses.

1. OVERVIEW OF ECONOMIC AND INSTITUTIONAL DEVELOPMENT IN THE REPUBLIC OF KOREA

1.1. INDUSTRIALIZATION[3]

After the end of the Korean War, the Republic of Korea embarked on a series of five year economic development plans pursuing what amounted to a classic pattern of economic development. Industrialization initially focused on light industries such as food, beverage and textiles, moving next to chemicals and metal products, and then to intermediate goods such as equipment and machinery. The focus was first on export oriented mass production, taking advantage of the Republic of Korea's abundant cheap labour and taking into account of scarcity of capital and of resources. By the mid-1960s, the Government had increasing access to private capital markets, facilitating both technology imports and investment.

From the outset of industrialisation there was a major emphasis on technology, science and research. At first, technology was imported for example as turnkey plants, and the focus was on improving local absorptive capacity. As a next major step, reverse engineering of imported capital goods made indigenization of mature technologies possible. As this became increasingly difficult to do legally under international trade rules, government research policy shifted to development of local research capabilities, with the setting up KAERI in 1958, regional research centres in the 1970s, and the Science Park in Daejeon.

By the early 1970s, the trend of industrialization had shifted to heavy industries. Imports of capital and technology were especially crucial for the development of the heavy and chemical industries, notably metallurgy (iron and steel especially), shipbuilding (and later automobiles) and construction. In contrast to early post-war years, the country was now more able to pay for technology and resources, and had a more highly skilled labour force than in the 1960s.

The heavy industries were a driving force for national economic development, broadening the industrial base and essentially restructuring the economy. By 1973, real per capita income had more than doubled the levels of the mid-1960s; and the economy had been transformed at a rate more rapid than any other country had ever experienced, with a major rural to

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[3] Inspired by and elaborated in part from 'The Korean Economy 1945-1995: Performance and Vision for the 21st Century', Dong-Se CHA, Kwang-Suk KIM, Dwight H. Perkins, eds. Korea Development Institute, KDI Press, April 1997, pp 313, 326, 391ff, 450ff.

urban shift, and shifts in GDP from some 50% primary commodity production and around 5% manufacturing in 1953–1955, to more even shares of around 25% each by 1973–1975. During this time, infrastructure was not ignored, though investment in education focused primarily at this time on basic rather than university level education.

The Republic of Korea's energy policy has quite consistently focused on supplying energy to fuel rapid industrialization and strong economic growth. This growth was driven by the expansion of energy intensive industries in the 1980s and 1990s, fostered by concentrated development policies and resulting in a very much higher national average standard of living.

All of this was done with a limited base of indigenous coal and hydro energy resources, and hence before nuclear power the Republic of Korea was a net importer for some 97% of its energy. Electricity generation was dominated (80%) by imported crude oil, creating economic problems as oil and energy prices rose in the 1970s. Faced with the need for further increases of increasingly expensive fuel imports to supply its rapidly growing industrial, transportation and electricity sectors, the government opted to diversify its energy sources focusing on nuclear power as a more technology oriented rather than resource oriented way to reduce reliance on imported energy. The energy and electricity intensive intermediate and heavy industries provided a ready market and a rationale for domestic nuclear power that would permit their continued competitive output and growth without dramatically increasing energy imports. In turn the development of the nuclear industry created domestic markets for equipment, the metallurgical and construction industries, electronics, and the business service sectors including finance and insurance, in effect creating a significant intersectoral symbiosis.

The electricity sector thus provided more than just electricity to the fledgling industrial sector. "The earliest and largest modernization projects in post-war Republic of Korea were power plants. Large domestic conglomerates were selected to construct, engineer and manage huge coal, oil and nuclear power plants" (Byrne et al., 2004). Between 1960 and 1987, the Republic of Korea built 20.6 GW of new generation capacity (14.8 GW of fossil fuelled plants and 5.8 GW of nuclear plants). Construction of these plants and the gradual increase in domestic contribution helped establish and expand the industrial base of the economy. Conversely, "South Korea's spectacular economic growth was, in part, based on a formula of doubling electricity capacity every ten years" (Byrne et al., 2004).

The 1980s saw a period of adjustment in government policies and an industrial shift to more service and high-tech industries. By 1995, exports had risen to about one third of GDP. The economy of the Republic of Korea grew by more than 8.7% per annum in real terms in this period (Table 1.1) and the use of energy and electricity grew faster than economic growth. Energy and electricity demand growth both slowed in the late 1990s with the slowing of economic growth and improved technological efficiency, and demand actually fell briefly during 1998 following the 1997 Asian economic crisis, but resumed growth in 1999.

TABLE 1.1. GDP, 1980–2005

Year	GDP (2000 const. Mill. US$)	GDP per capita	GDP Annual average growth rate (%)
1980	122 814	3 221	-
1985	178 970	4 386	7.82
1990	283 561	6 615	9.64
1995	413 011	9 159	7.81
2000	511 658	10 884	4.38
2005	637 946	13 210	4.51

Source: EEDB; IEA/OECD (2007).

The growth of light industries (semiconductor, telecommunications and fibreglass) paralleled the growing use of radioisotopes in industrial applications for gauging and precise measurement, and for non-destructive testing for precision quality control. These have permitted the maintenance of consistent quality control in hi tech goods manufacture in the Republic of Korea, raising the value of these goods in international markets and raising the reputation of products made in the Republic of Korea.

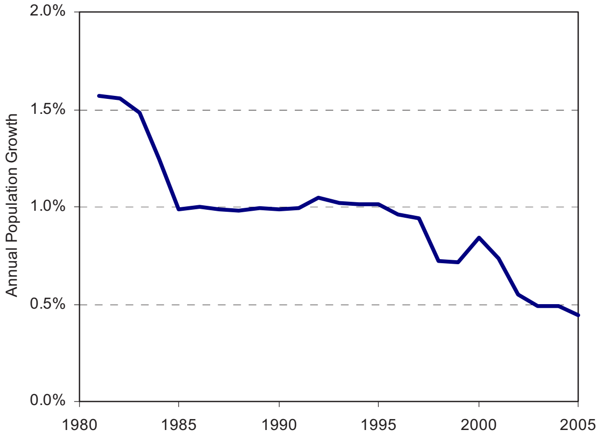

FIG. 1.1. Historical growth rate of population in the Republic of Korea.

Today the Republic of Korea has a population of over 48 million. Population growth has been slowing as income rises (Fig. 1.1), but the country still has the third highest population density in the world. The country is highly urbanized: nearly three-quarters of all people live in cities and nearly one-quarter in the capital, Seoul.

The Republic of Korea's rapid economic development has been driven by high rates of domestic savings and investment and a strong emphasis on education, which boosted the percentage of youth enrolled in universities to among the highest in the OECD area. In 2005, the Republic of Korea had a GDP of more than US $637 billion (in 2000 constant dollars at current exchange rates) and an average per capita income above $13 200. The Republic of Korea's growth was affected by the 1997 Asian economic crisis (see Fig. 1.2); in 1998 GDP shrank by 6.9% and total primary energy supply (TPES) by 8.5%. However, the Republic of Korea made a strong recovery from this crisis — faster than most other Asian countries.

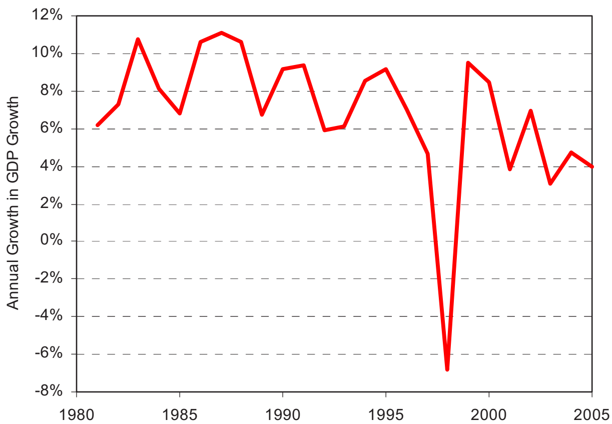

FIG. 1.2. Annual growth rate of GDP in the Republic of Korea.

Since 2000, relatively slower economic growth of 5% per annum has resulted also in lower growth (less than 5% per annum) of primary and final energy demand. Near term average annual growth of total final energy demand is expected to be around 2.7%, compared to 3.6% from 1995–2000. However, this relatively stable growth masks an increasing demand in the transportation and public and service sectors counterbalanced by a decline in demand in the industrial and residential sectors.

1.2. ENERGY POLICIES

1.2.1. Nuclear Power Development

Until the early 1990s, the electricity industry was essentially owned and operated by the Government, which had made a strong commitment to develop a nuclear power programme. This decision received impetus from three main factors: lack of domestic energy resources, favourable world nuclear markets in the 1980s, and active and concerted government involvement cooperating with a dedicated nuclear work force.

The Republic of Korea's commitment to nuclear power and its need for initial imports of nuclear technology were greatly aided by the depression of the world nuclear industry in the 1980s as the result of the collapse in international oil prices in the mid-1980s; growing excess generating capacity in OECD countries due to the delayed impact of efficiency improvements, economic restructuring prompted by the oil price hikes of the 1970s; and public reaction to the Three Mile Island and Chernobyl accidents and the resulting growth of the anti-nuclear movement. This created a buyer's market and made it possible for the Republic of Korea to conclude technology transfer agreements with foreign suppliers under favourable conditions.

Strong government commitment was essential first to foster and then to marshal the Republic of Korea's well-educated human resources to successfully implement the national nuclear technology self-reliance programme. The Republic of Korea's nuclear scientists and engineers engaged in overseas nuclear power programmes were attracted back to the Republic of Korea to play key roles in the localization of nuclear power technology development and enhancing direct national participation in nuclear power projects.

National participation in a project generally means the use of locally produced material and domestic staff resources without downgrading the quality and safety aspects of the project nor jeopardizing the schedule of project execution. Meaningful national participation in a nuclear power and plant construction industry requires the existence of a capable construction industry, and medium and heavy manufacturing, including cement, steel, machinery and equipment and chemicals, as well as competency in other services such as civil engineering, quality assurance and control and testing, and specialized manpower training including managerial skills.

The first nuclear power plant in the Republic of Korea[4] was an imported reactor with imported service and support; all early plants were built mainly through turnkey contracts, with little participation by domestic industries and limited use of local labour or construction materials (e.g. for on-site non-specialized purposes) (NEA, 2006). In 1985, the Government started implementing an incremental national self-reliance policy and began allocating some responsibilities to local organizations. At first these were limited to civil engineering and design, construction, and plant engineering, manufacture of some equipment and non-critical components for balance of plant and for project management. Design and manufacture of the primary systems and turbine generator was still contracted with foreign suppliers. With construction of the Yonggwang 3 and 4 nuclear power plants in 1989, domestic nuclear industries became the prime project contractors with only limited technological support and technology transfer from foreign subcontractors (NEA, 2006). Equally important, local manufacturers extended their normal product lines to incorporate nuclear designs and standards, and special factories were set up locally to manufacture heavy and specialized nuclear components, some under licensing arrangements with foreign suppliers.

The process of nuclear power development in the Republic of Korea is shown in Figs 1.3 and 1.4.

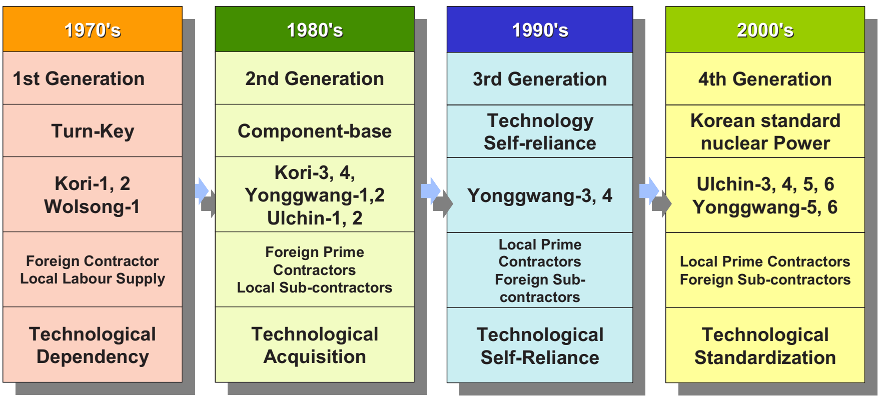

FIG. 1.3. Evolution of project structure(source: KHNP).

The Republic of Korea has rapidly accumulated extensive experience in nuclear sector development and planning and nuclear power plant

[4] Commercial nuclear power production commenced with the operation of Kori Unit 1 in 1978.

construction and operation. Over the past three decades, the Republic of Korea has become one of the world's leading nuclear power countries, with 20 nuclear power plants in commercial operation in 2005, with a total net generating capacity of nearly 17.5 GW, supplying approximately 18% of the Republic of Korea's total primary energy and more than 40% of the nation's electricity.

The Republic of Korea is already exporting reactor components, and is now also in a position to supply plants for export. It has already developed the Korean Standard Nuclear Reactor (KSNP), a PWR that is being used in Ulchin-3, 4, 5 and 6, and Yonggwang-5 and 6. It is also constructing a Korean Advanced Pressurized Reactor (APR) for Shin-kori 3 and 4, and the Optimized Power Reactor 1000 (OPR 1000). The Republic of Korea may therefore well be a strong competitor in the vendor and plant supplier market in the near future. Based on domestic technology and more than twenty years of experience in the construction and operation of nuclear power plants, the nuclear industry in the Republic of Korea is in fact actively developing an overseas nuclear power business aimed at supplying engineering and technical services, components, construction services, or even the complete building of a KSNP.The overseas engineering and technical services will cover the plant life cycle including project planning, project management, equipment procurement, commissioning and start-up, operation and maintenance, as well as replacement of major equipment, such as steam generators.

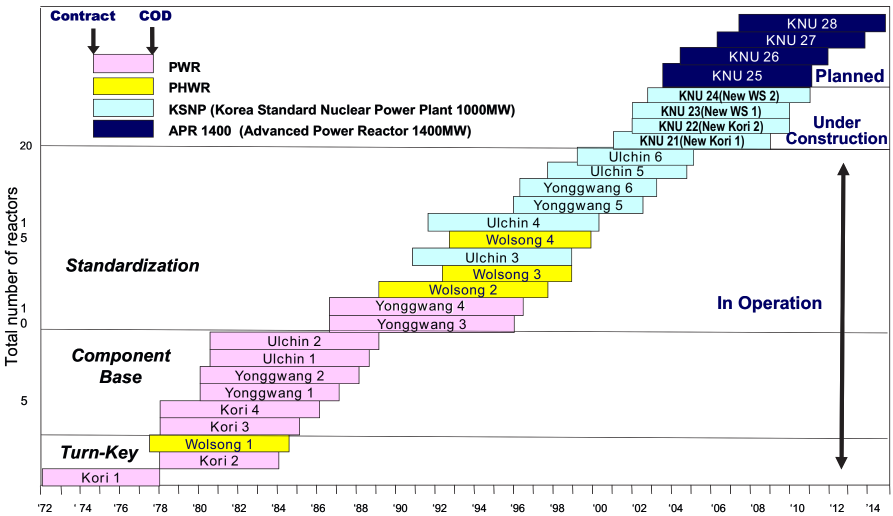

FIG. 1.4. Development schedule of nuclear power plants (source: KHNP).

The Republic of Korea has accomplished significant scientific and technological development through domestic research and international cooperation. It has two operating research reactors: the AGN (0.1 kW) in use for academic purposes since 1982 at Kyonghee University, and the HANARO (3MW), in use since 1996 producing radioisotopes for cancer treatment, medical applications and industrial uses. In 1992, the ten year "National Medium-and-Long-term Nuclear R&D Programme" was launched, in five research fields: advanced reactor and fuel, nuclear safety, radioactive waste management, application of radiation and radioisotopes, and fundamental technologies. Under the advanced reactor programme, near term reactor options such as the KNGR (Korea Next Generation Reactor) and SMART (System-integrated Modular Advanced Reactor), and mid and long term reactor options such as KALIMER (Korea Advanced Liquid Metal Reactor) for power generation and HYPER (Hybrid Power Extraction Reactor) as a burner of TRU waste, are all under development.

The country is now seeking a more active role in the global science and technology community both to contribute to scientific advancement and to further its knowledge for domestic social and economic development (NEA, 2006). This is being pursued actively through bilateral cooperation with the USA, the United Kingdom, Japan, China, Germany and the Russian Fedration, and multilateral cooperation within the Asia-Pacific Economic Co-operation (APEC), the Organization for Economic Co-operation and Development (OECD), with the Generation IV International Forum (GIF) and with the European Commission (NEA, 2006). The Republic of Korea is also pursuing a fast reactor (Kalimer). Under GIF, in 2004 it added to the Kalimer a high temperature reactor (HTR)-based hydrogen generation project, as well as a very high temperature reactor (VHTR) project.[5]

1.2.2. Energy supply security

Fuel import dependence, and hence vulnerability to international fuel price volatility, has been reduced with the development of nuclear power. Nonetheless, the Republic of Korea is still a major importer of energy. In 2005, The Republic of Korea's net energy imports corresponded to 84% of its total TPES as well as almost 10% of the total net energy imports of OECD countries in 2005. Depending on the year, energy imports (excluding uranium) account for some 15% to 20% of the Republic of Korea's total imports. While energy fuel imports continue to rise in absolute terms as the

[5] Nucleonics Week, 25 March 2004.

economy of the Republic of Korea expands, the rate of increase is lessened by the extent of substitution of nuclear for fossil-based generation.

The Republic of Korea has a number of policies in force to further reduce imports. (See Appendices 4-6). The government aims to boost the share of renewables to 5% of TPES in 2011 through various support policies such as tax incentives and preferential loans (IEA, 2004 & 2005). According to the "2nd Basic Plan of Long-term Electricity Supply and Demand" (KPX, 2004), finalised by the Ministry of Commerce, Industry and Energy (MOCIE) in 2004, ten new nuclear power units will be constructed by 2017, including four units already been ordered.

1.2.3. Market restructuring

The restructuring of the power sector of the Republic of Korea is part of a long term government move to privatize and liberalize its markets. Until the 1970s, the Government of the Republic of Korea, as in most developing countries, owned or controlled and operated the social infrastructure – electricity, telecommunication, roads, railways, ports, refineries, steel, etc. Industrial development provided new demand and markets for such services, including electricity, and hence more profits attracting the interest of private sector investors. At the same time, the trade liberalization begun in the 1960s and 1970s to facilitate exports, spread to increase foreign and then domestic competition. Ultimately, these policies and factors created strong pressure for deregulation, market liberalisation and privatization of the public service sector. This has been a steady but gradual process. Privatization began in 1968 with the heavy industries, then in 1980 for banking and oil. In 1987, the initial plan for privatizing electricity, telecom and the post was introduced, but final restructuring of the electricity sector and of the national electricity company KEPCO began in 2001 and will be completed in 2009.

The restructuring of the nuclear power sector in the Republic of Korea should be viewed in this context, as an integral part of this continuum. Restructuring of the energy/electricity sector began in the late 1990s to create a more competitive market, increase economic efficiency and improve financial stability in the electricity sector. The national generating company KEPCO has been divided into six generation companies including one larger combined hydro and nuclear power company, and five commercially and technologically equal thermal power companies. This restructuring was deemed crucial to improved efficiency, competitiveness and profitability of the generating power sector. The Korea Hydro and Nuclear Power Corp. (KHNP) also includes water supply and flood control, and power supply and demand forecast and analysis. This company will remain a public entity, while the other power generation companies, consisting of fossil fuel and pump storage power plants, will be privatized sometime in the future. A system/market operator, the Korea Power Exchange (KPX) operates all transmission and distribution business and operates an integrated market/dispatch system for the generation pool. Restructuring should be complete in 2009 with the implementation of retail competition.

The main national laws and regulations applicable to nuclear power are:

- 1958 Atomic Energy Act, implementing texts, and 1994, 1996, and 1999 amendments;
- 1969 Nuclear Compensation Act, last amended in 2001;
- 1971 Regulations on the Nuclear Installation Licensing System;
- 2004 Act on Physical Protection and Radiological Emergency.

The policies guiding the investment and marketing strategies for KHNP include those articulated by the Atomic Energy Commission in its 2006 *Direction to Long-term Nuclear Energy Policy Towards the Year 2030*. (NEA, 2006) These include:

- Achieving self-reliance in a nuclear reactor and proliferation resistant nuclear fuel cycle technology through comprehensive and systematic nuclear energy research and development;
- Fostering nuclear energy as a strategic export industry;
- Playing a leading role in the improvement of human welfare and the advancement of science and technology by expanding the use of nuclear technology;
- Enhancing the stability of energy supply by promoting nuclear energy as a major energy source of domestic electricity generation.

Environmental concerns can also be expected to help shape these policies and their implementation.

2. ENERGY/ELECTRICITY BALANCES: DEMAND AND SUPPLY

The patterns of energy and electricity supply have changed over time to keep pace with population and economic growth, and rising energy demand. Nuclear power has been an important part in this process.

2.1. ENERGY DEMAND

The structure of the Republic of Korea's final energy demand has been dominated by oil products (Fig. 2.1 — left part). These accounted for an almost unchanged 50% of total final energy demand from 1980 to 2005, mostly for industrial uses and transportation. Demand for oil has been growing since the 1970s, except immediately after the two oil shocks of 1973–1974 and 1979. The largest annual increases in oil demand — 13.6% — occurred between 1989 and 1997.

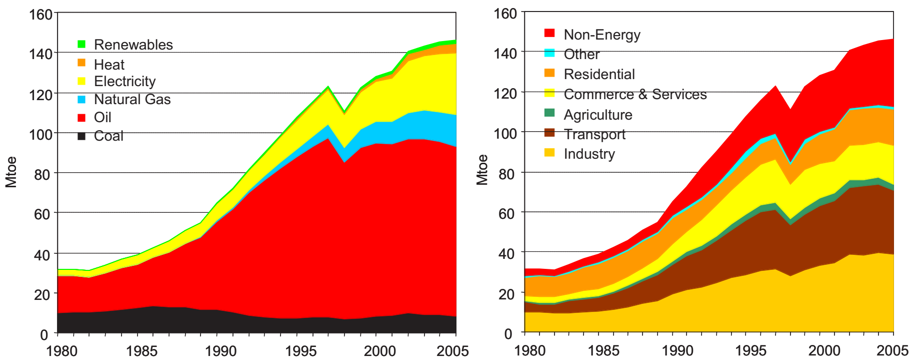

FIG. 2.1. Total final energy demand by fuel (left) and sector (right)(source: EEDB, IAEA; IEA/OECD, 2007).

Electricity supplies 20% of final energy demand in 2005, up from a 9% share in 1960. Use of coal has shifted dramatically away from domestic anthracite in residential use to the use of imported coal for power generation. Natural gas in the form of LNG, prized for its cleanliness and convenience, entered the market as relative newcomer in the late 1980s and has rapidly replaced coal in the residential and industrial sectors. In 2005, gas accounted for 11% of total final demand while coal use dropped from 31% in 1980 to less than 6% in 2005. Note that primary energy demand for oil and gas dropped during the Asian financial crisis of 1997–1978 (16% for oil and 6% for gas), while primary demand for coal, electricity (nuclear and hydro) and renewables continued to grow.

About 26.6% of total final energy use was used by industry, 25.8% by the residential and commercial sectors, 21.8% by the transport sector, 2.1% in agriculture sector and 23.7% by the others including the public sector and non-energy use (Fig. 2.1 — right part). Rapid economic growth and increase in personal income have led to a sharp growth in the demand for transportation and the number of cars has greatly increased — almost 120-fold in thirty years — with privately owned cars showing particularly rapid growth. In the passenger transport sector, subway routes continue to expand in line with the growth of national income. Domestic aviation and maritime shipping are both becoming increasingly important as transport modes for passengers and freight respectively. Figure 2.2 compares a further breakdown of final energy use by sector and fuel for 1980 and for 2005.

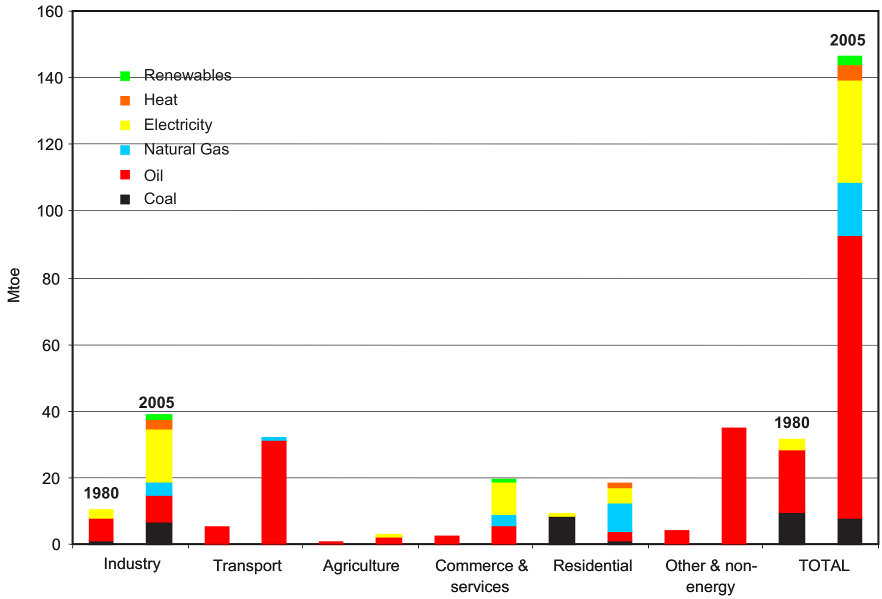

FIG. 2.2. Total final energy use by fuel and sector, 1980 and 2005(source: EEDB, IAEA; IEA/OECD, 2007).

2.2. ENERGY SUPPLY

With rapid national economic development, TPES has increased sharply since the early 1970s. By 2005, the Republic of Korea's TPES amounted to 213.8 million tonnes of oil equivalent (Mtoe), making it the tenth largest energy using nation in the world.

Figure 2.3 depicts the evolution of the Republic of Korea's primary energy mix (including imports) from 1980 to 2005. In 2005, oil held the major share with 45.0%, followed by coal (23.1%), nuclear power (17.9%), natural gas (12.8%), hydropower (0.1%) and other renewables (1.0%).

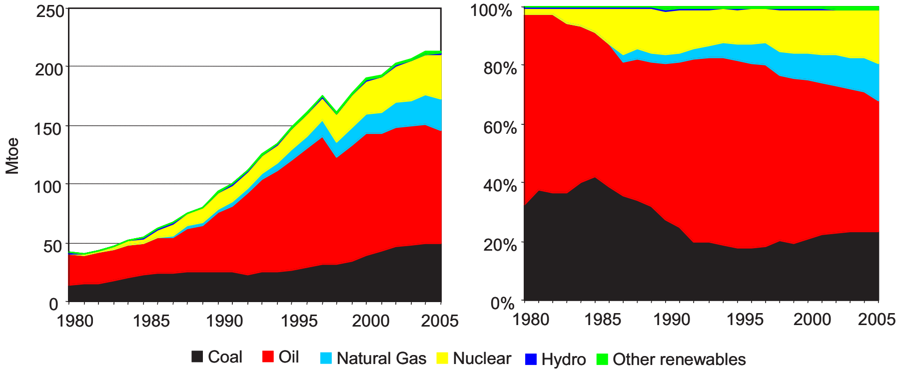

FIG. 2.3. Total primary energy supply by fuel, 1980–2005(source: EEDB, IAEA; IEA/OECD, 2007).

The country's energy resource endowment is limited and the Republic of Korea's industrialization has been fuelled largely with energy imports both in absolute and relative terms. Figure 2.4 shows TPES broken down into domestic production and imports. It shows (left side) a near four-fold increase in domestic energy production since 1980s, almost exclusively from nuclear energy. Nuclear power did not exist in the Republic of Korea before 1977, but has increased at an annual average rate of 21.5%.

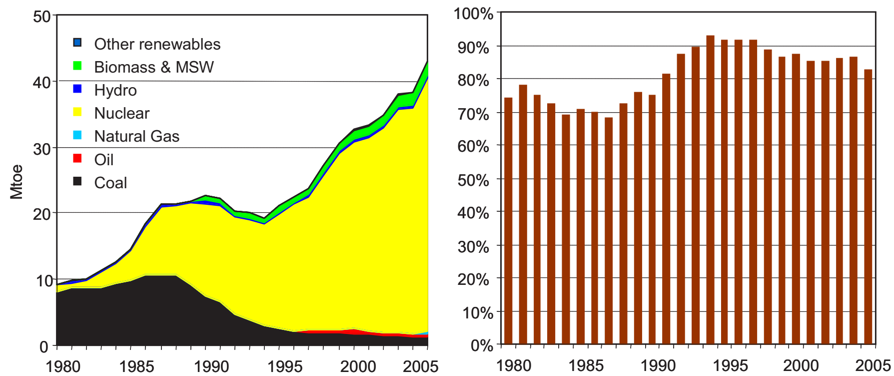

FIG 2.4. Domestic primary energy production (left) and energy import dependence (right)(source: EEDB, IAEA, 2007).

Coal production has fallen by over 80%. The production of renewable energy and crude oil together contributed less than 5% to domestic energy production in 2005, 40% of which came from combustible biomass and municipal solid waste utilization. There are no reliable data for renewables before 1994. Their share of TPES remains marginal: although renewables have grown at double digit growth rates (25% and more) per year, they still account for only about 0.5% of TPES in 2005.

The right hand diagram shows net energy import dependence declining during the early 1980s, but then increasing as a result of steadily slipping domestic coal production. This and the rapid growth in the demand for transportation fuels and non-energy chemical feedstock more than outpaced the market penetration of nuclear power. Without nuclear power, the Republic of Korea's energy net import dependence would be close to 100%.

Virtually 100% of the oil supply in the Republic of Korea is imported. Coal imports have grown continuously at an annual average rate of 6.9% for the past 30 years, almost exclusively for power generation. LNG imports were introduced in 1986 and grew quickly, to reach 10.6% of TPES in 2005. As described in Section 3.4, the Republic of Korea does import uranium, and purchases conversion and enrichment services abroad. In 2003, uranium imports accounted for 6.3% of total fuel imports (data on imports of nuclear fuel services are not available).

2.3. ENERGY INTENSITY

Energy intensity (TPES divided by GDP) remains high in the Republic of Korea. In the 1990s, economic growth was led by investments in energy-intensive industries — petrochemicals, steel and shipbuilding. Expanded industrial oil use, an expanding demand for transportation and greater use of electricity all contributed to high growth in energy demand. In the 1980s, GDP grew at an average rate of 8.7% per annum, TPES/GDP fell by 0.2% per year, and electricity/GDP grew at 2.4% per year. In the 1990s, GDP grew at an average rate of 6.1% per year, TPES/GDP grew at 1.2% and electricity/GDP at 3.0%. The trend of increasing primary energy intensities was reversed during the early years of the 21st century, but electricity intensity continues to rise. By 2005, GDP grew at an average rate of 4.5% per year, TPES/GDP fell by 2.1% and electricity/GDP grew at 4.0%.

2.4. ELECTRICITY DEMAND

Energy demand tends to increase as the economy grows, and the growth in electricity demand tends to be greater than that for total primary energy. This has certainly been the case in the Republic of Korea. Figure. 2.5 shows that growth in electricity generation (gross) by far outpaces both GDP and TPES growth, which highlights the critical role of electricity in Korea's economy.

Figure 2.6 (left) shows historical annual growth rates for electricity while Fig. 2.6 (right) shows the development of electricity demand by sector. As to future growth, there are different opinions whether future electricity demand in the Republic of Korea can be reduced drastically without sacrificing economic growth by shifting to a less energy intensive industrial structure and improving technical efficiency of energy use, or whether any reduction in electricity use would jeopardize continued economic growth.

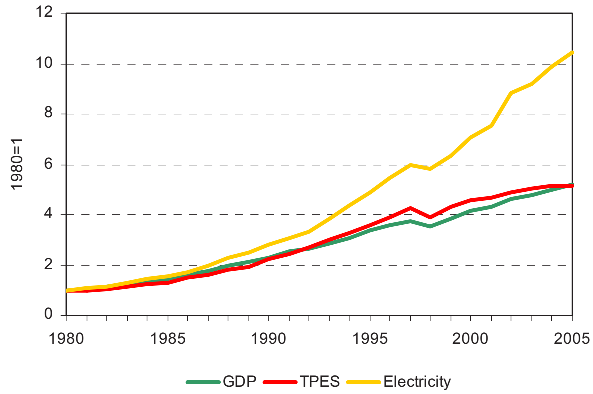

FIG. 2.5. Electricity and TPES in relation to GDP.

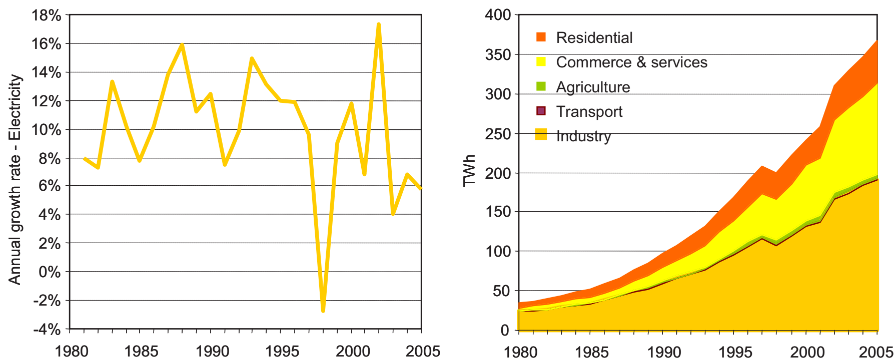

FIG. 2.6. Annual growth rates for electricity (left) and electricity use by sector (right).

2.5. ELECTRICITY PRICES

Electricity prices in the Republic of Korea have long been below the OECD average, reflecting in part a different level of economic growth, and in part some subsidization. Data for 2005 (OECD on-line database) show electricity prices for the industrial sector in the Republic of Korea comparable to those in France and lower than in Germany (by 32%), Italy (67%) and Japan (59%). The price was US 5 cents/kW·h in the Republic of Korea, while it was in the range of 8 to 16 cents for other countries. The electricity price for the household sector in the Republic of Korea was lower than in France (by 44%), Germany (60%), Italy (58%) and Japan (60%). The price was 8 cents/kW·h in the Republic of Korea while this price was in the range of 14 to 20 cents for the other countries.

2.6. ELECTRICITY SUPPLY

Figure 2.7 provides an overview of the Republic of Korea's electricity supply mix between 1980 and 2005. Fossil fuels (coal, gas and oil) generate the greatest share of electricity. They accounted for over 80% of generation in the early 1980s, falling to less than 40% by the end of the decade. This was due to a rapid increase in nuclear power uptake. In the 1990s, the share of fossil fuels grew from 44% in 1990 to 60% in 2005. In that same period, nuclear's relative contribution fell from 50% to 38%. This drop does not mean that nuclear power generation has decreased. These shares reflect only relative positions: both nuclear generation and total generation have been growing in absolute numbers, but total generation has been growing faster, requiring greater use of all generating technologies. LNG, initially used for peaking power, is now used for baseload generation as well. The contribution of hydro, pumped storage, renewables and waste (too small to be distinguished in this figure) is less than 7%.

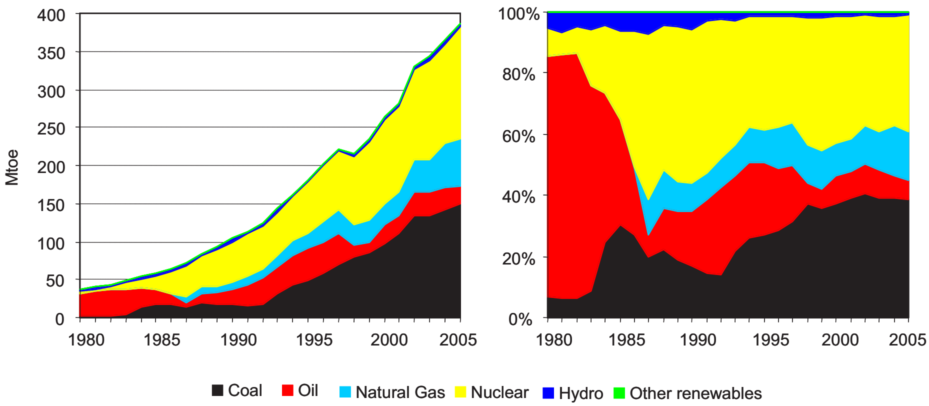

FIG. 2.7. Supply structure of gross electricity generation – absolute production (left) and shares (right).

The Republic of Korea produces a significant amount of combined heat and power (CHP). CHP can be highly fuel effective, but only if the demand for heat is high enough to maintain a constant production level. The load pattern of heat shows great seasonality in the Republic of Korea, and so CHP may not be competitive with other electricity options, including nuclear power.

In terms of generating capacity, coal fired power generation, fuelled almost exclusively by imported coal, is slightly greater than nuclear capacity (both around 29% in 2005), but nuclear has a small edge in generation (Table 2.1, Fig. 2.8). Investment in oil and hydro capacity has stagnated, but LNG capacity has expanded rapidly despite relatively high infrastructure and import costs.

TABLE 2.1. GROSS ELECTRICITY GENERATING CAPACITY BY FUEL, 1970-2005 (MW OF CAPACITY AND % OF TOTAL)

Fuel	1970	1980	1985	1990	1995	2000	2005
Nuclear	-	587 (6.3)	2 866 (17.8)	7 616 (36.2)	8,616 (26.8)	13 716 (28.3)	17 715 (28.5)
Coal	537 (21.4)	750 (8.0)	3 700 (22.9)	3 700 (17.6)	7,820 (24.3)	14 031 (29.0)	17 965 (28.9)
Oil	1 642 (65.5)	6 897 (73.4)	7 348 (45.5)	4 815 (22.9)	6,119 (19.0)	4 866 (10.0)	4 710 (7.6)
LNG	-	-	-	2 550 (12.1)	6,536 (20.3)	12 689 (26.2)	16 447 (26.4)
Hydro	329 (13.1)	1 157 (12.3)	2 223 (13.8)	2 340 (11.1)	3,093 (9.6)	3 149 (6.5)	3 883 (6.2)
Total	**2 508**	**9 391**	**16 137**	**21 111**	**32 184**	**48 451**	**62 258**

Source: Electricity Statistics, KEPCO, 2007.

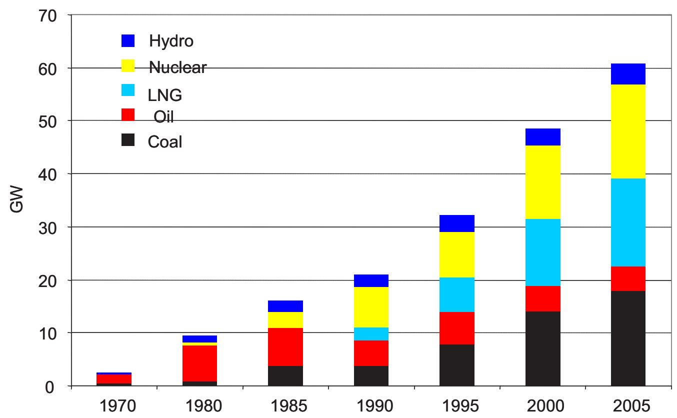

FIG. 2.8. Electricity generating capacity by fuel, 1970-2005(source: Electricity Statistics, KEPCO, 2007).

3. NUCLEAR POWER

3.1. HISTORY AND CURRENT STATUS

The nuclear power industry in the Republic of Korea has evolved from an importer to a potential exporter of nuclear plants and technologies. The active history of the industry started in 1978 when Kori-1, built on a turnkey basis by Westinghouse, first began commercial operation. Since then, 20 nuclear power reactors have been put into operation, and nuclear has achieved a major if not dominant share in total electricity generation and capacity. The 20 plants in operation are all owned by KHNP. Sixteen of them are pressurized water reactors (PWR), and the others are CANDU pressurized heavy water reactors (PHWR) (Table 3.1). Nuclear power plants operating in the Republic of Korea by sites are shown below in Fig. 3.1.

TABLE 3.1. NUCLEAR POWER PLANTS OPERATING IN THE REPUBLIC OF KOREA

Plant		**Reactor type**	**MW**	**Manufacturer**		**Operation**
				Reactor	**T/G**	
Kori	Unit 1	PWR	587	WH	GEC	1978
Kori	Unit 2	PWR	650	"	"	1983
Kori	Unit 3	PWR	950	"	"	1985
Kori	Unit 4	PWR	950	"	"	1986
Wolsong	Unit 1	PHWR	679	AECL	NEI-Parson	1983
Wolsong	Unit 2	PHWR	700	Hanjung/ AECL	Hanjung/GE	1997
Wolsong	Unit 3	PHWR	700	"	"	1998
Wolsong	Unit 4	PHWR	700	"	"	1999
Yonggwang	Unit 1	PWR	950	WH	WH	1986
Yonggwang	Unit 2	PWR	950	"	"	1987
Yonggwang	Unit 3	PWR	1000	Hanjung/CE	Hanjung/GE	1995
Yonggwang	Unit 4	PWR	1000	"	"	1996
Yonggwang	Unit 5	PWR	1000	Hanjung	Hanjung	2002
Yonggwang	Unit 6	PWR	1000	"	"	2002
Ulchin	Unit 1	PWR	950	Framatome	Alsthom	1988
Ulchin	Unit 2	PWR	950	"	"	1989
Ulchin	Unit 3	PWR	1000	Hanjung/CE	Hanjung/GE	1998
Ulchin	Unit 4	PWR	1000	"	"	1999
Ulchin	Unit 5	PWR	1000	Doosan	Doosan	2004
Ulchin	Unit 6		1000	"	"	2005

Source: IAEA Power Reactor Information System (PRIS), 2007.

Note: 1.Hanjung was renamed to Doosan in 2001.
2. Capacity is in gross MW.

The Republic of Korea is one of a few countries that relies heavily on nuclear power generation for their electricity demand. Other industrialized countries that generate substantial portions of their electricity from nuclear power include France (78.5%), Germany (31.0%), Japan (29.3%) and the USA (19.3%). By contrast, for large developing countries such as Brazil, India and China, the percentages are only 2.5%, 2.8% and 2.0%, respectively.

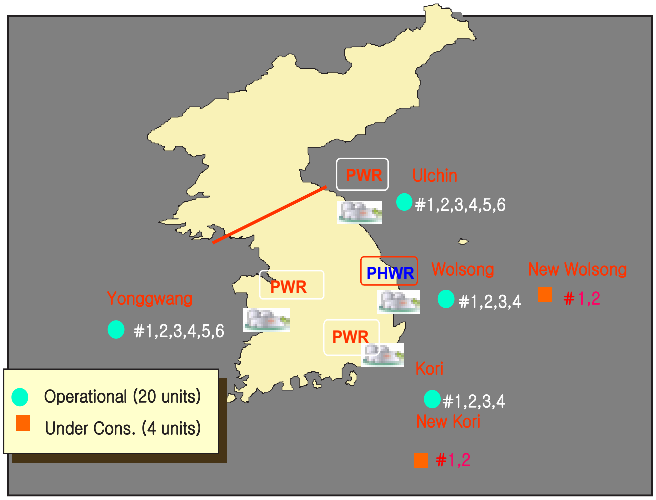

FIG. 3.1. Nuclear power stations in the Republic of Korea.

3.2. CONSTRUCTION SCHEDULE

The Republic of Korea is one of the few countries in which nuclear construction is currently being pursued. In 2006, four 1 000 MW(e) PWRs were under construction[6] and four 1400 MW(e) PWRs are planned to be built by 2015. The plants under construction and planned are listed in Table 3.2.

[6] As defined by the Government of the Republic of Korea and not consistent with PRIS.

TABLE 3.2. NUCLEAR POWER PLANTS UNDER CONSTRUCTION AND PLANNED IN THE REPUBLIC OF KOREA

	Plant	Reactor type	Gross Capacity (MW)	Commercial Operation
Under construction	Shinkori#1	PWR	1 000	2010
	Shinkori#2	PWR	1 000	2011
	Shinwolsong#1	PWR	1 000	2011
	Shinwolsong#2	PWR	1 000	2012
Planned (Advanced Power Reactor)	Shinkori#3	PWR	1 400	2012
	Shinkori#4	PWR	1 400	2013
	APR#1	PWR	1 400	2014
	APR#2	PWR	1,400	2015

Source: The 2nd Basic Plan of Long-term Electricity Supply and Demand, MOCIE, 2004.

3.3. OPERATING PERFORMANCE

Over the past decades, the Republic of Korea's operating nuclear power plants have shown steadily higher performance levels and demonstrated their economic competitiveness relative to alternative generating sources. Nuclear power plants have proved to be a reliable, environmentally acceptable and extremely efficient source of electrical energy. The average nuclear plant capacity factor in the Republic of Korea in the last ten years was 90.2%, higher than the world average (Fig. 3.2). The mean nuclear plant capacity factor in 2005 was 93.6%, a record high; in the same year, the world average was 81.7%. Nuclear plant records in the Republic of Korea for unplanned outages and trips are similarly among the best in the world (Table 3.3).

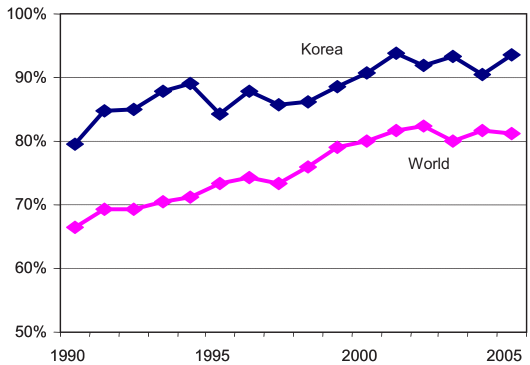

FIG. 3.2. Comparison of annual average capacity factor of nuclearpower plants between the Republic of Korea and the world(source: PRIS, IAEA, 2007).

TABLE 3.3. UNPLANNED OUTAGES RATIO (CASE/PLANT)

Year	Canada	France	Japan	Korea	United States
1990	4.6	6.7	0.4	**2.7**	3.6
1991	5.4	6.8	0.2	**3.2**	3.9
1992	2.7	5.9	0.3	**1.3**	3.8
1993	3.6	4.1	0.2	**1.4**	2.6
1994	3.7	4.8	0.1	**1.1**	2.3
1995	3.3	6.4	0.2	**1.0**	2.6
1996	3.3	4.1	0.2	**0.8**	2.5
1997	3.3	5.7	0.2	**1.2**	2.0
1998	2.5	5.5	0.3	**0.2**	1.9
1999	1.6	5.3	0.3	**0.9**	1.4
2000	1.9	4.5	0.4	**0.4**	1.4
2001	2.0	5.1	0.3	**0.5**	1.4
2002	1.6	3.4	0.5	**0.2**	1.2
2003	3.3	4.9	0.8	**0.5**	1.9
2004	3.3	4.9	0.9	**0.6**	1.3
2005	2.9	3.5	0.9	**0.5**	1.2

Source: PRIS, IAEA, 2007.

At the same time, nuclear power has proved itself to be competitive in terms of generating costs (Table 3.4). In 2005, the cost of nuclear generation (39.1 won/kWh) was less than that for coal (48.6 Won/kW·h). Both nuclear and coal were far below the cost of oil or LNG fired generation, the cost of hydropower, or the system average cost of 50.67 Won/kW·h. Since 1980, the growing share of low cost nuclear generation has contributed to the stability of electricity prices. The average price of electricity actually fell from 1982 to 1992, at a time when consumer prices generally rose by as much as 9% annually (Fig. 3.3).

TABLE 3.4. COMPARISON OF GENERATION COST BY SOURCE IN 2005 (WON/KW·H)

Nuclear	Coal	Oil	LNG	Hydro	Average
39.1	48.6	91.1	87.1		51.0

Source: KEPCO Statistics, 2007.

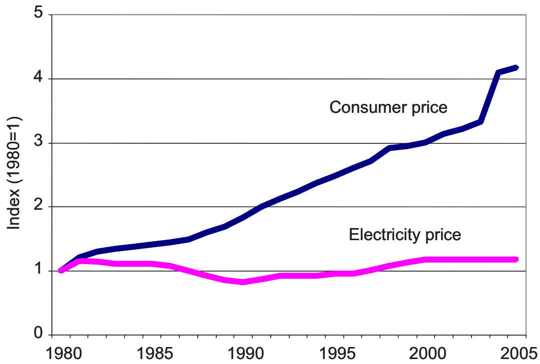

FIG. 3.3. Electricity price versus consumer price index(source: Korea National Statistical Office and KEPCO, 2007).

3.4. NUCLEAR FUEL AND TECHNOLOGY IMPORTS

The Republic of Korea's demand for uranium and nuclear fuel cycle services has grown with the expansion of its nuclear power capacity. Since the year 2000, the Republic of Korea accounts for about 5% of the world's uranium demand. It imports uranium concentrates from Australia, Canada, France, Kazakhstan and the USA. In 2005, the Republic of Korea imported a total of 9.8 million pounds of uranium (U_{238}) concentrates. Conversion and enrichment services are purchased by long term contract from the USA, the UK, France, Canada, and the Russian Federation. Fuel fabrication services are fully provided locally, using imported uranium.

Virtually all fission product radioisotopes are imported, mainly in keeping with non-proliferation commitments undertaken by the Republic of Korea. It also imports the nucleonic control systems for its operating reactors. Roughly 70% of the conventional radioisotopes used for medical and industrial purposes are imported. Industrial iridium sources and some medical isotopes are produced domestically and even partly exported.

4. VALUE ADDED FROM NUCLEAR POWER TO NATIONAL GDP

This section is attempts to quantify nuclear power's value added contribution over time to the value of industrial output in the Republic of Korea, and hence ultimately to GDP. The basis for this effort is an I–O analysis[7] that quantifies the purchases of goods and services that any one industry — in this case nuclear power — makes from other industries, and the extent to which these purchases contribute to the final value of the output in each of these other industries. This contribution is generally first calculated in terms of output, from which value added is derived. The time period studied is 1980 to 2005 in five year increments.

The economic impact of the nuclear power sector is calculated here only in terms of industrial output and value added as derived using I–O analysis, a limitation dictated in part by data availability. The analysis focuses on the inter-industry impacts of nuclear power plant construction and operations, defined first as the share that these purchases contribute to final demand for industry output, and ultimately by the contribution of nuclear power to the value added of this increased output. Because of this focus on nuclear power sector purchases from other industries, the analysis does not include factors of production (land, labour or capital), nor does it include intermediate inputs. Hence, neither employment nor sales of electricity are included in the calculation.

4.1. STRUCTURING THE I–O TABLES

For this analysis, we used I–O tables derived from the Korean National I–O Table, published by the Korean National Bank. The first major step was to review, refine and reconstruct the national I–O tables to accommodate the level of detail needed for our analysis, and to better trace those activities involving nuclear power. This involved constructing time series and I–O tables for industrial statistics to the three digit International Standard Industry Code (ISIC) level, based on the national team's extensive and thorough understanding of the economy of the Republic of Korea, a knowledge of which industries have been or are now associated with nuclear power, and the linkages between them. It was the most critical and among

[7] I–O analysis was pioneered by Wassilief Leontief (1930), with an I–O model at the national level. Regional I–O analysis was developed later by W. Isard (1951), with subsequent contributions by Moore and Petersen (1955), Isard and Kuenne (1953), Miller (1957), Hirsch (1959), Bourque and Cox (1970), and Giarratani, Maddy and Socher (1976).

the most demanding aspects of the project. The approach and structure of this analysis were validated and calibrated by KAERI using the nuclear electricity generation industry for the year 2000 as a test case.

The original National I–O Table has four levels of sector classifications: 404 sectors covered in the basic survey, regrouped first into 168 sectors, then into 77 larger sectors and finally into 28 major industrial classifications. To better reflect the industrial linkages of the various nuclear technologies, for this study the National I–O Table for the Republic of Korea was modified to comprise 36 sectors, with the industry sector divided into 16 sectors. All industry data from the original 28 industry sectors were first transformed to the three digit level of ISIC, then regrouped into the newly structured 16 industry sectors. Since all coefficients in a given sector or grouping of sectors are additive, this restructuring of the original table to a simpler form does not invalidate any of the input coefficients taken from the original table. This revised I–O structure was used for assessing the economic contributions of both the nuclear power and radio-isotope industries.

The economic activities associated with the nuclear power sector were broken down and classified as construction, nuclear fuel fabrication, operation and maintenance. In the case of plant construction, the activities are divided into civil construction, architecture engineering, and component manufacturing. Component manufacturing is further divided by main component (instruments, other machinery, and instrument and control devices). Additional sector classifications were made for finance and insurance, and external power supplies, which are needed for the construction and operation of a nuclear power plant.

The analysis and the presentation of results for construction and operation are not entirely parallel, due to differences in data availability. Data on expenditures and inputs for construction as provided by KHNP were sufficiently detailed to be used directly to calculate final demand in other sectors. In the case of operations, intermediate inputs were directly obtained from the national I–O table, and then used to calculate final demand generated by the nuclear power operations from each other sector, and subsequently to estimate the output and value added of plant operation.

I–O tables are generally constructed using current prices, with the price of each input indirectly incorporated into and hence reflected in the input coefficients. Current prices are necessary to be able to calculate the percentage share of any sector to the whole in a given year. Given the plethora of data involved in constructing an I–O table, and given the intricacy of some of the I–O inter-sectoral relations, adjusting the equations to produce constant prices would complicate and weaken the analysis.

TABLE 4.1. REORGANIZED 36 SECTORS IN THE NATIONAL I–O TABLE

	Sector	Related nuclear activity
1	Agriculture, forestry, and fisheries	Food processing
2	Mining and Quarrying	
3	Food, beverage and tobacco	Food processing
4	Textile products & leather products	Non-destructive testing
5	Wood and paper products	Non-destructive testing
6	Printing, publishing and reproduction of recorded media	
7	Petroleum and coal products	
8	Chemicals and allied products	Radiochemistry
9	Inorganic basic chemical products	Nuclear fuel fabrication
10	Non-metallic mineral products	Non-destructive testing
11	Primary metal products	Non-destructive testing
12	Fabricated metal products	Non-destructive testing
13	General machinery and equipment	Manufacturing of main components and other machinery
14	Electronic and other electric equipment	Manufacturing of instrument and control devices
15	Precision instruments	Non-destructive testing
16	Transportation equipment	
17	Furniture and other manufacturing products	
18	Water power generation	
19	Thermal power generation	External electricity supplied to nuclear power plant in operation
20	Atomic power generation	Nuclear power plant operation
21	Self-power generation	
22	Gas and water supply	
23	Repair construction	Construction related to the operation and maintenance
24	Electric power plant construction	Construction of new nuclear power plant
25	Wholesale and retail trade	
26	Eating and drinking places, and hotels and other lodging places	
27	Transportation and warehousing	
28	Communications and broadcasting	
29	Finance and insurance	Finance and insurance of nuclear power plant
30	Real estate agencies and rental	Siting
31	Business services	Architecture engineering
32	Public administration and defence	
33	Educational and research services	Research reactors
34	Medical and health services, and social welfare	Nuclear medicine
35	Social and other services	
36	Dummy sectors	

Consequently, all monetary values in Chapters 4–7 are given in current Won. It is true, however, that using current prices means growth rates from year to year cannot be calculated.

The names of each of the reorganized national I–O sectors, and the related nuclear activities for the sectors are shown in Table 4.1.

For this I–O analysis, the focus is on domestic transactions of domestic goods and services as being most suitable for analysing the impact a domestic industry has on the national economy. This domestic transaction table nonetheless accommodates the contribution of imported goods (in this case, nuclear fuel) to output.

4.1.1. Nuclear Power Plant Construction

Data gathering and preparation are important aspects of empirical analysis. KHNP provided the raw data on nuclear power plant construction costs. They are classified as follows: initial fuel, building and structures, machinery equipment, architect and engineering services, interest during construction and owner's cost. These costs can be viewed as expenditures, and were used in the formulation of the I–O analysis as estimates of final demand created by the activities associated with construction of nuclear power plants.

These cost items were then matched to the corresponding sectors in the reorganized I–O table. Initial fuel is matched to inorganic basic chemical products, building and structure to electric power plant construction, machinery equipment to electronic and other electric equipment, architect and engineering to business services, and owner's cost is spread across several sectors including business services, furniture and other manufacturing, finance and insurance. These allocations are summarized in Table 4.2.

TABLE 4.2. MATCHING NUCLEAR POWER PLANT CONSTRUCTION COSTS TO CORRESPONDING I–O SECTORS

Collected cost items	Sectors in I-O
Initial fuel	Inorganic basic chemical products (9)
Building, structures	Electric power plant construction (24)
Machinery equipment	General machinery and equipment (13), Electronic and other electric equipment (14)
Architect/Engineering	Business services (31)
Interest during construction	Finance and insurance (29)
Owner's cost	Business services (31), Furniture and other manufacturing (17), Finance and insurance (29)

After this allocation, the contribution of nuclear construction activities to the final demand in each relevant sector was calculated. Figure 4.1 shows the contribution and the growth in importance of nuclear plant construction to each of the relevant and affected industrial sectors. The amount of nuclear power's final demand contribution directly depends on the magnitude of construction activities carried out in each period.

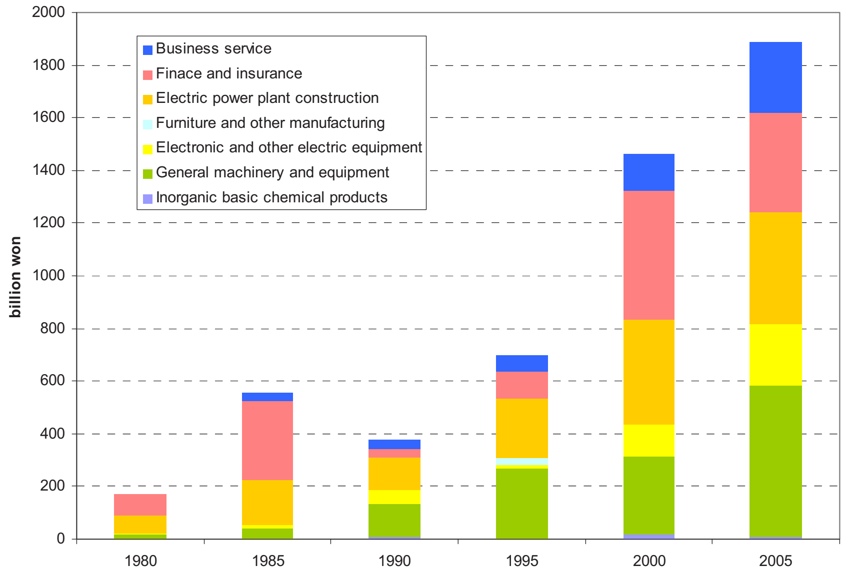

FIG. 4.1. Final demand in selected industries from nuclear power plant construction.

4.1.2. Nuclear Power Plant Operation

As with construction, the I–O analysis for nuclear power plant operations requires yearly final demand in each relevant industry generated by operating plants through expenditures for goods and services. The analysis of this annual final demand starts from the intermediate inputs to the nuclear sector taken directly from the reorganized I–O table in this study. Based on these intermediate inputs, some 29 sectors (out of 36) were identified as providing inputs to nuclear plant operations. The main ones include inorganic basic chemical products (for nuclear fuel fabrication), atomic power generation (input for internal power use), repair construction, finance and insurance, business services (all needed for plant maintenance), and educational and research services (including R&D activities in nuclear science and application). The uranium needed to support fuel fabrication services is imported, and is shown in the reorganized I–O table under the inorganic basic chemical products sector (11).

To be able to isolate the particular impact of nuclear plant operations among the inter-industry linkages of I–O table, the nuclear sector had to be treated conceptually as exogenous. This required a small modification of the model, and was expressed in the analysis as follows:

$$X = (I - A)^{-1} A_g X_g$$

where X = induced output, A = input coefficient without the nuclear sector, A_g = input coefficient of nuclear sector, X_g = output of the nuclear sector.

$A_g X_g$ is the domestic intermediate input to the nuclear sector in the I–O table, thus defining final demand attributable to nuclear operations in the model. The values for $A_g X_g$ (i.e. for the contribution of nuclear plant operations to each sector) thus obtained in the reorganized I–O table are shown below (Table 4.3).

4.2. EFFECTS OF NUCLEAR POWER PLANT CONSTRUCTION

The contribution to output and value added of nuclear power plant construction in each period are shown in Table 4.4 and Fig. 4.2. The I–O analysis results show that the industrial sectors affected by nuclear power plant construction varied as the character of the construction changed from turn-key plants to greater technological self-sufficiency. For example, before 1990, there were only two principal relevant industrial sectors: electric power plant construction, and finance and insurance. After 1990, as the Republic of Korea approached technological self-sufficiency in nuclear power plant construction, the number of relevant dominant affected sectors increased, to include primary metal products, general machinery and equipment, electronic and other electric equipment, and business services. In fact, the general machinery and equipment sector was the most dominant one for the years 1990 and 1995, reflecting large expenditures in these sectors for new plants.

Besides output generated as direct final demand for the nuclear sector, some industries have also experienced spill-over effects from the localization of plant construction activities. Most important of these is the primary metal products sector (11) (including steel), which has shown the greatest impact since 1990. This sector has been given a great indirect boost providing input to the construction of nuclear power plants, for example by developing special quality steel producing capabilities applicable to other sectors.

TABLE 4.3. BREAKDOWN OF NUCLEAR PLANT OPERATIONS AS DOMESTIC INTERMEDIATE INPUT IN THE REORGANIZED I–O TABLE (IN MILLIONS OF WON)

	1980	1985	1990	1995	2000	2005
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	30	76	1 330	2 274	3 112
5	0	25	74	185	323	358
6	104	643	1 334	1 773	2 153	3 045
7	193	3 426	7 107	9 440	21 621	23 911
8	0	111	1 272	1 858	2 627	3 270
9	4 357	25 958	53 754	170 342	445 846	405 139
10	0	66	721	405	2 662	3 711
11	0	26	35	6 710	7 700	10 799
12	0	604	2 437	4 023	9 933	14 807
13	0	1 937	4 929	12 065	39 286	54 457
14	595	4 630	18 542	33 254	91 882	102 087
15	0	823	3 233	2 195	7 493	7 914
16	50	414	1 552	2 440	1 228	1 721
17	896	38	135	1 414	942	1 589
18	8	70	7 953	7 244	2 548	3 558
19	97	629	71 576	152 619	78 755	104 983
20	11	284	79 528	96 303	100 769	126 081
21	0	0	0	0	0	0
22	39	186	535	480	400	939
23	870	15 094	132 230	286 238	427 227	517 382
24	0	0	0	0	0	0
25	1 478	6 064	27 617	12 266	28 510	31 368
26	0	0	0	0	0	0
27	184	1 056	4 801	8 610	12 727	35 849
28	157	1 006	2 545	14 082	23 168	28 867
29	3 392	15 218	36 764	46 801	223 453	261 556
30	306	1 314	2 820	2 458	4 103	5 635
31	78	5 928	35 471	56 318	144 434	225 961
32	0	0	0	0	0	0
33	157	1 644	3 815	92 797	148 772	253 768
34	8	550	645	4 294	25 015	57 044
35	0	327	788	1 881	4 823	6 764
36	3 826	9 169	31 463	30 300	55 752	67 664
Total	**16 806**	**97 270**	**533 752**	**1 060 125**	**1 916 426**	**2 363 141**

TABLE 4.4. INDUSTRIAL OUTPUT AND VALUE ADDED CONTRIBUTIONS OF NUCLEAR POWER PLANT CONSTRUCTION IN MAJOR RELEVANT INDUSTRIES (IN BILLIONS OF WON)

Sector	1980		1990		2000		2005	
	Output	VA	Output	VA	Output	VA	Output	VA
Primary metal products (11)	13.5	1.8	58.1	11.6	140.4	29.6	256.8	52.0
Fabricated metal products (12)	1.9	0.5	12.7	4.1	69.1	23.8	101.9	36.8
General machinery and equipment (13)	19.3	6.4	149.1	47.7	404.6	124.3	755.1	231.7
Electronic and other electric equipment (14)	22.5	6.2	107.2	30.3	254.5	69.5	386.2	109.1
Electric power plant construction (24)	65.7	22.2	122.7	45.2	398.9	134.5	428.1	151.6
Transportation and warehousing (27)	4.9	2.2	10.2	5.3	26.7	11.1	79.2	35.4
Finance and insurance (29)	93.6	69.3	50.3	34.0	609.2	419.0	481.2	341.7
Real estate agencies and rental (30)	3.6	2.8	9.6	7.4	53.1	41.3	63.3	48.[illegible]
Business services (31)	4.2	2.0	54.0	30.1	235.0	144.9	409.8	238.[illegible]
Educational and research services (33)	0.2	0.2	0.9	0.8	24.2	19.0	47.5	37.[illegible]
Total	**287.1**	**135.4**	**747.6**	**282.5**	**2 664.6**	**1 179.9**	**3 585.1**	**1 491.5**

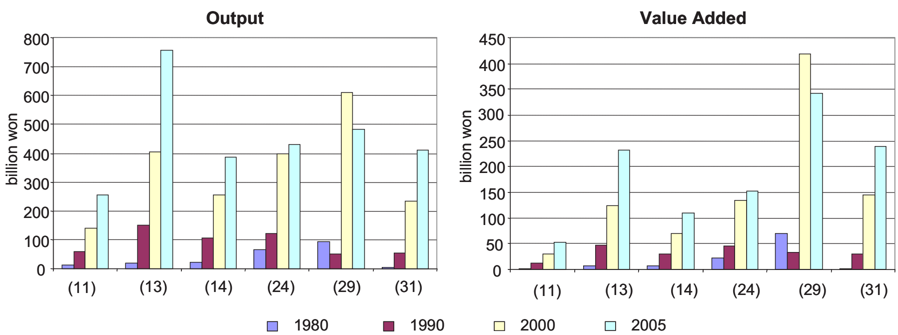

FIG. 4.2. Industrial output and value added contributions of nuclear power plant construction in major relevant industries.

4.3. EFFECTS OF NUCLEAR POWER PLANT OPERATIONS

Economic linkage effects of nuclear power plant operations show the same evolution as the construction phase, namely a shift in affected sectors as the number of plants and their degree of localization both grew. Before 1990, finance and insurance as well as inorganic basic chemical products were the sectors most affected by the operation of nuclear power plants. This is primarily due to the expenditures for nuclear fuel and interest payments for heavy loans made during that period. Since 1990, however, the construction sector (for repairs, extensions and maintenance) together with inorganic basic chemical products have become dominant, as nuclear power generation increased significantly, requiring inputs from these sectors for operation of the plants.

The output and value added contributions of nuclear power plant operation are shown in Fig. 4.3 and Table 4.5. There are three observations. First, thermal power generation plays a supporting role in the continuous operation of nuclear power plants, either to supply electricity to nuclear plants during shutdown periods (for overhaul and maintenance) or to serve as a redundant source of electricity as an operational safety measure. In some years this contribution has been more significant than others, largely depending on the timing of scheduled outages. Second, the finance and insurance and the business service sectors were found to have a lower value added from the plant operation phase than from the plant construction phase, despite the repayment of heavy construction loans extending into the operational phase. Finally, and not surprisingly, total demand for goods and services by the nuclear sector is increasing as time goes on, reflecting the growth of nuclear power generation in the Republic of Korea.

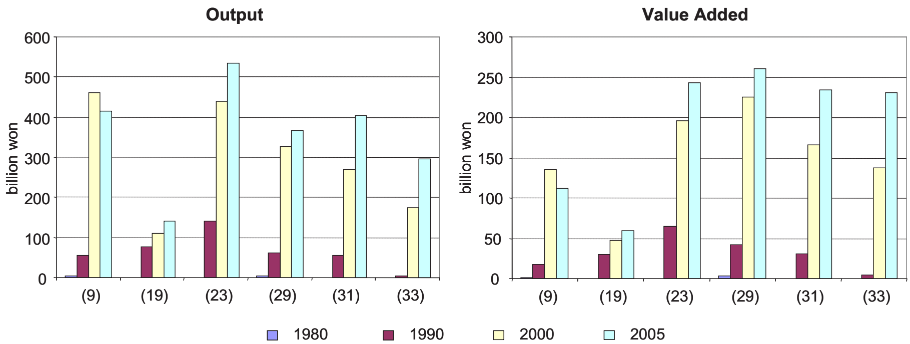

FIG. 4.3. Contribution of nuclear plant operations in major relevant industries.

TABLE 4.5. INDUSTRIAL OUTPUT AND VALUE ADDED CONTRIBUTION OF NUCLEAR POWER PLANT OPERATIONS IN MAJOR RELEVANT INDUSTRIES (IN BILLIONS OF WON)

Sector	1980		1990		2000		2005	
	Output	VA	Output	VA	Output	VA	Output	VA
Inorganic basic chemical products (9)	4.4	1.0	55.5	17.3	460.2	134.9	415.2	111.6
Thermal power generation (19)	0.5	0.2	78.3	29.2	111.2	46.8	141.7	59.7
Atomic power generation (20)	159.2	136.4	2 729.7	2 064.0	7 926.7	5 895.8	9 929.1	7 387.3
Repair construction (23)	1.0	0.4	141.2	65.2	439.7	195.7	532.9	242.5
Transportation and warehousing (27)	0.6	0.3	17.8	9.2	49.3	20.6	134.3	60.1
Communications and broadcasting (28)	0.4	0.3	9.2	7.7	72.5	42.4	88.5	53.6
Finance and insurance (29)	4.4	3.3	61.1	41.3	326.9	224.9	366.1	260.0
Real estate agencies and rental (30)	0.6	0.5	14.2	10.9	56.6	44.0	76.7	58.2
Business services (31)	0.3	0.1	56.1	31.2	269.2	166.1	402.9	234.3
Educational and research services (33)	0.2	0.1	4.5	3.9	174.9	137.7	295.7	230.5
Total	**191.2**	**148.4**	**3 570.8**	**2 413.8**	**11 081.1**	**7 281.3**	**13 864.6**	**9 163.0**

4.4. SUMMARY OF THE TOTAL NUCLEAR POWER CONTRIBUTION TO THE NATIONAL ECONOMY

Table 4.6 shows the estimated contribution of nuclear power to industrial output, from which was derived the industrial value added contribution of nuclear power to GDP. In 2005, the combined value added for both construction and operation of nuclear power plants were estimated to amount to some 1.3% of GDP in the Republic of Korea; 1.1% from operations and remaining 0.2% from construction. The overall value added from nuclear plant operations was greater than for construction for the whole study period except for 1980, when nuclear power generation accounted for only a small portion of electricity supply. This result is not surprising: the economic impact of construction is primarily limited to the period when the construction is done, while the economic impact of plant operations continues throughout the life of the plant.

TABLE 4.6. SUMMARY OF THE TOTAL NUCLEAR POWER SECTOR CONTRIBUTION TO GDP (IN BILLIONS OF WON)

		1980	**1985**	**1990**	**1995**	**2000**	**2005**
Gross output	Construction	287	938	748	1 514	2 665	3 585
	Operation	191	1 277	3 571	5 667	11 081	13 865
Value added	Construction	135	466	283	615	1 180	1 491
	Operation	148	1 018	2 414	3 581	7 281	9 163
GDP		37 116	78 848	178 317	375 803	599 645	810 516
Value Added Contribution to GDP		0.8%	1.9%	1.5%	1.1%	1.4%	1.3%

5. ESTIMATE OF NUCLEAR POWER'S INCREMENTAL CONTRIBUTION

The question that ultimately needs to be answered is whether nuclear power has provided positive incremental gains to the economy of the Republic of Korea: is the country better off for having invested in nuclear power, or not? Estimating the actual historical value added contribution of nuclear power to industrial output, as done in the previous chapter, is only a first step for answering this question. Although a full and complete analysis of the economy of the Republic of Korea is beyond the scope of this study, we can address at least the question of whether the nuclear power industry has made a positive incremental contribution to the value of industrial output.

This chapter therefore offers a truncated assessment of what GDP growth might have been if the nuclear power sector had not been developed in the Republic of Korea, and thus provides some indication of the net value added that has accrued from nuclear power sector development in the country. Completely restructuring the I–O tables to reflect the thermal sector more perfectly, was beyond the scope of this work. In order to carry out this rough assessment it was assumed that electricity demand remains unchanged, and that all power actually generated by nuclear was generated by thermal power, allocated among the different fuels according to historical shares. For this allocation the thermal power sector of the I–O tables was used, since it is more logical to assume a continued mix of thermal generation and because more detailed data for individual thermal power generation technologies are not available in the I–O table. The I–O tables prepared for Chapter 4 were used to estimate the value added contribution of this non-nuclear generation, including both construction and operation of the substitute plants. As in Chapter 4, the analysis is limited to the industrial value added contribution of the nuclear sector.

5.1. INCREMENTAL EFFECTS OF NUCLEAR POWER PLANT CONSTRUCTION

Our I–O analysis of value added from thermal power plant construction uses input data from KPX on the construction costs of coal and LNG plants. These cost data have been used to establish a proxy range of total sector costs, using coal plant costs to generate a maximum value and gas plant construction costs as a minimum value.

Domestic expenditures during the construction of a 1000 MW nuclear power were estimated to be around 1300 billion Won, some 490 billion Won for a 500 MW bituminous coal power plant, and some 155 billion Won for a

450 MW LNG power plant. Calculated on the basis of equivalent plant capacity, domestic expenditure for the construction of a bituminous coal power plant is 76% of that of nuclear power plant, while an LNG power plant is only 26%. Since there is a direct relationship between construction costs and expenditures and value added by the nuclear power sector to other industries, these relative cost comparisons between nuclear and fossil fuelled power plants give some insight into the relative impacts on industrial value added in the national economy, that might have risen from building only fossil fuelled power plants. As shown in Table 5.1, building bituminous coal power plants in place of nuclear would generate some 24% less value added. For LNG plants the loss of value added would have been greater - 74%.

TABLE 5.1. SUMMARY OF THE VALUE ADDED CONTRIBUTION OF THERMAL POWER PLANT CONSTRUCTION (IN BILLIONS OF WON)

Year	1980	1985	1990	1995	2000	2005
Bituminous Coal	103	354	215	467	897	1 133
LNG	35	121	74	160	307	388
Nuclear	**135**	**466**	**283**	**615**	**1 180**	**1 492**

5.2. INCREMENTAL EFFECTS OF THERMAL POWER GENERATION PLANT OPERATIONS

The output and the value added contribution of thermal power generation were calculated by applying the same method used in the analysis of nuclear power. The historical share of thermal power generation was adjusted by assuming that thermal power generation would expand proportionally to replace all of the power actually generated by nuclear. Historical generation from both nuclear and thermal power is shown in Table 5.2. The relative share of each thermal power type out of total thermal power generation is shown in Table 5.3.

TABLE 5.2. POWER GENERATION FROM NUCLEAR AND THERMAL POWER (GW·H)

	1980	1985	1990	1995	2000	2005
Nuclear	3 477	16 745	52 887	67 029	108 964	146 779
Thermal	31 778	37 603	48 422	112 154	151 826	209 509

Source: Electricity Statistics, KEPCO, 2007.

TABLE 5.3. FUEL MIX FOR THERMAL POWER GENERATION (% OF TOTAL)

	Anthracite coal	Bituminous coal	Heavy oil	Diesel	LNG	Total
1980	7.81	0.00	90.87	1.32	0.00	100
1985	7.57	39.33	52.25	0.85	0.00	100
1990	5.43	35.79	37.07	1.88	19.83	100
1995	3.69	39.84	34.54	2.95	18.99	100
2000	3.48	60.76	16.79	0.43	18.54	100
2005	2.14	61.66	8.27	0.20	27.74	100

Source: Electricity Statistics, KEPCO, 2007.

The results of this alternative assessment, expressed in terms of output and value added, are shown in Table 5.4.

TABLE 5.4. ESTIMATED OUTPUT AND VALUE ADDED CONTRIBUTION OF REPLACEMENT THERMAL POWER GENERATION IN NON-NUCLEAR SCENARIO IN RELEVANT MAJOR INDUSTRIES (IN BILLIONS OF WON)

Sector	1980		1990		2000		2005	
	Output	VA	Output	VA	Output	VA	Output	VA
Mining and quarrying (2)	5.3	3.6	94.8	63.9	135.8	86.1	149.6	97.0
Petroleum and coal products (7)	85.2	13.3	190.2	31.3	854.4	280.2	911.9	318.9
Electronic and other electric equipment (14)	1.1	0.3	42.4	12.0	142.5	38.9	140.6	39.7
Self-power generation (21)	0.2	0.1	8.3	4.3	146.9	43.6	192.0	47.7
Gas and water supply (22)	0.1	0.0	433.7	151.0	1 259.8	363.7	2 790.5	878.8
Repair construction (23)	0.8	0.3	179.6	82.9	371.3	165.2	418.0	190.2
Transportation and warehousing (27)	3.7	1.7	72.0	37.4	66.8	27.9	185.8	83.2
Finance and insurance (29)	4.8	3.6	87.0	58.8	369.1	253.8	405.9	288.3
Business services (31)	0.4	0.2	68.9	38.4	227.2	140.1	330.8	192.4
Educational and research services (33)	0.1	0.1	2.6	2.3	88.6	69.7	143.1	111.6
Total	**273.5**	**88.2**	**4 494.6**	**1 763.1**	**12 644.4**	**5 205.2**	**17 845.7**	**7 323.1**

5.3. DERIVING THE INCREMENTAL OUTPUT AND VALUE ADDED OF NUCLEAR POWER

The estimated total output and value added contributions of nuclear power and the hypothetical replacement scenario are shown graphically in Fig. 5.1. The incremental contribution of nuclear power can be estimated by subtracting the difference in both cases.

Subtracting the total value added of plant construction and operation for the alternative thermal power scenario, from the actual total value added from nuclear power, shows (Table 5.5) that value added without nuclear power would be some 92–160 billion Won lower than it actually was in 1980, and some 2198–2943 billion Won lower in 2005. This means that GDP in the Republic of Korea in 2005 would be some 0.39%–0.49% lower than it actually was, translating into an estimated incremental nuclear power contribution to GDP of around 0.4% for 2005. This contribution would likely increase over time with the growing scale of power generation. While this necessarily is a simplified and partial analysis, it does provide some indication that the incremental as well as the actual contribution of nuclear power development to the Korean economy has been positive.

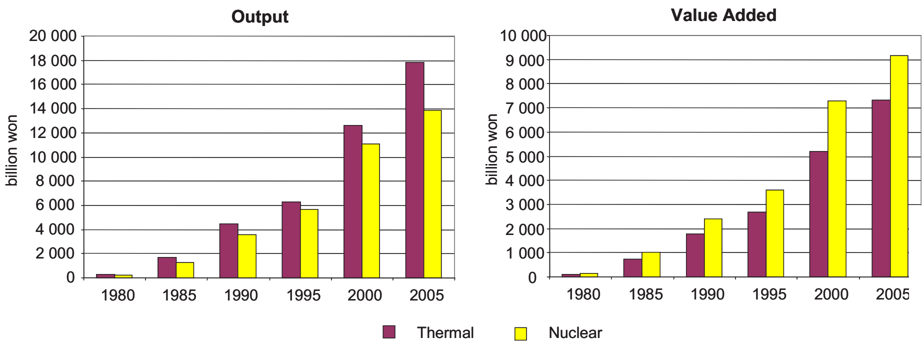

FIG. 5.1. Comparison of total output and value added contribution from nuclear and alternative fossil power plant operation.

TABLE 5.5. INCREMENTAL NUCLEAR VALUE ADDED CONTRIBUTION TO GDP (IN BILLIONS OF WON)

	1980	1985	1990	1995	2000	2005
Total nuclear value-added	283	1 484	2 697	4 196	8 461	10 654
Total thermal value-added	123-191	841-1 074	1 837-1 978	2 851-3 158	5 512-6 102	7 711-8 456
Total value-added loss (Net nuclear contribution)	92-160	410-643	719-860	1 038-1 345	2 359-2 949	2 198-2 943
GDP	37 116	78 848	178 317	375 803	599 645	810 516
Share of incremental nuclear value-added contribution to GDP	0.3-0.4%	0.5-0.8%	0.4-0.5%	0.3-0.4%	0.4-0.5%	0.3-0.4%

There are three observations. First, the largest contribution in terms of output and value added for both types of power generation was the contribution to its own respective sector (sector 19 for thermal power generation; sector 20 for nuclear power). Output contribution to its own sector is almost the same for both, because the power generation of the two sectors is assumed to be the same. Second, as with nuclear power, the actual GDP contribution of thermal power plant construction was much smaller than from plant operations, and for the same reason: the economic impact of construction is primarily limited to the construction period, while the economic impact of plant operations continues throughout the life of the plant. This effect is even greater for thermal plants because construction costs are less and fuel costs throughout the life of the plant are greater.

TABLE 5.6. IMPORTED FUEL FOR ELECTRICITY GENERATION IN THE REPUBLIC OF KOREA (IN BILLIONS OF WON)

	Coal	**Oil**	**LNG**	**Nuclear**	**Total**
1988	288	164	217	170	**838**
1989	372	234	193	135	**934**
1990	395	404	258	120	**1 176**
1991	445	561	258	142	**1 406**
1992	480	721	315	132	**1 647**
1993	587	640	357	197	**1 781**
1994	677	676	400	166	**1 919**
1995	851	779	419	155	**2 204**
1996	1 075	900	757	175	**2 906**
1997	1 912	1 696	1 487	350	**5 444**
1998	1 455	329	711	287	**2 784**
1999	1 245	389	870	293	**2 798**
2000	1 515	1 090	1 426	350	**4 381**
2001	1 838	1 102	1 565	354	**4, 859**
2002	1 739	847	1 642	336	**4 564**
2003	1 733	1 046	1 914	317	**5 011**

Source: Electricity Statistics, KEPCO, Year Book of Energy Statistics, MOCIE (2007).

Third, the total output contribution of thermal power generation is greater than that of nuclear power for all the periods, even though the difference is not substantial. By contrast, the total value added contribution of nuclear power is greater than that of thermal power generation throughout all periods. The reason for this is that fuel imports are included in output but they do not contribute to the value added of domestic industries. Fuel imports for the thermal sector, as shown in Table 5.6, are greater than for nuclear. In fact, imported fuel for nuclear is only 6.3% of total fuel imports for 2005, while its share of total power generation was 40%. The remaining fuel imports are thermal fuel; they are reflected in the petroleum and coal products sector in the I–O table in the case of oil and coal, and in the gas and water supply sector in the case of LNG. The economic vulnerability of these energy imports stems largely from changes in exchange rates and in international fuel prices.

6. RADIOISOTOPE AND RELATED INDUSTRIES

6.1. HISTORY AND CURRENT STATUS

The radioisotope industry generally encompasses both those who produce radio-isotopes as well as those who use them for specific applications. While use of radioisotopes has grown rapidly in the Republic of Korea, some 70% of the radioisotopes used in the country are imported, as are most of the radioisotope related machinery and gauges. Only the research reactor at KAERI produces radiopharmaceuticals and other radioisotopes, but as the number of users expands, so too will the need for domestic suppliers. The import substitution potential for this industry is therefore significant. The Government already envisions for the radioisotope industry, as for the nuclear power sector, an increasing level of national participation, gradually replacing imports as a source of both isotopes and related machinery and equipment.

This study focuses only on those selected industries that use radioisotopes for specific applications, namely the medical sector (e.g. for X ray and cancer treatment), and industrial use (for precision measurement or non-destructive testing). In agriculture, radioisotope applications include food preservation and sanitation, and species adaptation (e.g., development of insect resistant crop strains). In the public service sector radioisotope applications include water quality control, location and identification of wells, tracing of groundwater supplies, monitoring of pollution, and sewage monitoring. Environmental applications include a variety of different kinds of emissions monitoring. However, neither agricultural nor public service sector uses, though important, are evaluated here. Research applications, although negligible, are included. Consequently, as for nuclear power, the contribution of the radioisotope industries to industrial value added, and hence to GDP, is understated.

The radioisotope industry in the Republic of Korea first started in 1963 in the medical sector, with the use of X rays for medical examinations and diagnostic purposes. In 1963, the legal framework for registering and licensing radioisotope sources and users was first implemented, requiring all user industries to employ licensed technicians, certified by the government. In that year there were still only two enterprises using radioisotopes, both of which were hospitals. Since then, growth of this industry has been exponential. As of 2003, there were 5607 such licensed radioisotope personnel in the Republic of Korea. Besides these, there are 159 259 radiological technologist licensees who work around medical radioisotope generators and instruments, and 25 831 radiation workers in the nuclear industry who handle radioisotopes. This rapid growth in employment is reflected in the value added for the radioisotope industry in the I–O table.

Within the medical sector itself, radioisotope applications have expanded and multiplied far beyond X rays to include a range of other diagnostic uses, radiotherapy and other treatments. There is a rapidly growing demand for PET (positron emission tomography), a powerful early warning diagnostic tool, so the installation of radiation generators for this purpose is expanding rapidly. Radiation generators in the medical sector are monitored by the Ministry of Health, which reports a current total of some 27 000 generators in use in the medical industry, of which examination and treatment account for some 25 000 and dental applications some 2000.

Even more rapid has been the growth of radioisotope use in the industrial sector, where their capacity for microscopic measurement, non-destructive testing and materials identification and tracing, have made them the quality control tool of choice. The number of industries now using radioisotope include machinery and electrical equipment manufacture, ship building and construction industries, civil engineering, the petrochemical industry, paper, iron and steel manufacture, the non-destructive testing service industry, synthetic materials development, the manufacture of sophisticated measurement gauges and in the nuclear power industry.

radioisotope applications continue to be developed and to expand rapidly, so that the number of radioisotope user industries also continues to grow. By 2003, there were 2127 radioisotope user companies in the Republic of Korea, many using multiple radioisotope generators or sources. Table 6.1 shows a general distribution of radioisotope industry users and suppliers.

The same I–O sector classifications were used to quantify the impacts of radioisotope use as was done for nuclear power, that classification being sufficiently detailed for the purpose. But whereas the output and value added effects of nuclear power were calculated on the basis of the economic activities associated with plant construction and operation, the I–O impacts of radioisotopes are calculated on the basis of radioisotope utilization rather than with their supply. This choice was dictated largely by data availability. The study therefore estimates the output and value added generated by the various applications of radioisotope technology in different industries. Those applications include primarily the treatment of food for sterilization or long term preservation, precision measuring and non-destructive testing of structural materials, and medical diagnosis and treatment. Since the data are not complete even for these sectors, and since agricultural and public sector uses are not included, the estimates below are not maximum estimates.

TABLE 6.1. NUMBER AND CLASSIFICATION OF RADIOISOTOPE SUPPLIERS AND USERS

Classification	Status of organization				
	User	**Non-destructive Testing**	**User/Supplier**	**Supplier**	**Total**
Medical facilities	129	-	5	-	134
Industry	1 027	40	21	125	1 213
Research organization	229	1	2	-	232
Educational institutions	203	-	-	-	203
Public service sector	334	1	-	-	335
Agriculture	n.a	n.a	n.a	n.a	n.a
Others	10	-	-	-	10
Total	1 932	42	28	125	2 127

Data collection was different for each of the three sectors examined: manufacturing, medical, and R&D. For the medical sector, sales data are readily available from the published input output table. For the medical sector, the information prepared by National Health Insurance Corporation in the Republic of Korea was used. In the case of R&D, the expenditure on radioisotope R&D is assumed to be the value added itself, avoiding the need to estimate the benefits of education or innovation in this study. Data gathering for manufacturing was more complex.

6.2. MANUFACTURING APPLICATIONS

6.2.1. Analysis of the contribution of the radioisotope industries to industrial value added

The contribution of radioisotope processes and applications to sectoral output cannot be directly quantified from the published Input-Output table, since these applications often are an integral part of the manufacturing process. Two sets of additional input were required before the equations in the I–O table could be used to discern the proper share of radioisotope applications in each affected industry. Specifically, sales statistics on the contribution rate of radioisotopes to specific industries, and on the amount of total sales in each specific industry, were needed to refine the estimate of radioisotope valued added. This process required gathering accurate data both on the degree of contribution from radioisotopes in each sector, and on the total sales amount of each sector employing radioisotope technologies in the production processes. These specific sales statistics are neither published nor collated in exactly the required form, but were derived based on two different studies. One published data on total sales from radioisotope related industries to different manufacturing sectors; the other published data on total sales from each manufacturing sector using radioisotope technologies.

The first set of sales data comprise official census statistics published by the Economic Statistics Bureau in the Republic of Korea (Reports on Mining and Manufacturing Survey, Industrial Statistics Division, Economic Statistics Bureau). However, since the Bureau uses the International Standard Industrial Classification (ISIC), the data in the ISIC sectors had to be reconfigured to correspond to the sectors in the reorganized I–O table used in this study. Table 6.2 shows the relevant sectors for the radioisotope industries from this reconfiguration, as well as the corresponding sales by radioisotope related industries to each of these manufacturing sectors on a yearly basis in five year intervals.

The second set of data were provided directly by the organizations using radioisotope technology in their production processes, specifically from the "Survey on the status of radiation/radioisotope utilization in 2002" (Korea Radio-isotope Association, 2003) and from The 5th Survey on the Status of Nuclear Industries in 1999 (KAIF 2000).

There are some statistical differences between the two studies. Each has a different definition of contribution rate. The study carried out by radioisotope society defines it as the contribution to the over-all valued added of a given sector, while the KAIF study defines it as the contribution to the total value of a sector's sales. Moreover, sales of radioisotope related industries surveyed by KAIF include only organizations requiring some form of licensing to use radioisotopes, and do not include any organizations not subject to licensing requirements. For example, since radioisotope related industries doing non-destructive testing do not require licensing, their sales are excluded from the KAIF study. In order to incorporate as many users as possible, we used a combination of the two studies. Sales data were used from both studies, limited to those selected applications where the value added attributable to radioisotope could be estimated with satisfactory confidence. But we opted to use KAIF's definition of contribution rate. The contribution rates used in this study are shown in Table 6.3.

TABLE 6.2. SALES OF RADIOISOTOPE RELATED INDUSTRIES TO THE MANUFACTURING SECTOR

(in billions of Won)

Reorganized I-O with 36 sectors		**ISIC code**	**1980**	**1985**	**1990**	**1995**	**2000**	**2005**
3	Food, beverage and tobacco	311 313 314	113	1 460	2 028	3 832	5 904	8 376
4	Textile products & leather product	321 322 323 324	105	1 144	2 119	4 111	5 462	7 750
5	Wood and paper product	331 341	72	717	1 747	4 197	7 305	10 365
6	Printing, publishing and reproduction	342		-	-	23	51	72
7	Petroleum and coal products	353 354	-	6 427	6 936	15 509	38 351	54 411
8	Chemical and allied products	351 352 355 356	1 167	2 614	6 469	14 147	24 414	34 637
9	Inorganic basic chemical products							
10	Non-metallic mineral products	361 362 369	30	311	754	1 796	2 388	3 388
11	Primary metal products	371 372	4 608	3 752	7 887	14 996	23 730	33 668
12	Fabricated metal products	381	29	392	906	2 529	2 932	4 160
13	General machinery and equipment	382	-	316	846	1 105	1 309	1 858
14	Electronic and other electric equipment	383	93	1 318	4 726	16 290	25 543	36 239
15	Precision instruments	385				-	174	247
16	Transportation equipment	384	375	2751	6566	14 643	22 396	31 773
17	Furniture and other manufactured products	300 332	-			-	-	-
	Total		**6 593**	**21 203**	**40 984**	**98 178**	**159 969**	**226 944**

ISIC: International Standard Industrial Classification.

TABLE 6.3. CONTRIBUTION RATES USED IN THIS STUDY

	Sector	Contribution to total manufacturing sales (%)
3	Food, beverages and tobacco	2.00
4	Textile products and leather products	2.23
5	Wood and paper products	3.69
6	Printing, publishing and reproduction of recorded media	2.23
7	Petroleum and coal products	4.18
8	Chemicals and allied products (excluding Inorganic basic chemical products)	4.18
9	Inorganic basic chemical products	
10	Non-metallic mineral products	2.23
11	Primary metal products	2.44
12	Fabricated metal products	2.44
13	General machinery and equipment	1.29
14	Electronic and other electric equipment	1.29
15	Precision instruments	2.23
16	Transportation equipment	0.88
17	Furniture and other manufactured products	

Multiplying the total sales amount from radioisotope related industries as calculated above, times the contribution rates of radioisotopes[8], calculates the particular portion of total sales that is correctly attributable to radioisotopes in each affected manufacturing sector, and hence is a basis for deriving the value added by radioisotopes in those industries using the I–O model. The results of these calculations are shown in Table 6.4. The value added from radioisotope to manufacturing amounted to an estimated 6223 billion Won in 2005, up from 176 million Won in 1980. Among the relevant affected industries in the manufacturing sector, two sectors were dominant throughout the study period and account for more than half of the attributable value added: petroleum and coal products, and chemicals and allied products.

[8] It is possible that the radioisotope contribution rates may change over time as radioisotope and user technologies change. Ideally it might be desirable to apply different radioisotope contribution rates for each period, reflecting these technological changes. But this is far beyond the scope of this study. Therefore, the same radioisotope contribution rate (year 2000) is assumed to apply throughout.

TABLE 6.4. SALES AMOUNT ATTRIBUTABLE TO RADIOISOTOPE, DERIVED FROM TOTAL SALES IN MANUFACTURING SECTOR (IN BILLIONS OF WON)

	Sector	1980	1985	1990	1995	2000	2005
3	Food, beverage & tobacco	2.3	29.5	41.0	77.4	119.3	169.2
4	Textile products & leather product	2.3	25.5	47.2	91.7	121.8	172.8
5	Wood & Paper product	2.6	26.5	64.5	154.9	269.6	382.5
6	Printing, Publishing & Reproduction	-	-	-	0.5	1.1	1.6
7	Petroleum & Coal products	-	268.6	289.9	648.3	1 603.1	2 274.4
8	Chemicals & Allied products	48.8	109.3	270.4	591.3	1 020.5	1 447.8
9	Inorganic basic chemical products	-	-	-	-	-	-
10	Non-metallic mineral products	0.7	6.9	16.8	40.0	53.2	75.5
11	Primary metal products	112.4	91.6	192.4	365.9	579.0	821.5
12	Fabricated metal products	0.7	9.6	22.1	61.7	71.5	101.5
13	General machinery & equipment	-	4.1	10.9	14.2	16.9	24.0
14	Electronic & other electric equipment	1.2	17.0	61.0	210.1	329.5	467.5
15	Precision instruments	-	-	-	-	3.9	5.5
16	Transportation equipment	3.3	24.2	57.8	128.9	197.1	279.6
17	Furniture and other manufactured products						
	Total	**176.4**	**614.7**	**1 076.0**	**2 387.0**	**4 388.5**	**6 223.4**

Figure 6.1 shows the breakdown of output and value added to selected industries from radioisotope applications, as was done for nuclear power. The total value added calculated for radioisotope is much smaller than for nuclear power, reflecting both the relative size of the two sectors and the

limited data available for the radioisotope industries. The estimates of radioisotope value added were limited to those selected applications where the value added attributable to radioisotope could be estimated with satisfactory confidence.

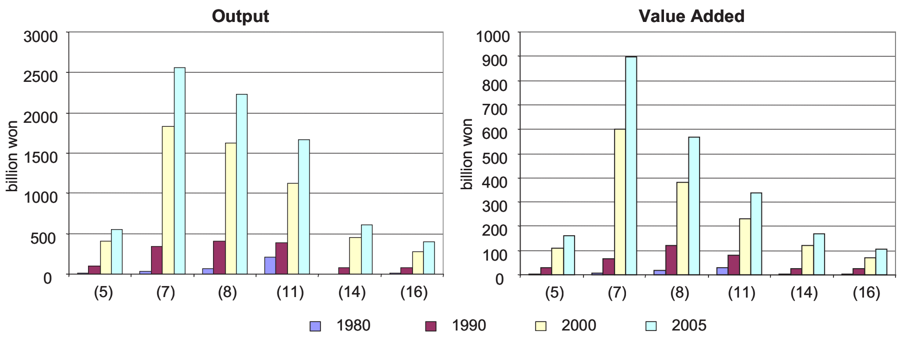

FIG. 6.1. Contribution of radioisotope manufacturing industry in major industries.

6.2.2. Summary of RI Manufacturing Sector Contributions to the National Economy

The value added attributable to selected radioisotope applications in the manufacturing sector grew significantly during the study period, from some 0.2% of GDP in 1980 to 0.4% of the GDP in 2000. It reached more than 0.4% in 2005 (Table 6.5).

TABLE 6.5. ESTIMATED CONTRIBUTION OF RADIOISOTOPE TO MANUFACTURING INDUSTRY (IN BILLIONS OF WON)

	1980	1985	1990	1995	2000	2005
Output	391	1 054	2 009	4 214	7 547	10 787
Value added	88	277	592	1 437	2 360	3 488
GDP	37 116	78 848	178 317	375 803	599 645	810 516
Value-Added Contribution to GDP	0.2%	0.4%	0.3%	0.4%	0.4%	0.4%

6.3. MEDICAL APPLICATIONS

As noted above, the amount of total sales for the medical sector could be taken directly from the statistics in the I–O table. This amount was multiplied by the share of radioisotope in total medical expenditures, as taken from statistics published by the National Health Insurance Corporation (NHIC) in the Republic of Korea.

NHIC has published a breakdown of total medical expenditures paid under the public health care system on a yearly basis since 1997. These expenditures are collected from all registered medical organizations providing medical services in the Republic of Korea. They are broken down into ten different categories, one of which is radiation therapy and diagnosis. The expenditures for radiation therapy and diagnosis, including computed tomography (CT) were adopted as a proxy value for the amount of the radioisotope contribution in medical sector.

In 2005, the share of radiation therapy and diagnosis in total medical expenditure was estimated by the NHIC to be 5.56% (radiation therapy and diagnosis: 4.16%, CT: 1.40%) (Table 6.6). However, these particular data apply only to major cities. To compensate for uncounted rural services, we applied the higher rate of 5.56% as the share of radioisotope in total medical expenditure for the whole study period.

TABLE 6.6. SALES AMOUNT CONTRIBUTED BY RADIOISOTOPE IN THE MEDICAL SECTOR (IN BILLIONS OF WON)

	Total sales amount of the medical sector	**Sales amount contributed by RI in the medical sector**
1980	482.4	26.8
1985	2 112.1	117.4
1990	4 043.9	224.8
1995	10 291.8	572.2
2000	23 536.2	1 308.6
2005	40 525.8	2 253.2

The major contribution made by medical use of radioisotope to the national economy is concentrated in the medical sector itself, as expected. Besides this, the chemicals and allied products sector has been significantly affected throughout the study period. A further breakdown of value added by radioisotope in relevant affected sectors is shown in Fig. 6.2.

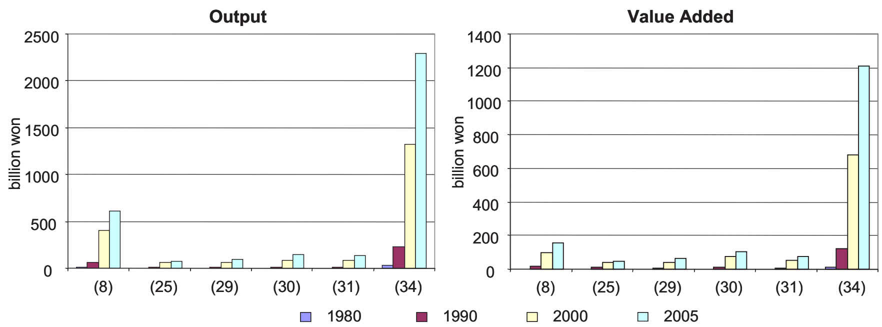

FIG. 6.2. Contribution of medical applications of radioisotope in major industries.

The value added attributable to radioisotope applications in the medical industry is summarized in Table 6.7.

TABLE 6.7. SUMMARY OF VALUE ADDED FROM RADIOISOTOPE APPLICATIONS IN THE MEDICAL INDUSTRY (IN BILLIONS OF WON)

	1980	1985	1990	1995	2000	2005
Output	49	207	408	970	2 398	4 040
Value added	22	102	196	504	1 101	1 904
GDP	37 116	78 848	178 317	375 803	599 645	810 516
Value-Added Contribution to GDP	0.06%	0.13%	0.11%	0.13%	0.18%	0.23%

6.4. RESEARCH APPLICATIONS

R&D expenditure can be regarded as straight value added, because R&D expenditures are treated as an investment in the National Income Account in the Republic of Korea. In this respect, R&D expenditure is different from other sectors. The statistics for R&D expenditure for radioisotope specifically date back only to 1997 in the country, so that the contribution of R&D in the radioisotope field was only available for this study for the year of 2005. This amounted to 15.1 billion Won. It is relatively small compared to the valued added in the manufacturing and medical sectors, and is taken as the value for research applications for all five periods studied.

6.5. SUMMARY OF RADIOISOTOPE APPLICATIONS

The total contribution to GDP from all of the surveyed radioisotope applications and sectors is summarized in Table 6.8. The total value added attributable to radioisotope in this study is estimated to have grown from some 0.30% in 1980, to more than double (0.67%) in 2005, with manufacturing applications accounting for almost 65% of all total radioisotope value added in that year. However, the most rapid increase in value added from radioisotope applications has been in the medical sector. Value added in the two sectors has grown impressively from 1980 to 2000: a 86-fold increase in the medical sector and a 40-fold growth in the manufacturing sector.

Unlike the case of nuclear power, where the electricity sector would have evolved using alternate fuels, there is really no ready and comparable substitute for radioisotope services. Valuing qualitative differences resulting from different process alternatives, instead of comparing value added, is beyond the scope of this study. The actual contribution of the radioisotope industries to industrial value added in GDP is therefore here taken to be fully incremental.

TABLE 6.8. SUMMARY OF VALUE ADDED TO GDP FROM SELECTED RADIOISOTOPE RELATED INDUSTRIES (IN BILLIONS OF WON)

		1980	**1985**	**1990**	**1995**	**2000**	**2005**
Output	Manufacturing	391	1 054	2 009	4 214	7 547	10 787
	Medical	49	207	408	970	2 398	4 040
	R&D	-	-	-	-	-	-
	Sub total	**440**	**1 261**	**2 417**	**5 184**	**9 945**	**14 827**
Value added	Manufacturing	88	277	592	1 437	2 360	3 488
	Medical	22	102	196	504	1 101	1 904
	R&D	-	15	15	15	15	15
	Sub total		**394**	**803**	**1 956**	**3 476**	**5 407**
GDP		37 116	78 848	178 317	375 803	599 645	810 516
Value-Added Contribution to GDP		**0.30%**	**0.50%**	**0.45%**	**0.52%**	**0.58%**	**0.67%**

7. NUCLEAR CONTRIBUTIONS TO THE REGIONAL ECONOMY

7.1. BACKGROUND

The overall purpose of this project is to chronicle and to assess the economic gains realised in the economy of the Republic of Korea as the result of the nation's concerted efforts to develop a strong domestic nuclear sector. The analysis reported in previous chapters estimated quantitatively the economic contribution of nuclear technologies to the national economy in the past 25 years, expressed as their impact on industrial value added and on GDP. The present chapter focuses on local impacts, describing and estimating quantitatively at least part of the contribution of a nuclear power plant to the surrounding local economy, reflecting a strong government commitment to progressive localization of nuclear power technology development and enhanced direct national participation in nuclear power projects.

Such analysis is especially appropriate given the recently enhanced autonomy of the provinces of the country, the decentralization and deregulation of the energy and power sectors, and the need to select locations for new nuclear sites to meet growing electricity and GHG mitigation needs. A publicly accessible quantitative and dispassionate estimate of the local contributions of nuclear power can serve as valuable input for this site selection process, consonant with the design of sustainable regional socioeconomic development plans.

This chapter starts with a brief description of the plant and the region selected for the case study. It then defines the regional effects to be considered, the analytical methods used, and the findings. The contributions of the plant to the regional economy are defined in terms of output and income effects, regional output being used to estimate incremental household income, the ultimate regional value added.

Our analysis of a nuclear power plant's contribution to the regional economic development is based on I–O analysis, evaluating direct, indirect and induced effects of increased output and expenditure of labour income as well as plant expenditures for goods and services during the construction and operation of the plant. The economic contribution of the Ulchin plant to the economy of the Ulchin region was estimated by evaluating the sequential impacts of wages and other plant expenditures (including taxes and special support projects) that generate demand for additional goods and services (output effect) thereby generating additional regional income (income effect). The direct and indirect effects of the plant arise mainly from five elements: wages paid as labour income during plant construction and operation, plant expenditures for inputs of intermediate goods during construction and operations, expenditures for regional development and other specially funded social support programmes, electricity subsidies, and expenditures in the form of local taxes paid by the nuclear power plant.

The study was done primarily using an I–O model derived specifically for the region in question, using as a basis our national model described in Chapter 4. Data were supplied largely by KHNP and by the Daegu-Gyeongbuk Development Institute. The analysis covers the period 1990 to 2005. However, some regional data were only available through 2004: these are noted in the text.

7.2. OVERVIEW OF THE ULCHIN REGION AND NUCLEAR POWER PLANT

There are four nuclear power plant sites in the Republic of Korea. Each of the host communities has benefited from the construction and operation of these plants. These benefits include tax revenues, financial contributions in terms of local expenditures by the plant, increased salaries, social investments and contributions, infrastructure development. This study focuses on the Ulchin region, where the Ulchin nuclear power plant is the sole supplier of power, with six reactor units in operation, and a total installed capacity of 5.9 MW(e). This region was selected primarily because it has relatively complete time series data for the past 25 years.

The Ulchin Kun region is an administrative district of Kyungbuk Province and incorporates two even smaller administrative entities — Eups (Ulchin Eup, Pyunghae Eup) and eight subdivisions called Myeons (Buk-myeon, Seo-myeon, Geunnam-myeon, Wonnam-myeon, Giseong-myeon, Onjeong-myeon, Jukbyeon-myeon, Hupo-myeon). The total area of the region is 989 km^2 with regional boundaries of 28 km from east to west, and 78 km from south to north.

The Ulchin region has been largely isolated from the national industrial economy and there has been a steady decline in regional population for several decades, largely as the result of urban migration, and reflecting limited economic opportunities in the region. In 1988, before the Ulchin power plant was built, the two most important economic activities in the region included those businesses in the I–O sector ‘food and accommodation’ (which includes fish processing) with a total of 1304 establishments and 2799 employees; and the ‘wholesale and retail sales’ sector with 1245 enterprises and 2252 employees. The ‘other services’ sector consisted of five electricity–gas–water service distribution companies with

1690 employees. In 2004, the registered total number of companies in Ulchin region was 4201 with employment of more than 16 000 employees.

Population peaked in 1966 at 117 602, falling to half that level by 2004. However, the number of statistical households has grown since the advent of the plant. This anomalous contrast is attributed in part to the large influx of workers to the Ulchin power plant whose families have not followed them to this duty station. In 2004, there were 23 532 households in the region, up from about 8000 households in 1988. In 2004, only 17.6% of total households in Ulchin region had a total annual income of more than 30 million Won.

The first unit of the Ulchin plant was put into operation in 1988. The last unit, Unit-6, was connected to the grid in 2005. The data for construction and operation reflect the actual number of plants operating or under construction at the time. Table 7.1 shows some characteristics of the six units of the Ulchin nuclear power plant. Although the regional analysis covers a span of 25 years, this description for simplicity provides only a snapshot of the plant for 2005.

TABLE 7.1. OVERVIEW OF THE NUCLEAR POWER PLANTS IN ULCHIN, 2005

Unit	Capacity (MWe)	Type	Reactor Supplier	Turbine Generator Supplier	Technical Service Supplier	Date of Commercial Operation
1	950	PWR	Framatome	Alsthom	Framatome Alsthom	’88.9.10
2	950	PWR	Framatome	Alsthom	Framatome Alsthom	’89.9.30
3	1 000	PWR	KHIC/ KPS/CE	KHIC/GE	KPS/S&L	’98.8.11
4	1 000	PWR	KHIC/ KPS/CE	KHIC/GE	KPS/S&L	’99.12.31
5	1 000	PWR	KHIC	KHIC	KPS	’04.7.29
6	1 000	PWR	KHIC	KHIC	KPS	’05.4.22

7.3. REGIONAL CONTRIBUTIONS OF NUCLEAR POWER PLANTS

Increasing national participation in the nuclear industry has meant the steadily increased use of locally produced material and domestic manpower resources. As noted earlier, meaningful national participation in nuclear power plant construction requires the existence of a capable construction industry; medium and heavy manufacturing including cement, steel, machinery and equipment and chemicals; as well as competency in other services such as civil engineering, quality assurance control and testing; and specialized manpower training including engineering and managerial skills. Many, though not all of these goods and services, are procured regionally wherever nuclear plants are built and operated.

The contributions to the local economy from construction and operation of a nuclear power plant are direct, indirect and induced. These include gains in labour income and increases in output of goods and services in the region as the result of plant construction and operation, of local tax payments and expenditures by the plant, and the impact of government infrastructure support programmes relevant inter alia to regions in which nuclear facilities are built. The increases in output could be viewed as contributing to regional development, while increased household income is akin to regional value added.

The construction phase is relatively short compared to the 30–60 year life of the plant. During the construction period, the influx of an additional labour force, and wages paid locally by companies working on the project, directly increase both regional income and expenditures. This indirectly affects other industries in turn by providing incentive and means for investment in expanded activity. For example, as various kinds of raw materials or services are needed for construction, purchases of these are made, and hence there is investment in facilities related to their procurement and production. This in turn causes additional demand for labour in related industries. The operating phase of a nuclear plant is much longer, and hence has more long term effects on the local economy than construction does. But not all of the plant's impacts are local.

Construction of a nuclear power plant takes about 5–7 years and requires a number of companies specializing in different fields: plant design, manufacture of plant components, major construction at the site itself, testing prior to commercial operation, and engineering work in all cases. Since plant design, component manufacture and test operations are highly specialized, they are not likely to have much economic effect on a specific local economy unless there exists within that locale companies with the needed professional competence. General construction work does have a great effect on the local economy through employment generation for both skilled and general labour, both local (permanent) and outside (temporary), and through the consequent labour income generation and expenditure, especially in the food and accommodation sectors.

Given that the lifetime of a nuclear power plant in the Republic of Korea is 30–60 years (with lifetime extension), the operation of a nuclear plant will have more regular and long term effects on local employment, income and expenditure.

The hosting of a nuclear power plant in a given region creates additional tax revenues, and also triggers a series of subsidies that apply variously to the location of different infrastructure projects in different regions of the country. These special regional support projects are described in more detail below. They include regional development funds and incentives, social welfare funds, and subsidized electricity.

7.3.1. Economic Effects of Construction

KHNP has fully encouraged local employment and local contracting for the construction and operation of the Ulchin plant, using wherever possible relevant construction companies within the Ulchin region. As shown in Table 8.2, some 44% of the total manpower employed in construction at Ulchin in 2004 was hired locally. The scale of wages paid was also considerably higher than the local average. Table 7.2 shows employment and expenditures for employment, respectively, for the construction of Ulchin units 5 and 6 in 2004. The three categories of employers are listed separately, since the nature of each company falls into a different I–O category. The data must be kept separately to permit accurate attribution of the income and output effects.

TABLE 7.2. EMPLOYMENT AND WAGES IN THE CONSTRUCTION OF ULCHIN UNITS 5 AND 6, 2004[9] (PERSONS; IN BILLIONS OF WON)

Classification	Employment			Total Wages
	Local	Non-Local	Total	
KHNP	11 (7%)	154	165	9.7
Construction Companies	165 (43%)	216	381	12.5
Other Companies	323 (56%)	254	577	12.2
Total	**499 (44%)**	**624**	**1 123**	34.9

[9] The statistical boundary of 'local' represents Ulchin-Gun, Kyungbuk Province. Numbers in parentheses is the percentage of total hires that are local.

7.3.2. Economic Effects of Operation

KHNP also has a policy of preferential employment for local labour for plant operations, including new recruits, technical services and temporary positions. At Ulchin, a total of 1936 employees (198 local and 1738 non-local employees) in 2004 are engaged in the operation of the five reactor units where local hires accounted for some 10% of all employees.

For the Ulchin region, expenditures on wages for the resident work force amounted to more than 105.4 billion won (86.5 billion Won for KHNP and 18.9 billion Won for its associated companies) in 2004 alone. In addition to this expenditure of labour income there are other plant activities during the operation period which have substantial investment impacts on the local economy. Operational expenditures by KHNP and its associated companies (KPS and Doosan Heavy Industries & Construction Co.) for procurement and incidental construction in 2004 amounted to some 22.9 billion Won. Excluding certain professional activities, most of these orders were given to local companies in the region.

Finally, nuclear plants contribute a significant share of local taxes, an increasingly important benefit given the relatively recent administrative changes in the Republic of Korea that increase both the autonomy and the fiscal responsibilities of the provinces. In 2005, total local tax revenues for the Ulchin region amounted to some 45 billion Won. Of this, some 32 billion Won (71.5%) came from KHNP and the ten companies collaborating in the nuclear plant's operation in one way or another, including KPS and Doosan Heavy Industries & Construction Co. Such revenues permit a large measure of financial independence from the federal government.

7.3.3. Special Support for Infrastructure and Regional Development Projects

For regions that host the location of infrastructure projects (including nuclear and other power plants) within their boundaries, the Government has established laws and a special support fund for local socioeconomic projects. This support programme is designed in large measure to promote regional development by facilitating the siting of infrastructure projects, and strengthening public acceptance of such projects. Revenues for the funds were initially (1987) raised by a levy of 0.3% on the sales of electricity. The nuclear relevant part of these laws was passed on 16 June 1989. In December 2000, the levy was changed to its present level of 1.12%, and the fund was put under the management of the Ministry of Commerce, Industry and Energy (MOCIE), as the "Energy Industry Foundation Fund" of Article

48 of the Electricity Enterprises Act. Funding for areas which host several nuclear power plants and radioactive waste management facilities is further enhanced by adding a 0.5% levy on the total construction cost of each plant or facility.

Support for host regions takes several specific forms: general regional development funds, subsidized electricity, social welfare projects, industrial relocation assistance, public information and education, environmental research and protection, aid to fishing and agriculture, and funding for projects of regional interest. Less directly oriented to economic development but nonetheless important, are support funds for cultural events and athletic activities. For the period 1990–2004 the total expenditure for local support projects for the Ulchin region amounted to 161 billion Won. In 2004, it amounted to 33.6 billion Won. Table 7.3 summarizes the amount paid by the Energy Industry Foundation Fund for subsidies to local residential and industry electricity costs.

TABLE 7.3. TOTAL VALUE OF FREE ELECTRICITY PROVIDED AS ELECTRICITY SUBSIDIES FOR REGIONS HOSTING NUCLEAR POWER PLANTS, 2004

	Residential	**Industry**	**Total**
Number of households and industry	23 564	343	**23 907**
Electricity subsidies (1 000 won)	997 427	97 452	**1 094 879**

7.4. STRUCTURING A REGIONAL I–O TABLE

The I–O tables derived for the Ulchin region are consistent with the I–O tables for the national economy derived and used in previous chapters, but they have been adapted in two important ways. First, the 36 sector national I–O table (including 28 industry sectors) was further modified to cover only the 16 sectors relevant to the Ulchin region. All industry data from the original 28 industry sectors were first transformed to the three digit level of the ISIC, then regrouped into the newly structured 16 industry sectors. The names of each of the reorganized sectors, and the related nuclear activities for the sector, are reproduced here in Table 7.4.

TABLE 7.4. I–O SECTORS FOR ULCHIN REGIONAL I–O TABLE

	Sector Classification
1.	Agriculture, Forestry and Fishing
2.	Mining and Quarrying
3.	Manufacturing
4.	Nuclear Generation
5.	Construction
6.	Wholesale and Retail
7.	Food and Hotels
8.	Transport and warehousing
9.	Communication
10.	Finance and Insurance
11.	Real estate, Renting
12.	Public Administration
13.	Education/Research
14.	Health and Welfare Services
15.	Other Services
16.	Household

Note that in order to analyse adequately the contribution of the nuclear plant to the regional economy, generation other than nuclear electricity, such as hydro and thermal, have been included in the 'Other services' sector along with public utilities such as gas and water distribution.

Adaptation and adjustment of the national model for the regional economy in this way is essential since the magnitude of the effect of any given industrial investment on the local economy varies not only absolutely according to the type and level of activity, but also relatively according to the economic environment and other economic activity taking place in the region. Thus, regional effects are not simply a scaled down version of national effects, nor can the I–O results for the Ulchin plant be transferred wholesale to any of the three other regions with nuclear plants. A regional model must be circumscribed to evaluate only the effects from local expenditures on goods and services, and screen out expenditures made outside the region.

7.5. INCLUDING HOUSEHOLDS AS A PRODUCTIVE SECTOR

The second modification involves the treatment of the household sector in the regional model. Capturing and quantifying the regional benefits requires treating households differently in the regional model from how they are generally treated in national I–O tables. The key feature of an I–O model is its utility for impact analysis of the effect of an exogenous change to an economy traced through the interdependence of industries. The inter-industry effects and their interdependent relationships are expressed and calculated by using the I–O coefficients and a set of I–O multipliers that express the difference between the initial effect of an exogenous change and the total effects of that change. These effects are calculated as income effects and output effects. They can also be classified as direct, indirect and induced effects.

Direct effects are changes in the industries associated directly with the exogenous change. For example, suppose that a new nuclear power plant is being constructed in a region. The wages paid directly by the plant during construction and operation are direct effects. Indirect effects are the additional wages paid, for example, to workers in construction supply companies, resulting from increased demand for construction supply goods and services. These other industries subsequently hire more labour and buy more output from other sectors in order to increase their own production. The increase in the production of these backward linked industries and the associated increase in income and jobs are indirect effects. Subsidies and tax payments also have both direct and indirect effects.

In most I–O models, the household sector, as the ultimate driver of final demand, is considered to be the exogenous sector. In the analysis in Chapter 4, the nuclear industry was considered to be this exogenous (driving) sector; since the focus was industrial value added, households were not considered. However, in a regional economy there is an interrelation between production, consumption and industrial employment not captured unless households are treated as a productive sector, namely, induced effects arising from household expenditures made from income earned as a result of direct or indirect output and income effects. Households earn incomes as payment for their labour inputs to production processes and they spend their income for consumption. Thus, a change in the output in one or more sectors results in a change in the amount of labour required in these sectors, which in turn leads to a change in the labour incomes and a change in the amount spent by affected households for consumption. Thus, as households purchase goods for final consumption, the amount of their purchases is related in this regional I–O model to the output of each of the sectors in the region, as businesses increase their own expenditures to satisfy growing demand. In this study, therefore, since the focus is on value added, the estimate is only the induced regional income effect, and not induced employment.

Once household income increases due to either direct or indirect effects, the amount spent by households for consumption will also increase, which generates new rounds of regional production, jobs and income. These induced effects can only be captured by treating household production and consumption as an integral and productive sector of the economy ('endogenizing' households), with regional household income treated as wage payments in any other productive sector. This is called closing the model with respect to households.

Subtracting the total effects of the regional analysis run without closing the model, and then as a closed model, exposes the induced effect as the difference between the two. Taking household income as an endogenous variable in the regional I–O table is the only way to capture and quantify these induced effects, all of which appear as the output in the household sector, and all of which are considered key regional economic benefits. This induced effect appears only in, and is attributable to, the household sector in the closed model.

Besides an open or closed model, there were other choices to be made about the type of regional model used, including between a single or multiregional model and between a competitive or non-competitive regional model. A 'multiregional I–O table' incorporates trade connections between regions. A 'single regional I–O table' by contrast considers the economic structure of a single given region and considers only wages paid and expenditures made within that region. Trades in goods and services with other regions are considered as imports or exports without regard for the origin of imports, and hence specific data on interregional trades are not required. This study uses a single region model. Competitive and non-competitive I–O analyses differ in how they treat regional imports. A competitive I–O model does not differentiate between local expenditures on imported and locally produced goods, but rather uses the sum of them. A non-competitive I–O model does differentiate between the two. A competitive model is used which focuses on regional manufacturing or production in a region.

Data gathering and preparation were crucial aspects of this empirical analysis. KHNP provided the raw data on the costs of nuclear power plant construction and operations. These costs can be viewed as expenditures, and were used in the formulation of the I–O analysis as estimates of final demand created by the activities associated with the construction and operation of the Ulchin nuclear power plant. Here as in the national study, current prices are used throughout. These cost items were then matched to the corresponding sectors in the reorganized I–O table. Initial fuel, for example, is matched to inorganic basic chemical products, building and structure to electric power plant construction, machinery equipment to electronic and other electric equipment, architect and engineering to business services; owner's costs are spread across several sectors including business services, furniture and other manufacturing, finance and insurance.

All available regional data were provided by the Daegu-Gyeongbuk Development Institute. However, not all of the data needed for our analysis were available for all years or in sufficient detail for our analysis. Additional data were therefore estimated using two approaches: the location coefficient (LQ) method and the RAS method. The location quotient method was used for 1995 and 2000 only (years for which relatively complete regional data were available), This quotient is calculated as the ratio of the contribution of a given sector to regional output, to the share of that sector in national GDP. This coefficient is then applied for each relevant national I–O sector to estimate the regional I–O coefficients by sector. As explained below, the RAS method was then used to extend these estimates to other years.

The thrust of our regional I–O analysis is to describe the regional development effect of increased plant expenditures on sectoral output and household income, translating increased household income into expenditures that lead to increased economic activity, output and investment in the Ulchin region, and ultimately into further increases in household income. In order to do this with incomplete data on consumption and expenditures by households, we used the LQ method to estimate the effects of household income growth as follows. First, to estimate the share of income attributable to each sector, the labour income of each sector in Ulchin was divided by the gross regional domestic product (GRDP) in Ulchin. Next, sectoral expenditure was derived by multiplying the percentage share of sectoral expenditure from the national I–O table and total regional sectoral labour income (excluding savings) in the Ulchin region. Savings are excluded because they do not generate output or income effects as do expenditures. The savings to be excluded are calculated by multiplying the national savings per capita as a percentage share of total income, times labour income in the Ulchin region. Table 7.5 shows the national savings share used for estimating the input coefficient matrix. The actual calculation of the location coefficients is shown in Appendix 3.

TABLE 7.5. NATIONAL SAVINGS SHARE OF TOTAL INCOME

Year	Savings (%)
1990	16.7
1995	13.3
2000	10.6
2001	8.0
2002	5.1
2003	6.2
2004	7.5
2005	6.5

The sectors with high location coefficients are the sectors that showed the greatest increase in output and greatest increase in the share of economic activity in the region, as a result of wage payments and household expenditures arising from the Ulchin plant. Besides the nuclear sector itself, these were mining and quarrying, and the agriculture, forestry and fishing sector. These sectors showed greater increases in outputs over time at the regional level than they did at the national level, indicating positive effects of the Ulchin plant on their activities in the region. By contrast, the sectors for food and hotels, real estate and renting, education/research, and health and welfare services had lower coefficients than the national average and showed a declining share in the region's economy. Note that a declining share of a growing regional economy does not necessarily mean a decline in absolute terms.

The next step was to extend the estimates for 1995 and 2000 to the rest of the study time series, namely the years 1990 and 2001–2005. This was done using the mathematical technique known as the RAS method (see Appendix 3), that effectively calculates the input and output coefficients of each sector in a matrix in a given target year on the basis of known data about total outputs, inter-industry sales and total inter-industry purchases for that year, applied to I–O coefficients from an earlier known (base year) matrix. The year 1995 was set as the base year for this study.

7.6. RESULTS OF REGIONAL I–O ANALYSIS: THE ESTIMATED CONTRIBUTION OF THE ULCHIN NUCLEAR POWER PLANT TO REGIONAL ECONOMIC DEVELOPMENT

This section presents the results of calculations of the contribution of the Ulchin nuclear plant to the economy of the Ulchin region, measured as the effects of output and income generated, documented for the period 1990–2005. The output effect is used ultimately to calculate the incremental household income in the region arising from the Ulchin plant.

7.6.1. Plant construction

Because most of the major construction work was carried out by construction companies from outside the Ulchin region, and because expenditures for materials related to construction were mainly made outside the region, the economic contribution of plant construction was largely confined to the income effect generated by wages paid during construction.

Construction wages were classified by enterprise and by region. The enterprises were divided into KHNP, construction companies and other companies even though all wages were ultimately paid by KHNP, because the three types of enterprise were in different I–O sectors. KHNP and the Korea Plant Service & Engineering are classified in the nuclear power generation (4)[10], and construction (5) sectors respectively. The share of KHNP in total construction employment in Ulchin is relatively low compared to the major construction and other service companies. Together these wages accounted for some 50% of the total expenditures by the plant in the region.

TABLE 7.6. WAGES PAID FOR PLANT CONSTRUCTION (LABOUR INCOME), BY I–O SECTOR (IN BILLIONS OF WON)

	Nuclear Power	Construction	Other services
1990	-	-	-
1995	2.4	35.3	2.9
2000	3.4	39.7	2.6
2001	0.9	45.4	-
2002	2.9	46.8	1.5
2003	2.7	44.3	0.9
2004	3.4	7.5	8.4
2005	-	-	-

Note: There were no nuclear power plant construction activities in 1990 and 2005.

Total direct income in the Ulchin region from plant construction was calculated based on the proportion of Ulchin workers in the total, and assuming that 30%[11] of the income going to workers from other regions is spent in the Ulchin region, generating additional regional income. Based on the above assumption and data from the *Nuclear Power White Book*[12], the labour income from plant construction by sector in the Ulchin region is shown in Table 7.6. The total economic impact of these construction labour wages includes induced income effects of regional household expenditures. These income effects are presented in Table 7.7.

[10] Numbers in parentheses refer to sector classification cells in the I–O table.

[11] See: Isard, W. (1951).

[12] MOCIE (2005).

TABLE 7.7. INCOME EFFECTS ASSOCIATED WITH ULCHIN PLANT CONSTRUCTION (IN BILLIONS OF WON)

	Direct/Indirect Effect	Induced Effect	Total Effect
1990	-	-	-
1995	47.6	17.5	65.1
2000	51.6	15.6	67.2
2001	50.6	15.1	65.7
2002	57.3	17.2	74.5
2003	53.4	15.3	68.7
2004	28.3	7.7	36.1
2005	-	-	-

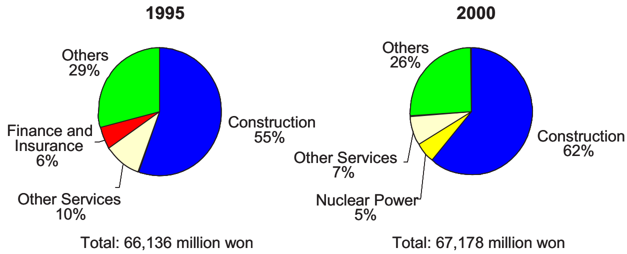

FIG. 7.1. Total income effects by sector from plant construction.

According to this table, for the period 1995–2002 the total income effects from plant construction contributed on average some 65–75 billion Won annually to the regional economy. This contribution dropped to 36 billion Won in the final year of the construction, 2004, and stopped thereafter as construction ceased. The biggest income effects were not surprisingly in the construction sector, followed by the finance and insurance and the service sectors, respectively (see Fig.7.1).

7.6.2. Plant operation

The contribution of plant operations to the regional economy is associated with both output and income generation, from which the output effects and then income effects were estimated.

7.6.2.1. Output effects of plant operation

Plant operations require the input of products or services from other industries as intermediate inputs. Since the nuclear sector is used as the exogenous sector in this regional model, the expenditures made to purchase these intermediate inputs give rise to additional output from other industries in the region (the output effect) The output effect of Ulchin plant operations is measured using data on plant expenditures in each sector from which the plant buys goods or services, comprising intermediate input into that sector; these expenditures are thus used to calculate nuclear power sector input coefficients (Table 7.8). The sectoral contributions of the Ulchin plant were calculated by multiplying the input coefficient of nuclear power generation for each sector by total nuclear power generation.

TABLE 7.8. INTERMEDIATE INPUT EXPENDITURES FROM THE OPERATION OF THE ULCHIN PLANT, BY INDUSTRIAL SECTOR (IN BILLIONS OF WON)

	1990	1995	2000	2001	2002	2003	2004	2005
1.	-	-	-	-	-	-	-	-
2.	-	-	-	-	-	-	-	-
3.	10.2	13.8	41.1	43.5	39.5	44.9	52.1	64.4
4.	10.2	13.7	40.8	43.0	39.1	44.5	51.6	63.9
5.	32.6	43.9	131.0	138.2	125.7	140.3	165.8	205.3
6.	1.5	2.0	5.9	6.2	5.7	6.4	7.5	9.2
7.	-	-	-	-	-	-	-	-
8.	0.4	0.6	1.7	1.8	1.6	1.8	2.1	2.6
9.	0.4	0.5	1.5	1.6	1.5	1.7	2.0	2.4
10.	5.5	7.4	22.2	23.4	21.3	24.2	28.1	34.7
11.	2.7	3.6	10.8	11.4	10.4	11.8	13.7	17.0
12.	-	-	-	-	-	-	-	-
13	11.7	15.7	46.8	49.4	44.9	51.1	59.3	73.4
14.	0.4	0.6	1.6	1.7	1.6	1.8	2.1	2.6
15.	3.3	4.5	13.4	14.1	12.8	14.6	16.9	20.9
16.	27.1	36.4	108.6	114.5	104.2	118.6	137.5	170.2
Total	**106.0**	**142.5**	**425.3**	**448.7**	**408.3**	**464.5**	**538.5**	**666.7**

The results of these calculations are shown in Table 7.9. The output effects of plant operations rose from 1.5 trillion Won in 2000, when Units 3 and 4 began operating, to 2.2 trillion Won in 2005 when Unit 5 started. The induced effect of this output, namely, the successive waves of additional regional output induced by rounds of increased household income, is captured using the regional household coefficients derived in closing the model. It was precisely to be able capture these larger income gains to the people of the region that the Ulchin region model was closed. And it is this incremental household income that we ultimately define as the regional economic benefit of the Ulchin power plant.

TABLE 7.9. OUTPUT EFFECTS OF ULCHIN PLANT OPERATIONS (IN BILLIONS OF WON)

	Direct/Indirect effect	Induced Effect	Total Effect
1990	382.4	199.3	581.7
1995	462.8	142.9	605.6
2000	1 308.8	251.0	1 559.8
2001	1 367.9	247.3	1 615.2
2002	1 235.8	209.5	1 445.4
2003	1 397.0	215.0	1 612.0
2004	1 610.1	225.1	1 835.2
2005	1 982.7	257.4	2 240.1

Fig.7.2 shows the major three I–O sectors responsible for much of the total output effect. The largest share by far is attributable to the nuclear power generation sector itself, a share that has increased with time. Much lower and declining relative shares are attributable to households and to manufacturing. The value of the output effects in both sectors is actually positive and growing, but this growth is overshadowed by that of output effect of the nuclear generation sector.

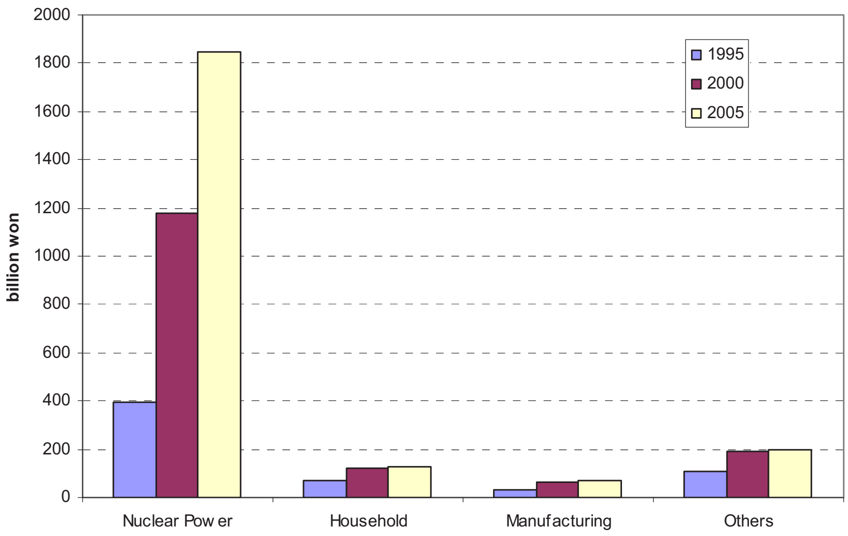

FIG. 7.2. Total output effects by sector from plant operations.

7.6.2.2.Income effects

Labour income for each sector during plant operation was calculated in the same way as for plant construction, and the same assumed share of 30% was used to derive the induced income effects for non-local wages. Table 7.10 shows income directly generated from the operation of the Ulchin plant in the two sectors most affected.

TABLE 7.10. TOTAL WAGES PAID DIRECTLY BY THE ULCHIN NUCLEAR POWER PLANT DURING OPERATIONS, BY I–O SECTOR (IN BILLIONS OF WON)

	Nuclear Power Sector	Construction Sector
1990	4.5	2.1
1995	7.7	1.8
2000	17.3	3.8
2001	22.7	4.6
2002	21.5	3.9
2003	36.0	5.5
2004	32.7	6.6
2005	33.8	6.9

Table 7.11 shows the total income effects derived from these direct wages, including indirect and induced income due to increased household income and expenditures. This total more than doubled from 1990 to 2000 (from 20 to some 45 billion Won). It almost doubled again in 2003 and was estimated to be 75.5 billion Won in 2005.

TABLE 7.11. EFFECT OF PLANT OPERATION ON HOUSEHOLD INCOMES (IN BILLIONS OF WON)

	Direct/Indirect Effect	Induced Effect	Total Effect
1990	13.3	6.6	20.0
1995	16.9	6.2	23.1
2000	34.4	10.4	44.8
2001	42.6	12.7	55.3
2002	39.2	11.8	50.9
2003	63.3	18.1	81.4
2004	58.1	15.9	74.0
2005	59.4	16.1	75.5

The I–O sectors that contributed most to this growth in income effects were the nuclear power generation sector, followed by the nuclear power construction sector and the education and research sector (which covers technology development and research), as shown in Fig.7.3.

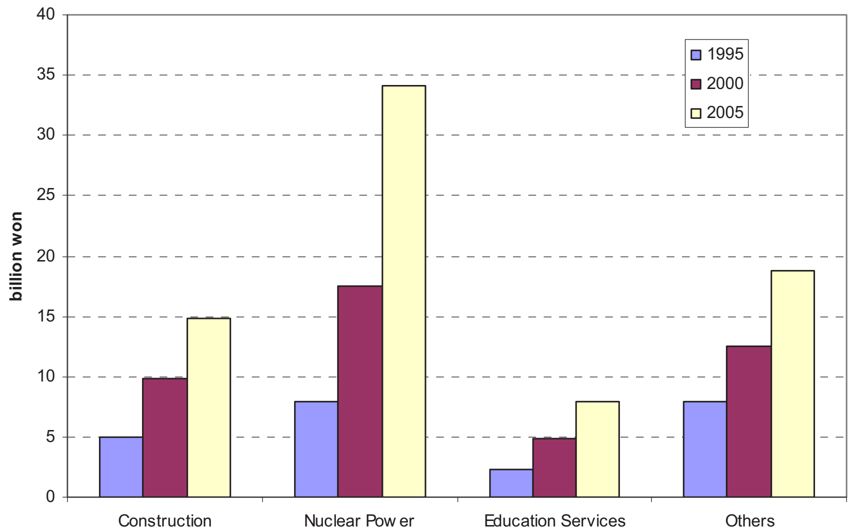

FIG. 7.3. Total income effects by sector from plant operation.

7.6.3. Effects of local tax payments

Taxes paid by the Ulchin nuclear power plant during both construction and operation of the plant, are a major source of finance for the local government's budget. The plant's share of total local tax revenue in 1995, 2000 and 2005 amounted to 21.5%, 54.2% and 71.5%, respectively. The local tax payment was particularly high in 2000 because the registration fee and acquisition tax for Ulchin Units 3 and 4 were paid in that year after completion of construction, as required by law. The plant's actual contribution to local tax payments is shown in Table 7.12.

Ideally, the output and income effects of these taxes should be calculated using a sectoral allocation of actual expenditures made from these tax revenues, based on the regional budget. However, since these data were not available to us, we have assumed that the entire amount of the local taxes paid in any given year by the Ulchin plant was solely used for local authority (i.e. public administration sector) expenditures in that same year. These estimates below are based on this hypothetical allocation of expenditures.

The total impact of these local tax payments on the regional economy includes an induced output effect. The total output effects of plant taxes, including direct, indirect and induced through local government expenditures, are presented in Table 7.13. This output effect is then used to derive the income effect below.

TABLE 7.12. LOCAL TAX REVENUE IN ULCHIN REGION (IN BILLIONS OF WON)

	1990	1995	2000	2001	2002	2003	2004	2005
Local Tax Revenue from NPP	n.a.	3.0	12.1	5.1	9.0	12.0	14.1	32.0
Total Local Tax Revenue	5.6	14.0	22.4	22.7	29.3	32.0	43.4	44.8
NPP's Local Tax share (%)	n.a.	21.5	54.2	22.6	30.6	37.4	32.6	71.5

Except for the anomalous surge in 2000, the output effect of taxes paid by the Ulchin plant has grown steadily, from some 8.4 billion Won in 1990 to almost 57 billion Won in 2005. The sector reflecting the greatest output effect (60% of the total in 2005) has been the public administration sector, since we have assumed that all taxes are routed through this sector, followed by the household sector. The share of these two sectors is gradually increasing, while the share of output effects from taxes for the manufacturing sector has decreased in the past ten years (see Fig.7.4).

TABLE 7.13. TOTAL OUTPUT EFFECTS OF THE PLANT'S LOCAL TAX PAYMENTS (IN BILLIONS OF WON)

	Direct/Indirect Effect	Induced Effect	Total Effect
1990	-	-	-
1995	3.5	4.9	8.4
2000	13.1	13.1	26.2
2001	5.6	5.0	10.6
2002	9.7	8.2	17.9
2003	12.9	10.0	22.9
2004	15.1	10.7	25.9
2005	34.0	22.6	56.6

The total income effect derived from these posited expenditures of local revenues is shown in Table 7.14. These include the indirect and induced effects, calculated on the same principle as the income effects from plant operations, using increased regional income and expenditure as the basis for generating regional output and hence induced regional income. With the exception of the surge in tax payments and their related income effects in 2000, the total income effect calculated has been steadily growing: it rose from 2.4 billion Won in 1995 to 5.2 in 2004, and then more than doubled in 2005 as Units 5 and 6 went on-line.

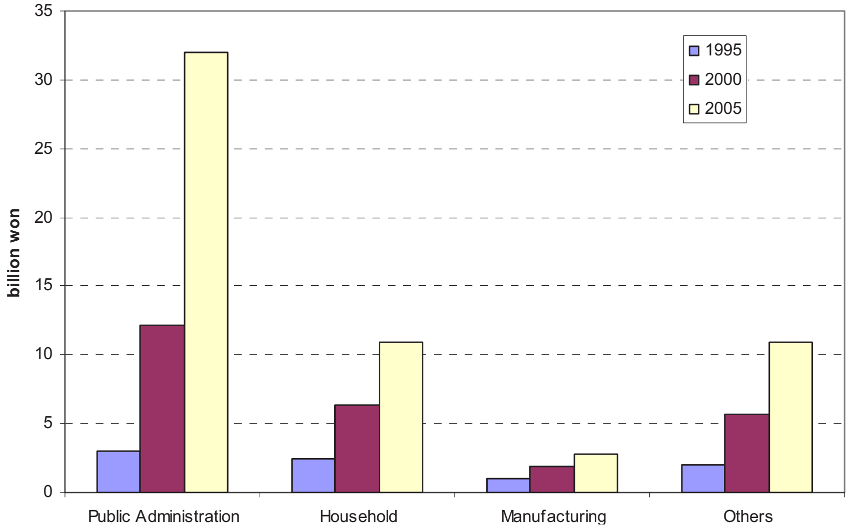

FIG. 7.4. Total output effects of local tax payments by sector.

TABLE 7.14. TOTAL INCOME EFFECTS OF THE PLANT'S LOCAL TAX PAYMENTS (IN BILLIONS OF WON)

	Direct/Indirect Effect	Induced Effect	Total Effect
1990	-	-	-
1995	1.8	0.6	2.4
2000	4.9	1.5	6.4
2001	1.9	0.6	2.4
2002	3.0	0.9	3.9
2003	3.7	1.1	4.8
2004	4.1	1.1	5.2
2005	8.6	2.3	10.9

By sector, total income effects throughout the study period (1995–2005) were mostly (65–75%) generated in the public administration sector (see Fig.7.5). The identity of the second most important beneficiary sector in terms of total income effects has changed over time. In 1995 manufacturing enjoyed the second largest single income effect — some 110 million Won. By 2000, the other services sector (15) had taken over second place with some 255 million Won and by 2000 the restaurant and accommodation facility sector was second with 700 million Won. This shift reflects among other things a diversification of the economy over time to include a broader spectrum of activities.

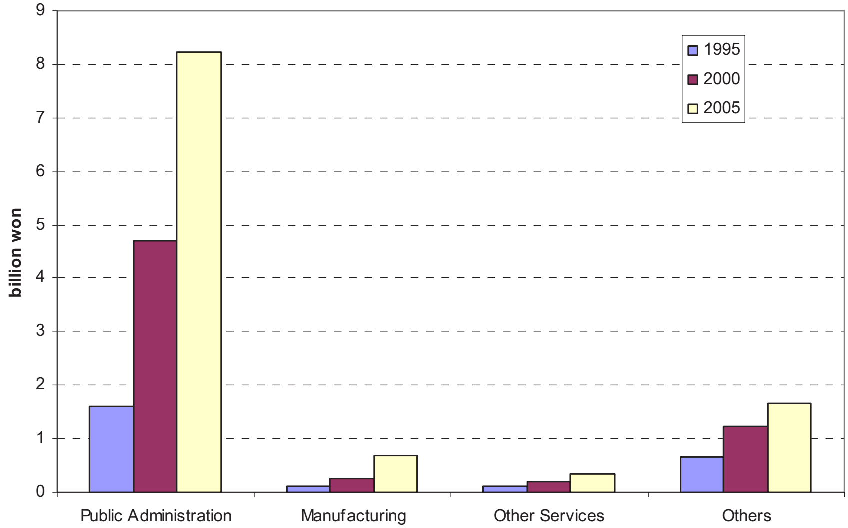

FIG. 7.5. Total income effects of local tax payment by sector.

7.6.4. Effects of special regional development and subsidy funds

Under the Energy Industry Foundation Fund, a number of special infrastructure and socioeconomic projects have been undertaken in the Ulchin region. The main efforts include: (1) projects for enhancing public welfare by increasing household incomes, expanding public facilities and subsidizing households through the partial payment of electricity bills by KHNP; (2) projects to facilitate local industrialization by encouraging companies to move into the region, providing both startup assistance and subsidized electricity; and (3) projects to develop human resources by providing teaching materials, scholarships and other aids to improved education. There are also projects ongoing to support local cultural events and health programs. As noted above, total expenditures for special projects in the Ulchin region amounted to some 161 billion Won. Expenditures for individual projects for selected years are listed in Table 7.15.

TABLE 7.15. EXPENDITURES FOR THE REGIONAL DEVELOPMENT PROJECTS IN ULCHIN REGION (IN BILLIONS OF WON)

	1995	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Basic Regional Development	0.5	1.6	1.7	1.2	0.5	0.5	1.1
Public Facilities	1.1	1.6	1.4	1.8	2.4	2.3	1.2
Social Welfare	0	200	0	0	0	0	0
Industry Relocation Assistance	0	0.6	0.3	0.3	0.3	0.3	0.3
Environmental Monitoring	0	0	0	0	1.1	0.3	0.4
Education	0.4	0.9	1.4	1.3	3.6	1.8	1.3
Electricity Subsidy	0.2	0.9	1.9	1.4	1.1	1.2	0.9
Public Information	0.05	0.2	0.2	0.1	0.1	0.1	0.01
Other	0	0	0	0	0	0	0
Total	**2.3**	**6.0**	**64.3**	**7.9**	**9.2**	**6.6**	**5.3**

To estimate the contribution of special fund projects to Ulchin's regional economic development, the related expenditures first had to be classified into sectors as defined for the regional I–O table, to permit estimation of their output and income effects (Table 7.16).

TABLE 7.16. RECIPIENTS OF SPECIAL SUPPORT PROJECTS BY I–O SECTOR

Project Type	Detailed Description	Recipient Sector
Basic Regional Development	Facilities for agriculture, forestry and fishery like public agricultural facilities, public fish farms, public processing plants, agricultural waterways, agricultural plantation facilities, etc.	Agriculture/ Forestry/ Fishery
	Industrial facilities including water supply, markets and cooperative markets	
Public Facilities	Construction and repairing of senior centers, town centers, etc.	Construction
	Electricity and communication facilities: public electricity, joint TV receiving facility, etc.	
	Water supply and drain systems	
	Educational facilities like libraries and cultural facilities	
	Radioactivity preventative facilities for public security	
Social Welfare	Maximum subsidy of 5 million won per person	Finance
Industry Relocation Assistance	Maximum subsidy of 20 million won per company	Finance
Environmental Monitoring	Support for public environmental monitoring system	Other Services
Education	Various scholarships	Educational Service
	Provision of teaching materials like computers and Aid for school cafeterias.	
	Support for school physical education programs and libraries	
Subsidised Electricity	Subsidies on electricity cost for household and industry (for 76 520 units)	Direct income increases, not a sector
Public Information.	Arranging presentation sessions for awareness	Other Services
	Public welfare programmes	
	Management of environmental monitoring system (in Kori, Yeonggwang and Ulchin)	
	Other affiliated projects	

7.6.4.1.Output effects of special fund projects

The total output effects of these special fund projects are shown in Table 7.17. Note that subsidies on electricity cost for household and industry are excluded from this calculation, since these are considered as direct income to households and hence are included as an income effect.

TABLE 7.17. OUTPUT EFFECTS OF SPECIAL FUND PROJECT IN THE ULCHIN REGION (IN BILLIONS OF WON)

	Direct/Indirect Effect	Induced Effect	Total Effect
1990	1.0	1.2	2.2
1995	2.5	2.4	4.8
2000	5.6	4.5	10.1
2001	5.6	4.7	10.3
2002	7.2	5.7	12.9
2003	9.3	9.1	18.4
2004	6.1	5.3	11.4
2005	5.1	4.0	9.1

Households were the major beneficiaries of these output effects followed closely the construction sector, the agriculture/forestry/fishery sector, and the educational service sector in 2005 (see Fig.7.6).

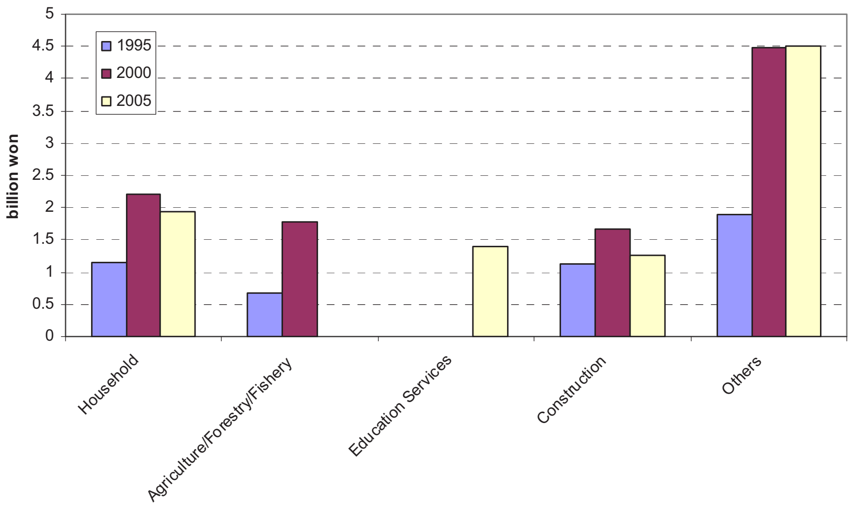

FIG. 7.6. Total output effects of special fund projects by sector.

7.6.4.2.Income effects of special projects

The income effects of these special fund programmes were calculated in the same way as for the income effect of taxes, namely, by calculating the income effects of the sectoral output specified in Table 7.15. The total income effects generated from the special fund projects doubled three times over between 1990 and 2003, but since then have fallen steadily, in parallel with the surge and decline in expenditures and hence in the output effect (see Table 7.18).

TABLE 7.18. INCOME EFFECTS FROM SUPPORTING PROJECTS (IN BILLIONS OF WON)

	Direct/Indirect Effect	Induced Effect	Total Effect
1990	0.4	0.2	0.6
1995	0.8	0.3	1.1
2000	1.7	0.5	2.2
2001	1.7	0.5	2.3
2002	2.1	0.6	2.7
2003	3.4	1.0	4.4
2004	2.0	0.6	2.6
2005	1.5	0.4	1.9

The education/research (including technology development and research) and construction sectors enjoyed the highest share of total income effects (Fig.7.7). In 2005, income effects amounted to 0.8 billion Won in the education/research sector and 0.3 billion Won in the construction sector.

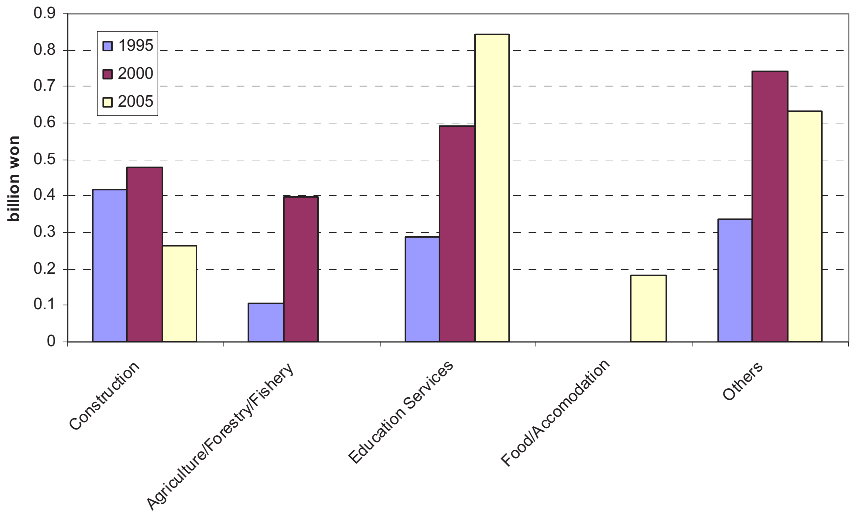

FIG. 7.7. Total income effects of special fund projects by sector.

7.6.4.3.Special case of income effects from electricity subsidies

By national law, power plants must provide specified amounts of subsidised electricity to the regions that host them. KHNP's Ulchin nuclear power plant provides a certain amount of free electricity to regional household and industrial customers. In this study, these subsidies are considered as additional household income, estimated using an income multiplier reflecting the sectoral weighted average of local income. This result was then applied to the amount of the electricity subsidized to calculate the income effect of the electricity subsidies. This effect was estimated to have peaked at 2.8 billion Won in 2001 and has steadily decreased since then, to some 1.3 billion Won in 2005 (See Table 7.19).

TABLE 7.19. INCOME EFFECTS OF THE ELECTRICITY SUBSIDIES (IN BILLION OF WON)

	Direct/Indirect Effect	Induced Effect	Total Effect
1995	0.2	0.1	0.3
2000	1.1	0.2	1.3
2001	2.3	0.4	2.8
2002	1.7	0.3	2.0
2003	1.4	0.3	1.6
2004	1.4	0.3	1.7
2005	1.1	0.2	1.3

7.7. TOTAL CONTRIBUTION OF ULCHIN NUCLEAR POWER PLANT TO REGIONAL ECONOMIC DEVELOPMENT

The total output and income effects of the Ulchin nuclear power plant to the Ulchin regional economy are summarized in Tables 7.20 and 7.21.

TABLE 7.20. TOTAL REGIONAL OUTPUT EFFECTS OF THE ULCHIN NUCLEAR POWER PLANT (IN BILLIONS OF WON)

	Nuclear Power		NPP Areas Regional Project	Local Taxes	Total	Shares to Total Regional Output
	Construction	Operation				
1990	n.a.	581.7	2.2	-	583.9	-
1995	n.a.	605.6	4.8	8.4	618.9	48%
2000	n.a.	1 559.8	10.1	26.2	1 596.1	69%
2001	n.a.	1 615.2	10.3	10.6	1 636.0	66%
2002	n.a.	1 445.4	9.8	17.9	1 473.1	60%
2003	n.a.	1 612.0	18.4	22.9	1 653.3	62%
2004	n.a.	1 835.2	11.4	25.9	1 872.5	72%
2005	n.a.	2 240.1	9.1	56.6	2 305.8	70%

The plant's total contribution to total regional output in Ulchin region is estimated at some 48% in 1995, rising to 70% by 2005. Its contribution to regional income hovered around 40% until 2004, when it fell by almost half. This is due in part to the end of plant construction, but mostly due to the growth and diversification of the regional economy, so that the same contribution becomes a smaller share of the total. The analysis indicates that the Ulchin plant has made a significant contribution to this growth, and is still making a significant contribution to the regional economy.

TABLE 7.21. TOTAL REGIONAL INCOME EFFECTS OF THE ULCHIN NUCLEAR POWER PLANT (IN BILLIONS OF WON)

	Nuclear Power		NPP Areas Regional Project	Local Taxes	Total	Shares to Total Regional Income
	Construction	Operation				
1990	0	20.0	0.6	-	20.5	-
1995	65.1	23.1	1.4	2.4	92.1	39%
2000	67.2	44.8	3.5	6.4	121.9	43%
2001	65.7	55.3	5.0	2.4	128.4	43%
2002	74.5	50.9	4.2	3.9	133.6	40%
2003	68.7	81.4	6.0	4.8	160.9	44%
2004	36.1	74.0	4.3	5.2	119.6	26%
2005	0	75.5	3.2	10.9	89.7	20%

These regional household income effects are the actual regional development gain resulting from the presence, construction and operation of the Ulchin nuclear power plant. They are derived from regional output.

8. FINAL CONSIDERATIONS AND CONCLUSIONS

8.1. ECONOMIC BENEFITS OF NUCLEAR TECHNOLOGIES

As estimated in this study, selected nuclear technologies, namely nuclear power generation and radioisotope applications, have contributed positive industrial value added to the national economy of Korea. Nuclear power plant construction and operation, in addition, were shown to have a positive value added effect on regional output and income.

For both nuclear power and radioisotope applications, the economic contribution was quantified only in terms of incremental industrial value added. At the regional level, the contribution of a nuclear power plant to the regional economy was measured only in terms of incremental income derived from incremental output. The actual contributions estimated are not insignificant: 1.3% nuclear power[13] and 0.67% for radioisotope applications at the national level; plant operation and construction at the regional level contributed 70% of regional output and 20% of regional income. But these estimates can only be considered as minimum estimates. There are other external benefits that clearly accrue, especially in the case of nuclear power; these should also be noted and described, at least qualitatively.

External benefits, like the more familiarly known external costs, are those that the public incurs but that are not included in the cost of production (in the generation cost in the case of nuclear power) and hence are not in the price of the product (electricity). External benefits of nuclear power are thus in a sense by-products of nuclear power generation. Many external benefits often occur in the form of avoided external or even internalized costs. Nuclear power generation, for example, to the extent that it replaces thermal generation, significantly reduces the external costs of air pollution and GHG emissions associated with fossil fuel combustion. Similarly, nuclear power generation creates benefits in terms of enhanced security of energy supply, and in terms of electricity price stability. Although private investors will make their decisions based largely on internalized costs, government investors and policy makers may wish to make and to affect decisions based on both internalized and external costs. Government decisions can include both public investment and regulatory decisions. With increasing pressure on the environment and human health, regulatory measures increasingly incorporate these externalities in such a way that the external costs are

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[13] For nuclear power the incremental contribution (versus actual) was estimated roughly to be around 0.4%.

appropriately internalized, i.e., reflected in the cost of production. Governments can thus indirectly affect private investment choices.

8.2. ENVIRONMENTAL BENEFITS

No form of energy production or use is without an environmental impact on a life cycle basis. This is true for all energy chains: from extracting resources, building facilities, and transporting material through the final conversion to useful energy services. The traditional air pollutants associated with fossil fuel combustion are principally sulphur dioxide (SO_2), nitrogen oxides (NOx) and suspended particulate matter (PM); GHG emissions from fossil fuel combustion include most notably CO_2 and methane (CH_4). Trace elements and heavy metals, like arsenic and mercury are also associated with coal combustion. Nuclear power plants emit virtually none of these air pollutants associated with fossil fuel combustion. Hence, a major environmental benefit of nuclear power is a significant avoidance of the costs associated with both air pollution and GHG emissions.

These avoided external costs can be difficult to quantify and convert to monetary values; any valuation process remains subjective, and results vary across countries. Despite the uncertainties and the national differences in valuation of externalities, however, several major studies have sought to estimate the external costs of air pollution associated with different electricity generating technologies. Perhaps best known is the ExternE project (providing global and standardized assessments) sponsored by the European Union and Oak Ridge National Laboratory in the USA. A comparison is provided of the external costs estimated by ExternE over time and for different electricity generating technologies. (Figs 8.1 and 8.2) A comparison of the external costs associated with nuclear and with other technologies gives some indication of the opportunity for avoided air pollution costs presented by nuclear power generation.

Figure 8.1 shows on an aggregate and average basis the ranges and the differences in external costs for specific existing generation technologies in use in the European Union in 1999. These costs are presented as costs generated per kW·h of generation, to obviate the need to adjust for plant size to make valid comparisons.

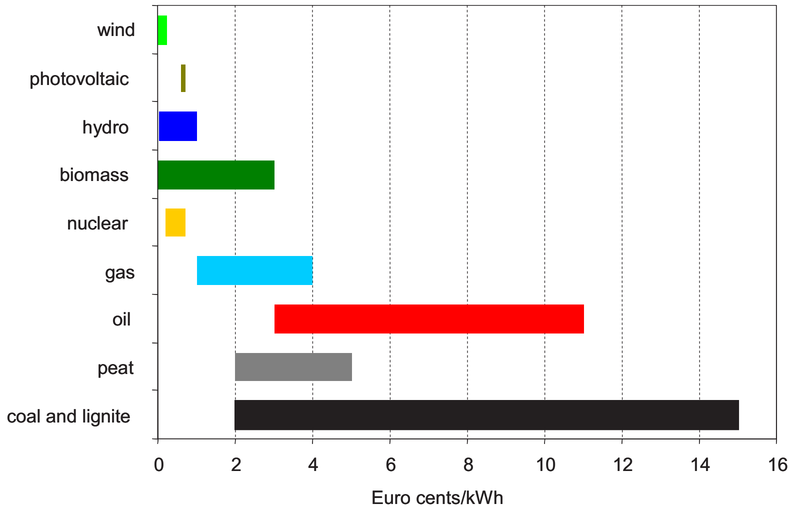
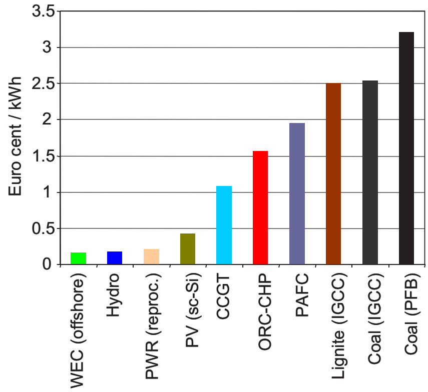


FIG. 8.1. Summary of external costs taken from ExternE based on technologies available in 1999 (Note: Health and environmental costs are included (EC, 2003)).

The above estimates are based on existing technologies. For insight into the potential future benefits from nuclear power in terms of avoided pollution costs, Figure 8.2 provides estimates of external costs (and hence the benefits of avoided external costs) based on technologies that are expected to be available in Germany in 2010 (left diagram) and in Switzerland in the 2010–2020 time frame.



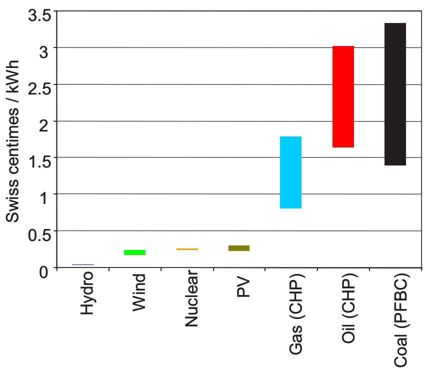


FIG. 8.2. Summary of external costs based on technologies expected to be available after 2010 (sources: adapted from Friedrich, 2005 (left diagram) and from PSI, 2001 (right diagram).

The external benefits of avoided costs in terms of GHG emissions reduction from nuclear power generation are presented in Fig. 8.3. Among the alternatives for generating electricity, fossil fuelled technologies (coal, oil, and natural gas) have the highest CO_2 emission rates per kW·h and create the majority of energy related GHG emissions. Figure 8.3 also shows that the complete nuclear fuel cycle, from resource extraction to waste disposal including reactor and facility construction, emits only 1–6 grams of carbon equivalent per kW·h (gCeq/kW·h)[14]. This is about the same as wind and hydropower, including construction and component manufacturing. All three, together with solar power and biomass, are well below coal, oil, and natural gas (60–460 gCeq/kW·h) even with carbon capture and storage. At present nuclear power helps avoid some 8% of CO_2 emissions globally each year. This contribution is higher in countries with nuclear power.

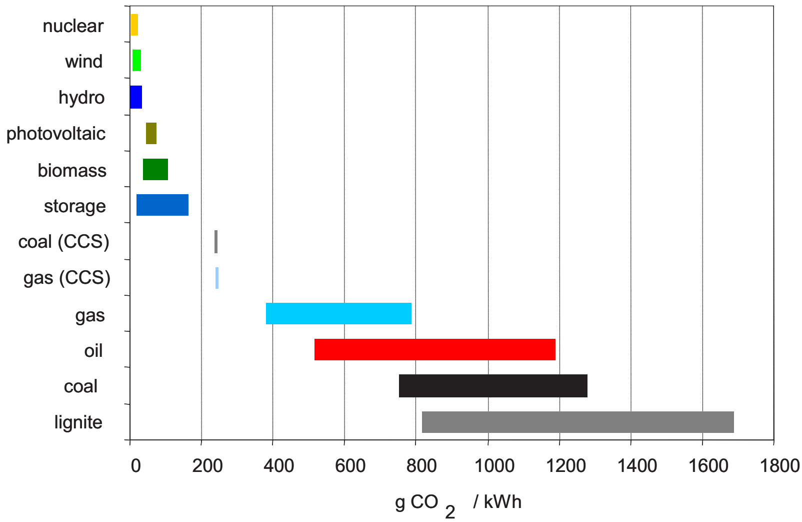


FIG. 8.3. CO_2 emission rates for alternative electricity generation.Note: Storage = batteries, pumped hydro, compressed air storage; CCS = carbon capture and storage (Weisser, 2007).

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[14] GHG emissions for nuclear energy chains depend largely on the choice of reactor type (e.g. PWR, BWR), and most notably the choices about enrichment and reprocessing. Diffusion enrichment technology is more energy intensive than centrifuge technology and, depending on the electricity supply mix of the enrichment plant (whether coal or gas fired, for example), can significantly affect total life cycle GHG emissions. GHG emissions associated with downstream activity, such as decommissioning and waste management, range between 0.13–0.22 gCeq/kW·h.

The Kyoto Protocol to the UNFCCC gives a clear signal that a global carbon emission constraint is emerging that might become increasingly stringent. All rational actors will hedge against the risk of tighter future CO_2 reduction requirements. This triggers investments in non-carbon technologies, including nuclear technologies. Yet any measurable impact of these effects on nuclear power will only become visible if the carbon constraint is sufficient and permanent.

The external costs of nuclear power generation are expressed above as a percent of actual generation costs. In absolute terms they range from 0.25–0.7 euro cents/kW·h, compared to a range of 1–15 euro cents/kW·h for fossil fuels and 0–0.7 for renewables. The relative level of external costs associated with nuclear power production is thus such that replacing future fossil fuel generation with further growth in nuclear power production to meet growing electricity needs, would provide relative environmental benefits in terms of avoided costs.

8.3. SUPPLY SECURITY CONSIDERATIONS

Energy supply security encompasses physical sufficiency of energy supply, import vulnerability, price volatility, affordability, and the competitive efficiency of a country's energy system, however configured.

Supply diversity is a key strategy for reducing vulnerability to supply disruptions from a given source of supply, or price volatility for a given fuel. Future price increases for fossil fuels are likely to be more permanent than the price hikes of the 1970s to the extent that are driven by increased demand. The impact of such price levels was estimated by the IEA (IEA, 2004) to cost OECD countries a GDP loss of 0.4% for each $10 increase in the price of oil.

For most countries, expanding nuclear power would increase the diversity of their energy supplies and thus their energy supply security. Nuclear power has two features that increase supply resiliency. First, the basic fuel, uranium, is available from a variety of producer countries, and small volumes are required, making it easier to establish strategic inventories. In practice, the trend over the years has been away from strategic stocks toward supply security based on a diverse well functioning market for uranium and fuel supply services. This is the option that the Republic of Korea has chosen to follow. But the option of relatively low-cost strategic inventories remains available for countries that find it important.

Second, nuclear electricity generating costs are less sensitive to changes in fuel prices than are the costs of fossil fired generation. Although the benefits to the economy of the Republic of Korea of the opportunity for lower electricity prices from nuclear power were not estimated, it was noted that insulation from price volatility — another avoided cost — is a positive benefit of nuclear power. The trebling of uranium prices in 2006–2007 resulted in only a 6–8% difference in nuclear power generating costs, while a doubling of international fossil fuel prices translates into generation cost increases of about 35–45% for coal fired electricity and 70–80% for natural gas. Since the competitiveness of nuclear power depends in part on the economics of fossil fuel alternatives, such rising fossil fuel prices tend to improve nuclear power's competitive standing. In Korea, nuclear power competes with coal and to some extent with gas, but it is not in direct competition with oil for electricity generation.

Energy price data from OECD Member States show interesting implications for electricity prices in OECD countries with and without nuclear power (see Fig. 8.4). Countries with significant shares of conventional thermal electricity generation (Germany, Netherlands and Ireland) have experienced considerable fluctuations and increases in the price of electricity. By contrast, countries like the Republic of Korea, France and Japan, with significant shares of nuclear have an electricity price structure less exposed to the ups and downs of the international energy commodity markets, and have enjoyed lower electricity prices overall. So, as a special case, has renewables-rich Denmark, largely because its regional grid can absorb power fluctuations.

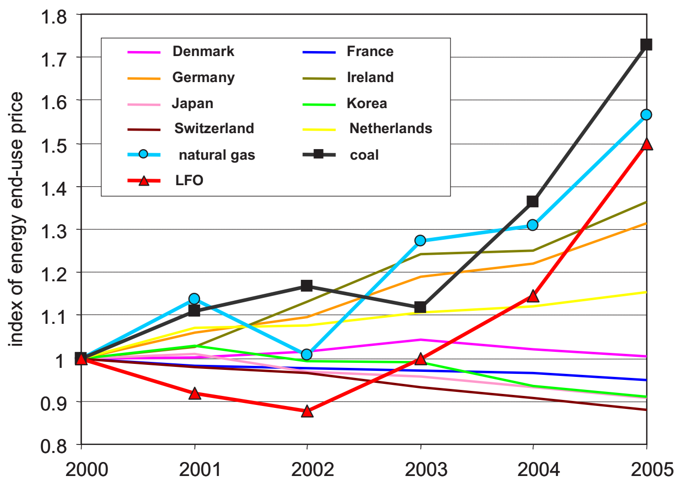

FIG. 8.4. Electricity price indices for selected countries and energy price development in the OECD (source: IEA/OECD, 2006).

8.4. ENVIRONMENTAL CONCERNS AND EXTERNAL COSTS OF NUCLEAR POWER

The two major environmental concerns generally associated with nuclear power are the question of radioactive emissions and long term high level waste disposal.

Complicating the debate on long term disposal of highly radioactive materials is the fact that, among countries, there is no agreed definition of high level nuclear waste (e.g. many countries exclude spent fuel) Although the scientific and technical communities generally agree that high level waste can be disposed of safely in stable geologic formations, the definition of 'stable' is also a matter of debate (particularly in terms of an acceptable time frame for estimating impacts). There is currently no operating repository for the final disposal of high level radioactive materials from civilian nuclear power plants. Final repositories low and medium level radioactive waste have been licensed and are in operation in many countries. At the end of 2005, the Republic of Korea agreed on a central repository for low and intermediate level radioactive waste in Gyeongju, some 270 km southeast of Seoul, ending two decades of government studies to find a host region with appropriate geological conditions and with public support. Spent fuel is currently stored at the reactor site in the Republic of Korea in dry casks.

From an economic point of view, the storage and ultimate disposal of spent fuel is not an external cost. The estimated costs of spent fuel management and disposal (including environmental protection measures as dictated by regulation) are already included in the cost of the fuel as delivered to the plant, and so are already incorporated into the generating cost. Similarly, companies producing nuclear power are required as a matter of law or regulation to assure financing of decommissioning and waste disposal from each and all of their facilities. Again, this is an annual cost of business that is reflected in the cost of generation and hence in electricity prices.

Public concerns about radiation exposure from nuclear power plant emissions were heightened by the accidents at Three Mile Island and Chernobyl. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has published a worldwide comparison of average radiation doses (on a logarithmic scale) from nuclear power production and the average dose from natural background sources (Fig. 8.5): the average radiation dose from global nuclear power production is one ten-thousandth of the dose from natural background sources. Background sources include cosmic rays and naturally occurring radioactive substances in the air (mainly radon), in food and water (such as potassium), and in the earth. Human bodies are radioactive and human activities create additional exposure, most significantly from medical X rays and nuclear medical procedures. Living in a brick, stone or concrete building; watching television or using a computer terminal; travelling in a jet airplane; and wearing a luminous wristwatch all add to the dose. The incremental dose from a home smoke detector is comparable to that from living within 50 miles of a nuclear power plant.

In a similar vein, according to the European Commission's Marina II study (Nucleonics Week, 2003), the radioactivity from phosphate discharges in the North Sea now account for more than 55% of the European population's total exposure (alpha activity and collective dose) to radioactivity from industrial discharges. North Sea oil and gas operations contribute 35.5%, while the total contribution from nuclear facilities is 5.6%, including the residues of phosphate production at Sellafield during World War II and subsequent reprocessing of nuclear fuel at Sellafied and La Hague. Fallout from weapons tests and from Chernobyl account for another 3.5%.

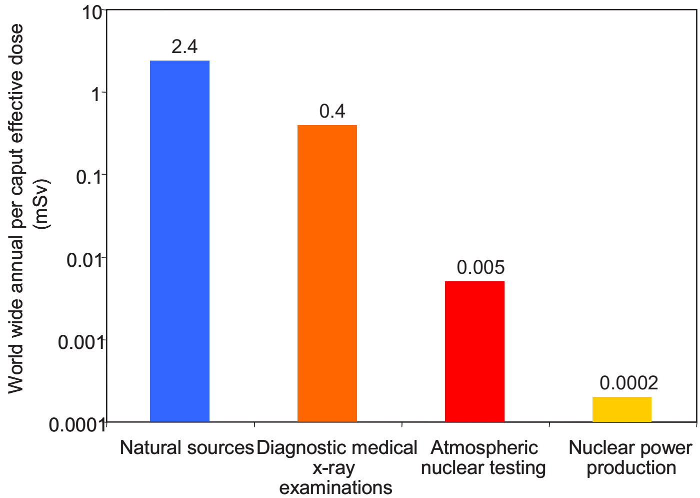

FIG. 8.5. Worldwide average annual per capita dose from natural and anthropogenic radiation (Note: Adapted from UNSCEAR (2000)).

REFERENCES

BECK, P., GRIMSTON, M., Double or Quits? The Global Future of Civil Nuclear Energy, Royal Institute of International Affairs, London (2002).

BOSTER, P.J., MARTIN, W.E., The value of primary versus secondary data in interindustry analysis: A study in the economic models, Ann. Regional Sci. **6** 2 (1972).

BOURQUE, P.J., COX, M., An inventory of regional input-output studies in the United States", Graduate School of Business Administration, University of Washington, Seattle (1970).

BYRNE, J., GLOVER, L, LEE, H., WANG, Y., YU, J., Electricity reforms at a cross roads: problems in South Korea's power liberalization strategy, Pacific Affairs**77** 3 (2004).

CHA, D., KIM, K,, PERKINS, D.H., Eds, The Korean Economy 1945-1995: Performance and Vision for the 21st Century, Korea Development Institute, KDI Press (1997).

CHANG, W.H., Variations in Multipliers and Related Economic Ratios for Recreation and Tourism Impact Analysis, PhD thesis, Michigan State University (2001).

CHENERY, H.S., CLARK, P.G., Interindustry Economics, Wiley, New York (1959).

CZAMANSKI, S., MALIZIA, E.E., "applicability and limitations in the use of national I–O tables for regional studies", Papers and Proceedings, Regional Science Association **23** (1969).

DONES, R.; HECK, T., HIRSCHBERG, S., Greenhouse Gas Emissions from Energy Systems, Comparison and Overview, Encyclopaedia of Energy, **3** (2004) 77–95.

EUROPEAN COMMISSION External Costs — Research Results on Socio-Environmental Damages due to Electricity and Transport, EC Study EUR 20198, Brussels (2003).

ENERGY INFORMATION ADMINISTRATION, International Energy Outlook, EIA/DOE, Washington, DC (2006).

EUROPEAN UNION ExternE (Externalities of Energy) Methodology 2005 Update Brussels (2005).

FRIEDRICH, R., ExternE: Methodology and Results, presented at External Costs of Energy and their Internalisation in Europe, Dialogue with Industry, NGO, and Policy-makers, European Commission, Brussels (2005).

FRIEDRICH, R., et al., New Elements for the Assessment of External Costs from Energy Technologies, Final Report to the, DG Research, Technological Development and Demonstration (RTD), European Commission, Brussels (2004).

GIARRATANI, F., MADDY, J.D., SOCHER, C.F., Regional and Interregional Input-Output Analysis, West Virginia University, Morgantown (1976).

GYEONGSANGBUK-DO, 2002 Gross Regional Domestic Product by City and Province (2004) (in Korean).

GYEONGSANGBUK-DO, 2003 Gross Regional Domestic Product by City and Province 2006 (in Korean).

HA, IN-BONG, Regional Economy Forecast and a Model of Policy Analysis, Korea International Economic Association Winter Scholarship Meeting 1994 (in Korean).

HIRSCH, W.Z., Interindustry Relations of a Metropolitan Area, Review of Economics and Statistics **41** (1959) 360–369.

INTERNATIONAL ATOMIC ENERGY AGENCY, Energy, Electricity and Nuclear Power Estimates for the Period up to 2030, Reference Data Series No. 1, July 2005 Edition, IAEA, Vienna (2005).

INTERNATIONAL ATOMIC ENERGY AGENCY, Power Reactor Information System, IAEA, Vienna (2007).

INTERNATIONAL ENERGY AGENCY, Energy Policies of IEA Countries: The Republic of Korea — 2002 Review, IEA, Paris (2002).

INTERNATIONAL ENERGY AGENCY,, World Energy Outlook 2004, OECD, Paris (2004).

INTERNATIONAL ENERGY AGENCY,, Energy Policies of IEA Countries – 2004 Review, OECD, Paris (2004).

INTERNATIONAL ENERGY AGENCY, World Energy Statistics and Balances: Energy Balances of OECD Countries — Economic Indicators, Vol. 2005, release 01, OECD, Paris (2005).

INTERNATIONAL ENERGY AGENCY, Electricity Information 2005, OECD, Paris (2005).

INTERNATIONAL ENERGY AGENCY, CO_2 Emissions from Fuel Combustion, OECD, Paris (2005).

INTERNATIONAL ENERGY AGENCY, Energy Prices and Taxes — Indices of Real Energy End-Use Prices, release 01, OECD, Paris (2006).

INTERNATIONAL ENERGY AGENCY, Energy Efficiency Policies and Measures Database, , OECD, Paris (2006) (http://www.iea.org/textbase/pamsdb/grindex.aspx).

INTERNATIONAL ENERGY AGENCY, Global Renewable Energy Policies and Measures Database, OECD, Paris (2006) (http://www.iea.org/textbase/pamsdb/grindex.aspx).

INTERNATIONAL ENERGY AGENCY, Climate Change Database, OECD, Paris (2006) (http://www.iea.org/textbase/envissu/pamsdb/index.html).

INTERNATIONAL INSTITUTE OF APPLIED SYSTEMS ANALYSIS AND WORLD ENERGY COUNCIL, Global Energy Perspectives, Cambridge University Press, Cambridge (1998).

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, Special Report Emissions Scenarios, Summary for Policymakers, Cambridge University Press, Cambridge (2000).

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, Special Report Carbon Dioxide Capture and Storage, Cambridge University Press, Cambridge (2005).

IPSOS, M. NucNet, Friday, 20 January (2006).

ISARD, W., Interregional and Regional I–O Analysis: A Model of a Space Economy, Review of Economics and Statistics **33** (1951).

ISARD, W., KUENNE, R.E., The Impact of Steel Upon the Greater New York-Philadelphia Region, Review of Economics and Statistics **35** 4 (1953) 289–301.

JO, S.H. LEE, S.Y., “An Analysis for the Regional Economic Structure of Busan by 2000 Busan Regional Input-Output Model”, Journal of Economic Study, The Korea Economics and Business Association (2004) (in Korean).

KANG, K.-H.,Theory of Input-Output Analysis, Yunamsa 2000 (in Korean).

KOREA ELECTRIC POWER CO. LTD, Electricity Statistics, KEPCO, Seoul (2007).

KIM, K.-S., A Study on the Induced Effects through the Intra-Regional Input-Output Analysis in Kangwon, J. Ind. Econ. Study, Korean Industrial Economic Association (2004) (in Korean).

KIM, E.J., YU, W., The Evaluation of Estimating Methods for the Metropolitan Area Input-Output Table", A collection of learning papers of the Scholarship Publication Meeting, Architectural Institute of Korea, (1987) (in Korean).

KIM, J.G., A Study on the Chung-Buk Input-Output Analysis, Journal of The East-West Economics Study of Korea, The East-West Economics Association of Korea (2005) (in Korean).

Korea Atomic Industrial Forum, Nuclear Power Yearbook (2006).

KOREA POWER EXCHANGE, The 2nd Basic Plan of Long Term Electricity Supply and Demand, 2004-2017, KPX, Seoul, (2004).

LEE, C.-K., Estimation Method of Regional Input-Output Model and Its Appication of Daegu, Daegu-Gyeongbuk Development Institute, 1993 (in Korean).

LEE, C.-K., An Interindustry Analysis by the Kyong-buk Regional Input–Output Model — Comparative Analysis of the Location Quotient and RAS Method, J. Econ. Study, The Korean Economic Association (1998) (in Korean).

LEE, C.-K., YEO, T.-D., KIM, Y.-J., Analysis on the Industrial Structure in Daegu Using the Regional Input–Output Model, J. Econ. Study, The Korea Economics and Business Association (2003) (in Korean).

LEE, J.-C.., Regional Economic Analysis through Input–Output Model, Primarily Chungju", Journal of Chungbuk Development Study, Chungbuk Development Institute (1991) (in Korean).

LEE, M., Head of Economic Analysis Section, KAERI, (2006) personal communication.

LEONTIEF, W.W., Quantitative I–O Relations in the Economic System of the United States, Rev. Econ. Stat. **18** (1936).

LEONTIEF, W.W., The Structure of American Economy 1919–1939, Oxford University Press, New York (1951).

LEONTIEF, W.W., Input–Output Economics, Oxford University Press, New York (1951).

MEDLOCK III AND HARTLEY, The Role of Nuclear Power in Enhancing Japan's Energy Security (2004).

MIERNYK, W. H., The Elements of I–O Analysis, Random House, New York (1965).

MILLER, R.E., The Impact of the Aluminium Industry on the Pacific Northwest: A Regional Input-Output Analysis, Rev. Econ. Stat. **39** 2 (1957) 200–209.

MILLER, R.E., Blair, P.D., I–O Analysis: Foundations and Extensions, Prentice-Hall, Englewood Cliffs, NJ (1985).

MINISTRY OF AGRICULTURE AND FORESTRY,: Selected Statistics on Agriculture and Forestry (2006).

MINISTRY OF COMMERCE, INDUSTRY AND ENERGY, The 2nd Basic Plan of Long-term Electricity Supply and Demand (2004).

MINISTRY OF COMMERCE, INDUSTRY AND ENERGY, White Paper on Nuclear Power (2005).

MINISTRY OF COMMERCE, INDUSTRY AND ENERGY, Year Book of Energy Statistics (2007).

MOORE, F.T., PETERSON, J.W., Regional Analysis: An Interindustry Model of Utah, Rev. Econ. Stat. **37** (1955) 368–383.

MORRISON, W.I., SMITH, P., Non-survey I–O Techniques at the Small Areas Level: An Evaluation, J. Regional Sci. **14** 1 (1974) (1974).

MOSES, L.M., Output and Prices in Inter-industry Models, Papers of Regional Science Association **32** (1974).

MOSES, L.M., The Stability of Interregional Trading Patterns and I–O Analysis, Am. Econ. Rev. **XLY** 5 (1955).

OECD/NUCLEAR ENERGY AGENCY, Country Profiles – Korea, OECD, Paris (2006)(http://www.nea.fr/html/general/profiles/korea.html).

OECD NUCLEAR ENERGY AGENCY AND INTERNATIONAL ENERGY AGENCY, Projected Costs of Generating Electricity: 2005 Update, OECD, Paris (2005).

OECD NUCLEAR ENERGY AGENCY/INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).

North Sea Study: Oil, Gas Emit More Radioactivity than Nuclear — EU Marina II study Nucleonics Week **44** 2XX (May 15 2003).

NukNet, 2004; World Nuclear Agency, 11 May 2004 / News N°110 / 04 / A

PAEK, J.-O., YOON, T.-H., HYUN, S.-M., Economic Effects of National Defence Expenditures – In Perspective of the Input-Output Table of Year 2000, Book of Public Finance Theory, The Korean Association of Public Finance 2005 (in Korean).

PAUL SCHERRER INSTITUT, Annual Report 2000 – Annex IV, PSI, Villigen (2001).

RICHARDSON, H.W., I–O and Regional Economics, Halsted Press, New York (1972).

RICHARDSON, H.W., I–O and Economic Base Multipliers: Looking Backward and Forward, J. Regional Sci. **25** 4 (1985).

RIEFLER, R.F., Interregional I–O: A State of the Arts Survey, Studies in Economic Planning over Space and Time, North-Holland Amsterdam (1973).

RIEFLER, R.F., TIEBOUT, C.M., Interregional I–O: An Empirical Califonia-Washington Model, J. Regional Sci. **10** 2 (1970).

ROGNER, H.-H., An Assessment of World Hydrocarbon Resources, Annu. Rev. Energy Environ. **22** (1997) 217-262.

SCHAFFER, W.A., CHU, K., Nonsurvey Techniques for Constructing Regional Interindustry Models", Papers and Proceedings, Regional Science Association **23** (1969).

SONG, H.-A., Framing of Regional Input-Output Table through The Non-Survey Method and Application of Regional Economy — A Case Analysis of Younggwang, J. Rural Economy **11** 4 (1988) (in Korean).

SPATH, P.L. MANN, M.K., Biomass power and conventional fossil systems with and without CO_2 sequestration – comparing the energy balance, greenhouse gas emissions and economics, National Renewable Energy Laboratory. Prepared under task No. BB04.4010 (2004).

STONE, R., I–O and National Accounts, OECD, Paris (1961).

The Bank of Korea, A Manual of Input-Output Analysis (2004) (in Korean).

The Bank of Korea, Framing and Application of Actual Survey Regional Input-Output Table of Korea (2004) (in Korean).

UNITED NATIONS COMMISSION ON SUSTAINABLE DEVELOPMENT, Backgrounder – Water for Life, UNCSD, New York (2005).

UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE, UNFCCC/INFORMAL/84. United Nations, New York (1992).

UNITED NATIONS DEVELOPMENT PROGRAMME, World Energy Assessment: Energy and the Challenge of Sustainability, UNDP,New York (2000).

UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION, Sources and Effects of Ionizing Radiation, Report, Vol. I:. United Nations, New York (2000).

WORLD ASSOCIATION OF NUCLEAR OPERATORS, Performance Indicators, WANO, London (2004).

WEISSER, D.A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies, ScienceDirect, Energy, **32** 9 (2007) 1543-1559.

WORLD NUCLEAR ASSOCIATION, The New Economics of Nuclear Power (2005) http://www.world-nuclear.org/wgs/wg.htm.

YANG, G.-N., Regional economic impacts of nuclear power plant-related facility sitings, PhD thesis, Chungnam University (1994) (in Korean).

YOON, Y.-S., (A) study on the application technique of the regional input-output analysis for the regional economic analysis, Master’s Thesis, Seoul National University Environmental Graduate School (1983) (in Korean).

ACRONYMS AND ABBREVIATIONS

APR	Korean Advanced Pressurized Reactor
CCGT	combined cycle gas turbine
CHP	combined heat and power
GDP	gross domestic product
I–O	Input-Output model
KAERI	Korea Atomic Energy Research Institute
KEEI	Korean Energy Economics Institute
KEPCO	Korean Electricity Power Company
KHNP	Korea Hydro & Nuclear Power Co.
KINS	Korea Institute of Nuclear Safety
KPX	Korea Power Exchange
KSNP	Korean Standard Nuclear Reactor
LNG	liquefied natural gas
MOST	Ministry of Science and Technology
MOCIE	Ministry of Commerce, Industry and Energy
NP	nuclear policy scenario
OECD	Organisation for Economic Co-operation and Development
OPR	Optimized Power Reactor
TPES	total primary energy supply

UNITS USED

Won	Korean won
bcm	billion cubic meter
Gcal	giga calorie (10^9 calories)
gC/kW·h	grams of carbon per kilowatt-hour
GJ	giga joule (10^9 joules)
GW(e)	gigawatt electrical
GW(th)	gigawatt thermal
kgce	kilogram of coal equivalent
ktce	kilo (10^3) tonne of coal equivalent
kV	kilovolt
kVA	kilovolt-ampere
kW	kilowatt
kW·h	kilowatt-hour
MJ	mega joule (10^6 joules)
Mt	million tonnes
Mtce	million tonnes of coal equivalent
MW	megawatt
MW·h	megawatt-hour
PJ	peta joule (10^{15} joules)
tce	tonne of coal equivalent
TJ	tera joule (10^{12} joules)
TW·h	terawatt-hour

Annex I
ANALYTICAL MODEL FOR NATIONAL I–O ANALYSIS

I–O MODEL

This study uses I–O analysis to quantify the linkage effect of a limited number of nuclear technologies on GDP growth and economic development in the economy of the Republic of Korea and its infrastructure. The I–O analysis is an analytical framework based on the interdependence of industries in an economy; each industry consuming goods from other industries (inputs) in the process of producing its own output, which in turn is sold to other industries as inputs. The inter-industry transactions for each year are recorded as equations in an I–O table.

STRUCTURE OF AN I–O TABLE

To illustrate the structure of an I–O table, a two industry economy is considered. For each industry's output, there are two types of demand; one is intermediate demand and the other is final demand. The first represents other industries' demand for the output to be used as inputs to their own industrial production processes and the latter represents demand by purchasers who are external to the producing industries, for example, households, government and foreign trade. If the following notation is used,

X_i = the total output of industry i,

z_{ij} = the observed value of the flow from industry i to industry j and

F_i = the final demand for industry i's output,

then it can be expressed as

$$\begin{array}{l} X_1 = z_{11} + z_{12} + F_1 \\ X_2 = z_{21} + z_{22} + F_2 \end{array} \Longrightarrow X = Zi + F \text{ in matrix terms,} \qquad (1)$$

where 'i' is a column vector, elements of which are all 1.

Consider the ith column of z's on the right hand side,

$$\begin{bmatrix} z_{i1} \\ z_{i2} \end{bmatrix}$$

These elements are ith purchases of the products of other industries being used as inputs, and which constitute intermediate input. Clearly, the industry pays for other items – for example, labour and capital, which are also included in the value added. Because the value of output is equal to the sum of the total value of intermediate inputs and direct value added, and if the value added of industry i is denoted by V_i, then

$$\begin{aligned} z_{11} + z_{21} + V_1 = X_1 \\ z_{12} + z_{22} + V_2 = X_2 \end{aligned} \implies iZ' + V = X' \text{ in matrix terms} \qquad (2)$$

The I–O table is thus a table recording the magnitudes of inter-industry flows, with industries of origin (sellers) listed on the left and the same industries, now destinations (purchasers) listed across the top. The typical structure of an I–O table is presented in Table A-1.1.

TABLE A-1.1. STRUCTURE OF I–O TABLE

		Industry		**Final Demand**	**Total Output**
		1	**2**		
Industry	1	z_{11}	z_{12}	F_1	X_1
	2	z_{21}	z_{22}	F_2	X_2
Value Added		V_1	V_2		
Total Input		X_1	X_2		

The most important characteristic of an I–O model is perhaps the fact that it makes the analysis of linkage effects possible. These are the effects of an exogenous change to an economy traced through the interdependence of industries. In the I–O literature, the economic linkage effect is classified into two types; backward and forward linkages. The first analyses the effect of change in final demand on output and value added. This focus is used to expose the effects of nuclear power plant construction and operation on other industries and hence on the economy, as construction and operation create demand for goods and services and so contribute to value added. Sales of electricity are not part of this calculation as electricity provides intermediate input to other sectors but does not create final demand. The second type of linkage presents the effect of change in output and value by summing up the contributions of intermediate goods on final output and value added. This approach, in the case of nuclear technologies, would look at sales of electricity or radioisotopes as input to other sectors along with land, capital and labour, but would not consider the effects to a country or a region from plant construction and operation.

CONSTRUCTING AN I–O MODEL

A fundamental assumption of an I–O model is that an industry uses intermediate inputs in fixed proportion. The ratio of input to output is termed an I–O coefficient.

As a simple example, a small economy having only one industry is considered, for example a nuclear power industry. Assuming that the I–O coefficient is 0.4 in nuclear power industry, implying that in order to produce \$1, the nuclear power industry needs output of \$0.4 from itself as intermediate input (this could be in terms of electricity generated on-site for example for on-site use). Supposing that the final demand for the nuclear power industry increases by \$1000. The I–O model examines the question of outputs needed to satisfy this final demand. Initially, it is clear that the nuclear power industry needs to produce \$1000. Since it is assumed that a small economy, having only one nuclear power industry to produce \$1000, the industry needs \$0.4*1 000 from itself as inputs to the productive process. In order to engage in the production of the needed \$0.4*1000, the industry will need yet another \$0.4*0.4*1000 in inputs from itself again. Continuing in this way, the total impact on output of the initial increase in final demand by \$1000 is

$$x = \$1000 + \$0.4 * 1000 + \$0.4^2 * 1000 + ... = \$(1 - 0.4)^{-1} * 1000 \qquad (3)$$

If the I–O coefficient is denoted as a and the initial increase in final demand as f, then Eq. (3) can be generalized as follows;

$$x = f + af + a^2 f + ... = (1 - a)^{-1} * f \qquad (4)$$

For a real economy which has many industries, a matrix of I–O coefficients is needed, termed as A, which is found by dividing each column of I–O table by the total output of the industry represented by that column. In matrix terms, it can be defined as

$$A = \begin{bmatrix} a_{11} & .. & a_{1n} \\ & .. & \\ a_{n1} & .. & a_{nn} \end{bmatrix}$$

where $a_{ij} = z_{ij} / X_j$. Then from Eq. (1),

$$X = Zi + F = AX + F \qquad (5)$$

If $\left|I-A\right| \neq 0$, then the unique solution is given by

$$X = (I - A)^{-1} F \tag{6}$$

which has the same form as Eq. (4) in the small one-industry economy. The formula $(I-A)^{-1}$ is sometimes referred to as the Leontief inverse model. Given an A matrix for an economy, the necessary new output, ΔX, needed to satisfy some exogenously determined new final demand, ΔF, is found as $\Delta X = (I-A)^{-1} \Delta F$ ·

The Leontief inverse relates sectoral gross outputs to the amount of final demand, which is a unit of product leaving the inter-industry system at the end of the process. However, an alternative point of view can be taken to relate sectoral gross output to the primary inputs, which are the units of value entering the inter-industry system at the beginning of the process. Just as input coefficients are assumed to be fixed on the demand side, output coefficients are assumed to be fixed on supply side: if output of industry i is doubled, then the sales from i to each of the industries that purchase from i will also be doubled. The ratio of intermediate demand to output is termed an output coefficient.

A standard I–O matrix calculates the new price of a product from an exogenous change in the price of some primary factor; the inverse matrix calculates the new production costs of an industry for a given change in the primary costs. As a consequence, the typical element g_{ij} denotes the additional production costs in industry j that are made (directly and indirectly) when the primary costs in industry i are increased by one unit. Thus when the primary costs in industry i increase by \$1, the production costs (and hence the output value) in industry i also increase by \$1, which is the direct effect. Since a fraction b_{ij} of the output is sold to industry j, the production costs in industry j increase by b_{ij}. In its turn, industry j passes a part (viz. b_{jk}) of this increase on to industry k, yielding an increase of $b_j b_{jk}$ in industry k, and so forth. All direct and indirect effects together yield $\mathbf{I} + \mathbf{B} + \mathbf{B^2} + \ldots = \mathbf{G}$.

As an illustration, the small one-industry economy is again considered, having only a nuclear power industry. Assume that the output coefficient is 0.6, implying that, of an output of \$1, \$0.6 is sold as intermediate demand and the remaining US\$ 0.4 is sold as final demand. Suppose the value added for the nuclear power industry increases by \$1 000. The inverse matrix facilitates examining the total output value or production cost generated from this value added. Initially, it is clear that the value of the nuclear power industry output increases by \$1 000. However, since \$0.6*1000 out of this

$1 000 is sold to itself as intermediate demand, the output value or production cost of the industry increases by $0.6*1000 again. Continuing in this way, the total impact on output value or production cost of the initial increase in value added by $1 000 is

$$x = \$1000 + \$0.6*1000 + \$0.6^2*1000 + ... = \$(1-0.6)^{-1}1000 \qquad (7)$$

If the output coefficient is denoted as b and the initial increase in final demand as v, then the equation (7) can be generalized as follows;

$$x = v + bv + b^2v + ... = (1-b)^{-1} * v \qquad (8)$$

For a real economy which has many industries, a matrix of output coefficients is needed, termed as B, which is found by dividing each row of I–O table by the total output of the industry represented by that row. In matrix terms, define

$$B = \begin{bmatrix} b_{11} & .. & b_{1n} \\ & .. & \\ b_{n1} & .. & b_{nn} \end{bmatrix}$$

where $b_{ij} = z_{ij} / X_i$. Then from Eq. (2),

$$X' = i'Z + V = X'B + V \qquad (9)$$

If $|I - B| \neq 0$, then the unique solution is given by

$$X' = V(I-B)^{-1} \qquad (10)$$

which has the same form as Eq. (8) in the small one-industry economy. $(I-B)^{-1}$ is referred to as the output inverse matrix, with the matrix of output coefficients, B. Given a B matrix for an economy, the new output value, ΔX, generated from some exogenously determined new value added, ΔV, is found as $\Delta X' = \Delta V(I-B)^{-1}$.

Annex II

ANALYTICAL MODEL FOR REGIONAL I–O ANALYSIS

Closing the model with respect to households moves the household sector from the final demand column and places it inside the technically interrelated table of productive sectors. This requires deriving a row and a column for the new endogenous household sector. The row shows how the output of the household sector is used as an input by the various sectors and the column shows the structure of its purchases distributed among the sectors.

Thus, if the household sector is placed in the n+1th sector and denoted by F_i, with the remaining final demand for sector i's output exclusive of that from households denoted by Z_i, and X_i being the total output of sector i, then the equilibrium condition for the sector i, as shown in Eq. (1) of Appendix 1, would be modified to

$$X_i = Z_{i1} + Z_{i2} + \ldots + Z_{ii} + \ldots + Z_{\in} + Z_{i,n+1} + F_i^* \tag{11}$$

$$X_{n+1} = Z_{n+1,1} + \ldots + Z_{n+1,i} + \ldots + Z_{n+1,n} + Z_{n+1,n+1} + F_{n+1}^* \tag{12}$$

where the z terms on the right-hand side represent the interindustry sales by the sector. Using the I–O coefficient $a_{ij} = Z_{ij} / X_j$, equation (11) becomes

$$X_i = a_{i1}X_1 + a_{i2}X_2 + \ldots a_{ii}X_i + \ldots + a_{in}X_n + a_{i,n+1}X_{n+1} + F_i^* \tag{13}$$

or $-a_{i1}X_1 - a_{i2}X_2 - \ldots + (1 - a_{ii})X_i - \ldots - a_{in}X_n - a_{i,n+1}X_{n+1} = F_i^*$

For notational simplicity, the following matrix notations have been introduced,

$$\underline{H}_R = \left[a_{n+1,1} \;\; a_{n+1,2} \;\; \ldots \;\; a_{n+1,n}\right]$$

$$\underline{H}_C = \begin{bmatrix} a_{1,n+1} \\ a_{2,n+1} \\ \ldots \\ a_{n,n+1} \end{bmatrix}$$

$$\widetilde{A} = \begin{bmatrix} A & \underline{H}_C \\ \underline{H}_R & a_{n+1,n+1} \end{bmatrix}$$

$$\underline{X} = \begin{bmatrix} X_1 \\ X_2 \\ \cdots \\ X_n \end{bmatrix}$$

$$\underline{\tilde{X}} = \begin{bmatrix} \underline{X} \\ X_{n+1} \end{bmatrix}$$

$$\underline{F}^* = \begin{bmatrix} F_1^* \\ F_2^* \\ \cdots \\ F_n^* \end{bmatrix}$$

$$\underline{\tilde{F}}^* = \begin{bmatrix} \underline{F}^* \\ F_{n+1}^* \end{bmatrix}$$

Then the new system of n+1 equations, with households endogenous, can be represented as either

$$(I - \tilde{A})\underline{\tilde{X}} = \underline{\tilde{F}}^* \tag{14}$$

or $$\begin{bmatrix} I - A & -\underline{H}_C \\ -\underline{H}_R & 1 - a_{n+1,n+1} \end{bmatrix} \begin{bmatrix} \underline{X} \\ X_{n+1} \end{bmatrix} = \begin{bmatrix} \underline{F}^* \\ F_{n+1}^* \end{bmatrix}$$

or $$\begin{cases} (I - A)\underline{X} - \underline{H}_C X_{n+1} = \underline{F}^* \\ -\underline{H}_R \underline{X} + (1 - a_{n+1,n+1})X_{n+1} = F_{n+1}^* \end{cases}$$

If the (n+1) x (n+1) coefficient matrix is non-singular, the unique solution can be found using an inverse matrix as follows,

$$\underline{\tilde{X}} = (I - \tilde{A})^{-1}\, \underline{\tilde{F}} \tag{15}$$

The key analysis in an I–O model is impact analysis of the effect of an exogenous change to an economy traced through the interdependence of industries. These effects and the interdependent relationships are calculated and expressed by a set of I–O multipliers that express the difference between the initial effect of an exogenous change and the total effects of that change.

These effects are calculated as income effects and output effects. They can also be classified as direct, indirect and induced effects, but induced effects for households can only be derived by closing a model to incorporate households as a sector. The summation of the indirect and induced effects is also called the secondary effect.

OUTPUT EFFECT

The output effect for sector j is defined as the total value of production in all sectors of the economy required to satisfy the exogenous change in final demand for sector j's output. This total production is the direct and indirect output effect obtained from a model in which households are exogenous and can be calculated using Leontief inverse matrix. Given exogenous final demand, a Leontief inverse determines total value of production required to satisfy it as follows:

$$\underline{X} = (I - A)^{-1}\,\underline{F} \tag{16}$$

If the vector of changes in final demand is denoted by $\Delta\underline{F}' = (\Delta F_1, ..., \Delta F_n)$ and by $(I - A)^{-1} = [\alpha_{ij}],\ i, j = 1, ..., n$ the Leontief inverse, then the total change in each sector's output generated by the change in final demand is found as

$$\Delta\underline{X} = (I - A)^{-1}\Delta\underline{F} = \begin{pmatrix} \sum_{j=1}^{n} \alpha_{1j}\Delta F_j \\ \vdots \\ \sum_{j=1}^{n} \alpha_{nj}\Delta F_j \end{pmatrix}$$

If the model is closed with respect to households, then the additional induced effects of household income generation are captured in the model through payments for labour services and the associated consumer expenditures on goods produced by the various sectors. Using notations for the closed model, the relationship between final demand and the total value of outputs produced by all sectors is described as

$$\underline{\tilde{X}} = (I - \tilde{A})^{-1}\,\underline{\tilde{F}} \tag{17}$$

If the Leontief inverse of the closed model is denoted by $(I - \tilde{A})^{-1} = [\tilde{\alpha}_{ij}]$, $i, j = 1, ..., n$, then the total change in each sector's output generated by the change in final demand is found as

$$\Delta\underline{\tilde{X}} = (I - \tilde{A})^{-1} \Delta\underline{\tilde{F}} = \begin{pmatrix} \sum_{j=1}^{n} \tilde{\alpha}_{1j} \Delta \tilde{F}_j \\ \vdots \\ \sum_{j=1}^{n} \tilde{\alpha}_{nj} \Delta \tilde{F}_j \end{pmatrix},$$

which includes induced effects as well as direct and indirect effects.

In the usual form of the standard I–O model, the final demand elements are considered exogenous. However, in order to assess the output effect generated by the construction and operation of a nuclear power plant, a mixed type of model is needed where output from the nuclear power sector is specified exogenously. As an example, in an open four-sector model with nuclear power being the fourth sector denoted as g, assume that F_1, F_2, F_3, X_g are treated as exogenous. The basic I–O relationships still hold in the following equation:

$$\begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \begin{pmatrix} X_1 \\ X_2 \\ X_3 \end{pmatrix} + \begin{pmatrix} a_{41} \\ a_{42} \\ a_{43} \end{pmatrix} X_g + \begin{pmatrix} F_1 \\ F_2 \\ F_3 \end{pmatrix} = \begin{pmatrix} X_1 \\ X_2 \\ X_3 \end{pmatrix}$$

Or, in matrix form,

$$A_d \underline{X}_d + \underline{A}_g X_g + \underline{F}_d = \underline{X}_d,$$

where A_d is the matrix of coefficients exclusive of the row and column of the nuclear power sector, $\underline{X}_d$ is the output vector exclusive the nuclear power sector, $\underline{A}_g$ is the nuclear power sector's column vector in the coefficients matrix exclusive of the sector's element, and $\underline{F}_d$ is the final demand vector exclusive of the nuclear power sector's element. If the final demand for all sectors except for the nuclear power sector is set at zero, then one can clearly show the demand generated by the nuclear sector by rearranging the above equation as

$$\underline{X}_d = (I - A_d)^{-1} \underline{A}_g X_g.$$

This equation gives the indirect output effect generated by intermediate input demand $\underline{A}_g X_g$ when the output of the nuclear power sector is given exogenously as X_g. Since the direct output effect isX_g, the output effect including these direct and indirect effects is given as

$$\begin{bmatrix} \underline{X}_d \\ X_g \end{bmatrix} = \begin{bmatrix} (I - A_d)^{-1} \underline{A}_g X_g \\ X_g \end{bmatrix} \tag{18}$$

In a closed model, intermediate input demands for the output of the nuclear power sector, X_g, are $\underline{\tilde{A}}_g X_g$, where $\underline{\tilde{A}}_g$ is the nuclear power sector's column vector in the coefficients matrix of the closed model. Thus given the output of the nuclear power sector exogenously as X_g, the indirect output effect generated by intermediate input demand $\underline{\tilde{A}}_g X_g$ is found as

$$\underline{\tilde{X}}_d = (I - \tilde{A}_d)^{-1} \underline{\tilde{A}}_g X_g \tag{19}$$

where $\tilde{A}_d$ is the matrix of coefficients in the closed model exclusive of the row and column of the nuclear power sector and $\underline{\tilde{X}}_d$ is the output vector in the closed model exclusive the nuclear power sector.

HOUSEHOLD INCOME EFFECT

The output effect described above consists of changes in the total value of sectoral output required to satisfy an exogenous change in final demand. These changes in outputs will lead to changes in household income through changes in the amount of labour input. Household income effect translates the impacts of a change in final demand spending into further changes in income received by households. This can be done by converting the output effects into dollars of household income using household input coefficients. These are the coefficients that make up the (n+1)st row, $\underline{H}_R$, in the coefficients matrix in the model closed with respect to households, $\tilde{A}$, and which indicate household income received per dollar of sectoral output;

$$\tilde{A} = \begin{pmatrix} A & \underline{H}_C \\ \underline{H}_R & a_{n+1,n+1} \end{pmatrix} \text{ and}$$

$$\underline{H}_R = \begin{pmatrix} a_{n+1,1} & a_{n+1,2} & \cdots & a_{n+1,n} \end{pmatrix}.$$

Thus in open model, changes in household income generated by a final demand spending change are found by multiplying $\underline{H}_R$ times output effects as

$$\underline{H}_R{}'.*\Delta\underline{X} = \underline{H}_R{}'.*(I-A)^{-1}\Delta\underline{F} = \begin{pmatrix} a_{n+1,1}\sum_{j=1}^{n}\alpha_{1j}\Delta F_j \\ \vdots \\ a_{n+1,n}\sum_{j=1}^{n}\alpha_{nj}\Delta F_j \end{pmatrix}$$

where $A.*B$ is the element-by-element product of matrices A and B.

In a closed model, the household income effect can be derived which includes induced as well as direct plus indirect effects. Here, the entire (n+1)st row in the coefficients matrix of the closed model is used to convert the output effects into dollars of household income;

$$\tilde{\underline{H}}_R{}'.*\Delta\tilde{\underline{X}} = \tilde{\underline{H}}_R{}'.*(I-\tilde{A})^{-1}\Delta\tilde{\underline{F}} = \begin{pmatrix} a_{n+1,1}\sum_{j=1}^{n+1}\tilde{\alpha}_{1j}\Delta\tilde{F}_j \\ \vdots \\ a_{n+1,n+1}\sum_{j=1}^{n+1}\tilde{\alpha}_{n+1j}\Delta\tilde{F}_j \end{pmatrix}$$

where $\tilde{\underline{H}}_R = \left(a_{n+1,1} \quad \cdots \quad a_{n+1,n} \quad a_{n+1,n+1}\right)$.

This study calculates the household income effect by considering as exogenous changes the nuclear power sector's wage payments as distributed among the other sectors. This can be done by first estimating sectoral changes in final demand equivalent to these sectoral labour payments as allocated among the relevant sectors, and then putting them into the above equation. If the nuclear power sector's wage payments distributed among sectors are denoted by $\Delta\underline{W} = \left(\Delta W_1 \quad \cdots \quad \Delta W_n\right)$, then the hypothetical sectoral value of final demand would be

$$\Delta\underline{F} = \begin{bmatrix} \Delta W_1 / a_{n+1,1} \\ \vdots \\ \Delta W_n / a_{n+1,n} \end{bmatrix} = (\Delta\underline{W}./\underline{H}_R)' \qquad (20)$$

and the total change in household income in open model is found as

$$\underline{H}_R{}'.*(I-A)^{-1}\Delta\underline{F} = \underline{H}_R{}'.*(I-A)^{-1}(\Delta\underline{W}./\underline{H}_R)' \qquad (21)$$

In the closed model, the corresponding nuclear power sector's wage payments and posited sectoral value of final demand would be

$$\Delta\tilde{\underline{W}} = \left[\Delta W_1 \ \cdots \ \Delta W_n \ \ 0\right] \qquad (22)$$

$$\Delta\underline{\tilde{F}} = \begin{bmatrix} \Delta W_1 / a_{n+1,1} \\ \vdots \\ \Delta W_n / a_{n+1,n} \\ 0 / a_{n+1,n+1} \end{bmatrix} = (\Delta\underline{\tilde{W}} ./ \underline{\tilde{H}})' \tag{23}$$

and the total change in household income is found as

$$\underline{\tilde{H}'} .* (I - \tilde{A})^{-1} \Delta\underline{\tilde{F}} = \underline{\tilde{H}'} .* (I - \tilde{A})^{-1} (\Delta\underline{\tilde{W}} ./ \underline{\tilde{H}})' \tag{24}$$

The household income effect generated by the construction and operation of a nuclear power plant can be derived similarly as for output effects by treating the nuclear power sector exogenously. The open model is first considered.

[Step 1] Given the output of the nuclear power sector exogenouslv as X_g, the indirect output effect generated by intermediate input demand, $\underline{A}_g X_g$, is found as

$$\underline{X}_d = (I - A_d)^{-1} \underline{A}_g X_g \tag{25}$$

[Step 2] If the nuclear power sector is put as the nth sector, household income received per dollar of sectoral output exclusive of the nuclear power sector is

$$\underline{H}_R^g = \begin{bmatrix} a_{n+1,1} & a_{n+1,2} & \cdots & a_{n+1,n-1} \end{bmatrix} \tag{26}$$

[Step 3] Thus, in open model, the indirect household income effect generated by the nuclear power sector's output is

$$\underline{H}_R^{g'} .* \underline{X}_d = \underline{H}_R^{g'} .* (I - A_d)^{-1} \underline{A}_g X_g \tag{27}$$

[Step 4] The direct output effect is the nuclear power sector's output itself, X_g, which results in indirect household income effect by $a_{n+1,n} X_g$.

[Step 5] In sum, the direct and indirect household income effects due to the construction and operation of a nuclear power plant are found as

$$\begin{bmatrix} \underline{H}_R^{g'} .* \underline{X}_d \\ a_{n+1,n} X_g \end{bmatrix} = \begin{bmatrix} \underline{H}_R^{g'} .* (I - A_d)^{-1} \underline{A}_g X_g \\ a_{n+1,n} X_g \end{bmatrix} \tag{28}$$

[Step 6] In a closed model, one can similarly derive the corresponding household income effects as

$$\begin{bmatrix} \underline{\tilde{H}}^{g'} .* \underline{\tilde{X}}_d \\ a_{n+1,n} X_g \end{bmatrix} = \begin{bmatrix} \underline{\tilde{H}}^{g'} .* (I - \tilde{A}_d)^{-1} \underline{\tilde{A}}_g X_g \\ a_{n+1,n} X_g \end{bmatrix} \tag{29}$$

where $\underline{\tilde{H}}^g = \begin{pmatrix} a_{n+1,n} & \cdots & a_{n+1,n-1} & a_{n+1,n+1} \end{pmatrix}$ indicate household income received per dollar of sectoral output exclusive of the nuclear power sector.

These effects include induced as well as direct and indirect effects. Note that the induced effects are calculated as the difference between the total effects of the open and the closed I–O models, and appear only in the household sector.

Household Employment Effect

The household employment effect translates the impacts of final demand spending changes into changes in employment in physical terms. Although this study does not address or calculate this induced household employment effect for a nuclear power plant, it may be of interest subsequently or to others and so is explained here. This effect can be calculated by converting the output effects into the number of employees hired, by using physical labour input coefficients. These are computed by dividing the number of sectoral employees by the output of the corresponding sector, denoted as

$$\underline{L}_R = \begin{bmatrix} l_{n+1,1} & l_{n+1,2} & \cdots & l_{n+1,n} \end{bmatrix} \tag{30}$$

The household employment effect parallels the household income effect, with the major difference being that the physical labour input coefficients, $l_{n+1,j}$, are used instead of the monetary labour input coefficients, $a_{n+1,j}$.

Thus in open model, changes in employment generated by changes in final demand spending are found by multiplying $\underline{L}_R$ by the output effects as

$$\underline{L}_R{}' .* \Delta \underline{X} = \underline{L}_R{}' .* (I - A)^{-1} \Delta \underline{F} = \begin{pmatrix} l_{n+1,1} \sum_{j=1}^{n} \alpha_{1j} \Delta F_j \\ \vdots \\ l_{n+1,n} \sum_{j=1}^{n} \alpha_{nj} \Delta F_j \end{pmatrix}$$

In the closed model, the household employment effect, which includes induced effects (calculated as above) as well as direct plus indirect effects, can be derived as,

$$\underline{\tilde{L}}_R{}'.*\Delta\underline{\tilde{X}} = \underline{\tilde{L}}_R{}'.*(I-\tilde{A})^{-1}\Delta\underline{\tilde{F}} = \begin{pmatrix} a_{n+1,1}\sum_{j=1}^{n+1}\tilde{\alpha}_{1j}\Delta\tilde{F}_j \\ \vdots \\ a_{n+1,n+1}\sum_{j=1}^{n+1}\tilde{\alpha}_{n+1j}\Delta\tilde{F}_j \end{pmatrix}$$

where $\underline{\tilde{L}}_R = \begin{pmatrix} l_{n+1,1} & \cdots & l_{n+1,n} & l_{n+1,n+1} \end{pmatrix}$.

One would estimate the household employment effect by considering as exogenous the changes in the nuclear power sector's employment as distributed among other sectors. This can be done by first estimating sectoral changes in final demand equivalent to these changes in sectoral employment as allocated among the relevant sectors, and then putting those into the above equation. If the nuclear power sector's employment distributed among other sectors are denoted by $\Delta\underline{E} = \begin{pmatrix} \Delta E_1 & \cdots & \Delta E_n \end{pmatrix}$, then the sectoral value of final demand would be

$$\Delta\underline{F} = \begin{bmatrix} \Delta E_1 / l_{n+1,1} \\ \Delta E_n / l_{n+1,n} \end{bmatrix} = (\Delta\underline{E}./\underline{L}_R)' \tag{31}$$

and the total change in number of employees in open model is derived as

$$\underline{L}_R{}'.*(I-A)^{-1}\Delta\underline{F} = \underline{L}_R{}'.*(I-A)^{-1}(\Delta\underline{E}./\underline{L}_R)' \tag{32}$$

In a closed model, the corresponding nuclear power sector employment and sectoral value of final demand would be

$$\Delta\underline{\tilde{E}} = \begin{bmatrix} \Delta E_1 & \cdots & \Delta E_n & 0 \end{bmatrix} \tag{33}$$

$$\Delta\underline{\tilde{F}} = \begin{bmatrix} \Delta E_1 / l_{n+1,1} \\ \vdots \\ \Delta E_n / l_{n+1,n} \\ 0 / l_{n+1,n+1} \end{bmatrix} = (\Delta\underline{\tilde{E}}./\underline{\tilde{L}})' \tag{34}$$

with the total change in the number of employees defined as

$$\underline{\tilde{L}}'.*(I-\tilde{A})^{-1}\Delta\underline{\tilde{F}} = \underline{\tilde{L}}'.*(I-\tilde{A})^{-1}(\Delta\underline{\tilde{E}}./\underline{\tilde{L}})' \tag{35}$$

Annex III
CALCULATION OF LOCATION COEFFICIENTS

The data used to calculate the location coefficients for the Ulchin region (presented in Table A-3.4.) are shown in Tables A-3.1–A-3.3. These data were provided by the Daegu-Gyeongbuk Development Institute and adapted by Kyungbuk National University. This estimation for 1995 and for 2000 required data for sectoral outputs at the national and regional level for both years, shown in Tables A-3.1 and A-3.2, respectively. Sectoral outputs as shown in Table A-3.2 are calculated on the basis of "total gross regional domestic product of Kyungpook Province" with the exception of the 'nuclear generation sector' (I–O sector 4). Outputs from the nuclear generation sector are calculated by multiplying nuclear electricity generation times generation cost, as shown Table A-3.3.

TABLE A-3.1. SECTORAL OUTPUTS AT THE NATIONAL LEVEL, 1995 AND 2000 (BILLION WON)

	Sector	1995	2000
1.	Agriculture and Forestry and Fishing	31 942	38 287
2.	Mining and Quarrying	3 256	2 648
3.	Manufacturing	400 873	647 344
4.	Nuclear Generation	3 934	7 927
5.	Construction	82 508	99 269
6.	Wholesale and Retail	49 599	69 844
7.	Food and Hotels	7 008	41 144
8.	Transport and warehousing	33 320	51 161
9.	Communication	11 869	33 891
10.	Finance and Insurance	32 282	63 435
11.	Real estate, Renting	72 498	137 433
12.	Public Administration	25 702	43 601
13.	Education/Research	26 421	41 762
14.	Health and Welfare Services	13 601	31 045
15.	Other Services	46 704	84 136
16.	Household	n/a	n/a
Total		**841 519**	**1 392 928**

TABLE A-3.2. SECTORAL OUTPUTS IN THE ULCHIN REGION, 1995 AND 2000 (BILLION WON)

	Sector	1995	2000
1.	Agriculture, Forestry and Fishing	108	123
2.	Mining and Quarrying	40	53
3.	Manufacturing	80	83
4.	Nuclear Generation	395	1 179
5.	Construction	152	223
6.	Wholesale and Retail	23	27
7.	Food and Hotels	46	48
8.	Transport and warehousing	9	16
9.	Communication	10	24
10.	Finance and Insurance	27	32
11.	Real estate, Renting	30	40
12.	Public Administration	62	98
13.	Education/Research	51	51
14.	Health and Welfare Services	7	14
15.	Other Services	21	23
16.	Household	n/a	n/a
Total		**1 061**	**2 031**

Using these location coefficients for each sector as calculated above and shown in Table A-3.4, regional I–O coefficients for each sector in the Ulchin region for the years 1995 and 2000 can be derived. This is done by applying the sectoral location coefficients in Table A-3.4 to national input coefficients as presented in Tables A-3.5 and A-3.6. The resulting regional I–O coefficients for these two years are presented in Tables A-3.7 and A-3.8.

TABLE A-3.3. SECTORAL OUTPUTS FOR NUCLEAR GENERATION IN ULCHIN REGION

	Nuclear generation (MWh)	**Generation cost** (Won/kWh)	**Total output** (million Won)
1990	12 378 792	23.75	293 996
1995	15 693 472	25.17	395 005
2000	29 977 625	39.34	1 179 320
2001	31 375 958	39.65	1 244 057
2002	28 622 573	39.55	1 132 023
2003	32 401 183	39.75	1 287 947
2004	37 782 984	39.52	1 493 184
2005	47 278 305	39.10	1 848 582

TABLE A-3.4. SECTORAL LOCATION COEFFICIENTS IN ULCHIN REGION

	Sector	**1995**	**2000**	**Remarks**
1.	Agriculture, Forestry and Fishing	2.6883	2.1984	
2.	Mining and Quarrying	9.6289	13.5977	↑
3.	Manufacturing	0.1592	0.0876	
4.	Nuclear Generation	79.6469	102.0312	↑
5.	Construction	1.4580	1.5407	
6.	Wholesale and Retail	0.3758	0.2688	
7.	Food and Hotels	5.2001	0.7922	↓
8.	Transport and warehousing	0.2191	0.2090	
9.	Communication	0.6357	0.4814	
10.	Finance and Insurance	0.6543	0.3457	
11.	Real estate, Renting	0.3230	0.1985	↓
12.	Public Administration	1.9289	1.5376	
13.	Education/Research	1.5347	0.8309	↓
14.	Health and Welfare Services	0.4213	0.2982	↓
15.	Other Services	0.3531	0.1861	

TABLE A-3.5. NATIONAL INPUT COEFFICIENTS BY SECTOR, 1995

Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.0476	0.0017	0.0460	0	0.0015	0	0.0018	0	0	0	0.0004	0.0010	0.0002	0.0059	0.0329
2	0	0	0.0342	0	0.0090	0	0	0	0	0	0	0.0002	0	0	0.0388
3	0.2000	0.1155	0.4788	0.0777	0.3903	0.0451	0.1282	0.1931	0.0380	0.0230	0.0516	0.1849	0.0696	0.2185	0.3023
4	0.0008	0.0118	0.0042	0.0245	0.0006	0.0037	0.0086	0.0019	0.0042	0.0020	0.0040	0.0054	0.0027	0.0039	0.0038
5	0.0008	0.0027	0.0005	0.0729	0.0003	0.0020	0.0023	0.0005	0.0027	0.0006	0.0641	0.0386	0.0026	0.0015	0.0098
6	0.0079	0.0041	0.0232	0.0031	0.0237	0.0086	0.0093	0.0103	0.0025	0.0013	0.0022	0.0109	0.0057	0.0164	0.0336
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1048
8	0.0127	0.0192	0.0129	0.0022	0.0156	0.0238	0.0065	0.1287	0.0083	0.0176	0.0079	0.0196	0.0047	0.0060	0.0195
9	0.0023	0.0030	0.0027	0.0036	0.0022	0.0509	0.0128	0.0045	0.0327	0.0176	0.0251	0.0132	0.0030	0.0044	0.0110
10	0.0249	0.0166	0.0235	0.012	0.0332	0.0365	0.0281	0.0288	0.0174	0.0808	0.0366	0.006	0.0068	0.0070	0.0088
11	0.0307	0.0831	0.0253	0.0171	0.0903	0.1175	0.2100	0.0966	0.0447	0.0909	0.1068	0.0331	0.0179	0.0853	0.0526
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.0004	0.0017	0.0118	0.0236	0.0049	0.0018	0.0007	0.0033	0.0054	0.0006	0.0005	0.0013	0.0190	0.0010	0.0169
14	0.0024	0.0005	0.0011	0.0011	0.0007	0.0020	0.0086	0.0025	0.0007	0.0023	0.0015	0.0033	0.0012	0.0082	0.0012
15	0.0136	0.0552	0.0258	0.0489	0.0149	0.0489	0.0527	0.0242	0.0458	0.0525	0.0362	0.0825	0.0514	0.0544	0.0890

TABLE A-3.6. NATIONAL INPUT COEFFICIENTS BY SECTOR, 2000

Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.0481	0.0019	0.0393	0	0.0024	0	0.0553	0	0	0	0.0001	0.0004	0.0001	0.0053	0.0054
2	0	0	0.0549	0	0.0038	0	0.0002	0	0	0	0	0.0001	0	0	0.0773
3	0.2226	0.1215	0.5005	0.0913	0.3729	0.0407	0.3580	0.2399	0.0405	0.0197	0.0397	0.1280	0.0620	0.2717	0.1836
4	0.0010	0.0157	0.0051	0.0127	0.0008	0.0058	0.0055	0.0017	0.0038	0.0018	0.0048	0.0062	0.0042	0.0044	0.0045
5	0.0007	0.0020	0.0005	0.0539	0.0003	0.0019	0.0039	0.0005	0.0030	0.0007	0.0481	0.0066	0.0034	0.0026	0.0078
6	0.0117	0.0070	0.0260	0.0036	0.0249	0.0352	0.0440	0.0103	0.0044	0.0022	0.0027	0.0099	0.0079	0.0253	0.0234
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1961
8	0.0081	0.0134	0.0097	0.0017	0.0095	0.0193	0.0081	0.1896	0.0057	0.0106	0.0053	0.0141	0.0042	0.0056	0.014
9	0.0030	0.0046	0.004	0.0029	0.0039	0.0523	0.0063	0.0076	0.1670	0.0214	0.0261	0.0117	0.0064	0.007	0.0138
10	0.0234	0.0615	0.0187	0.0289	0.0201	0.0322	0.0114	0.0246	0.0197	0.1368	0.0540	0.0142	0.0160	0.0223	0.0187
11	0.0378	0.0771	0.0304	0.0208	0.0960	0.1290	0.0719	0.0754	0.0696	0.0759	0.0658	0.0459	0.0264	0.0783	0.0572
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.0004	0.0013	0.0114	0.0188	0.0068	0.0039	0.0005	0.0033	0.0076	0.0025	0.0050	0.0026	0.0200	0.0013	0.0023
14	0.0022	0.0006	0.0014	0.0032	0.0018	0.0018	0.0042	0.0024	0.0009	0.0015	0.0021	0.0037	0.0018	0.0102	0.0014
15	0.0168	0.0593	0.0248	0.0184	0.0173	0.0479	0.0259	0.0275	0.0932	0.0393	0.0336	0.0748	0.0606	0.0519	0.0915

TABLE A-3.7. CLOSED REGIONAL INPUT COEFFICIENT MATRIX IN ULCHIN REGION, 1995

Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.0476	0.0017	0.0460	0	0.0015	0	0.0018	0	0	0	0.0004	0.0010	0.0002	0.0059	0.0329	0.0575
2	0	0	0.0342	0	0.0090	0	0	0	0	0	0	0.0002	0	0	0.0388	0
3	0.0318	0.0184	0.0762	0.0124	0.0621	0.0072	0.0204	0.0307	0.0061	0.0037	0.0082	0.0294	0.0111	0.0348	0.0481	0.3188
4	0.0008	0.0118	0.0042	0.0245	0.0006	0.0037	0.0086	0.0019	0.0042	0.0020	0.0040	0.0054	0.0027	0.0039	0.0038	0.0037
5	0.0008	0.0027	0.0005	0.0729	0.0003	0.0020	0.0023	0.0005	0.0027	0.0006	0.0641	0.0386	0.0026	0.0015	0.0098	0
6	0.003	0.0016	0.0087	0.0012	0.0089	0.0032	0.0035	0.0039	0.0009	0.0005	0.0008	0.0041	0.0022	0.0062	0.0126	0.1017
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1048	0.0146
8	0.0028	0.0042	0.0028	0.0005	0.0034	0.0052	0.0014	0.0282	0.0018	0.0039	0.0017	0.0043	0.0010	0.0013	0.0043	0.0479
9	0.0014	0.0019	0.0017	0.0023	0.0014	0.0323	0.0081	0.0029	0.0208	0.0112	0.0159	0.0084	0.0019	0.0028	0.007	0.0171
10	0.0163	0.0109	0.0154	0.0078	0.0217	0.0239	0.0184	0.0189	0.0114	0.0528	0.0239	0.0040	0.0044	0.0046	0.0058	0.0423
11	0.0099	0.0269	0.0082	0.0055	0.0292	0.0380	0.0678	0.0312	0.0145	0.0294	0.0345	0.0107	0.0058	0.0276	0.017	0.1062
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.0004	0.0017	0.0118	0.0236	0.0049	0.0018	0.0007	0.0033	0.0054	0.0006	0.0005	0.0013	0.019	0.0010	0.0169	0.0473
14	0.0010	0.0002	0.0005	0.0005	0.0003	0.0009	0.0036	0.0010	0.0003	0.0010	0.0006	0.0014	0.0005	0.0035	0.0005	0.0467
15	0.0048	0.0195	0.0091	0.0173	0.0053	0.0173	0.0186	0.0086	0.0162	0.0185	0.0128	0.0291	0.0182	0.0192	0.0314	0.0632
16	0.1571	0.2163	0.1138	0.0684	0.3677	0.2609	0.2734	0.3488	0.3455	0.5355	0.1434	0.5345	0.5425	0.7524	0.3790	0

TABLE A-3.8. CLOSED REGIONAL INPUT COEFFICIENT MATRIX IN ULCHIN REGION, 2000

Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.0481	0.0019	0.0393	0	0.0024	0	0.0553	0	0	0	0.0001	0.0004	0.0001	0.0053	0.0054	0.0318
2	0	0	0.0549	0	0.0038	0	0.0002	0	0	0	0	0.0001	0	0	0.0773	0
3	0.0195	0.0107	0.0439	0.0080	0.0327	0.0036	0.0314	0.0210	0.0036	0.0017	0.0035	0.0112	0.0054	0.0238	0.0161	0.2547
4	0.0010	0.0157	0.0051	0.0127	0.0008	0.0058	0.0055	0.0017	0.0038	0.0018	0.0048	0.0062	0.0042	0.0044	0.0045	0.0045
5	0.0007	0.0020	0.0005	0.0539	0.0003	0.0019	0.0039	0.0005	0.0030	0.0007	0.0481	0.0066	0.0034	0.0026	0.0078	0
6	0.0031	0.0019	0.0070	0.001	0.0067	0.0095	0.0118	0.0028	0.0012	0.0006	0.0007	0.0027	0.0021	0.0068	0.0063	0.0662
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1553	0.0674
8	0.0017	0.0028	0.0020	0.0003	0.0020	0.0040	0.0017	0.0396	0.0012	0.0022	0.0011	0.0029	0.0009	0.0012	0.0029	0.0381
9	0.0015	0.0022	0.0019	0.0014	0.0019	0.0252	0.0030	0.0037	0.0804	0.0103	0.0125	0.0056	0.0031	0.0034	0.0067	0.0359
10	0.0081	0.0212	0.0064	0.0100	0.0069	0.0111	0.0039	0.0085	0.0068	0.0473	0.0187	0.0049	0.0055	0.0077	0.0065	0.0597
11	0.0075	0.0153	0.0060	0.0041	0.0191	0.0256	0.0143	0.0150	0.0138	0.0151	0.0131	0.0091	0.0052	0.0155	0.0114	0.1419
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.0003	0.0011	0.0094	0.0156	0.0057	0.0032	0.0004	0.0027	0.0063	0.0020	0.0041	0.0021	0.0166	0.0011	0.0019	0.0454
14	0.0006	0.0002	0.0004	0.0009	0.0005	0.0005	0.0012	0.0007	0.0003	0.0004	0.0006	0.0011	0.0005	0.0031	0.0004	0.0649
15	0.0031	0.0110	0.0046	0.0034	0.0032	0.0089	0.0048	0.0051	0.0173	0.0073	0.0062	0.0139	0.0113	0.0097	0.0170	0.0837
16	0.1474	0.2382	0.0817	0.0464	0.2877	0.2315	0.2575	0.3422	0.1583	0.3839	0.1371	0.3869	0.5742	0.3875	0.3339	0

The final step in the process of deriving regional I–O coefficients is to extend the estimates for 1995 and 2000 as shown in Tables A-3.7 and A-3.8, to the rest of the study time series, namely the years 1990 and 2001–2005. This was done by extrapolation using a mathematical technique known as the RAS method, that effectively calculates the income and output coefficients of each sector in a matrix in a given target year on the basis of known data about total outputs, inter-industry sales and total inter-industry purchases for that year, applied to coefficients from an earlier (base year) matrix. The year 1995 was set as the base year for this study. The RAS method is most often used to generate a time series, but can also be used to derive a regional I–O table from a national matrix.

More specifically, the RAS technique generates a coefficient matrix for a particular year, A(1), given observations on total outputs, total inter-industry sales, and total inter-industry purchases for that year – X(1), U(1), and V(1), and using as a starting point an earlier coefficient matrix, A(0). While it is inherently a mathematical technique, the economic notions of uniform substitution and fabrication effects are compatible with the procedure. The regional coefficients for 1995 for the closed I–O model of the Ulchin region, shown in Table A-3.7, were used in precisely this way to derive regional coefficients for other years where data were lacking. The 1995 coefficients were first applied to the intermediate outputs for the Ulchin region for 2000 (Table A-3.2), which produces a ratio that is the regional I–O coefficient for each sector for that year. This ratio can then be applied, using the following equation, to the intermediate outputs for the Ulchin region for the years 1990 and for 2001–2005, to similarly derive by extrapolation the regional input coefficient matrix for 1990 and 2001–2005 successively:

$$A(s) = R^{(s-1995)/(2000-1995)} A(1995) S^{(s-1995)/(2000-1995)}$$

where s = 1990, 2001-2005

A(s) = closed regional input coefficient matrix in Ulchin in year s

A(1995) = 1995 closed regional input coefficient matrix in Ulchin

Since coefficient tables for regional I–O models are essential for regional analysis, one way to have a wider variety of tables available for various regions of a nation is to apply the same RAS principles, using a national I–O table, A(N), and marginal information about regional economic activity-X(R), U(R), and V(R). Or, instead of A(N), one may even have an I–O table for some other region in the country, R', and then use the known A(R') as the matrix to be adjusted to satisfy the observed marginal information for the region of interest, R. Thus, instead of using the RAS procedure to adjust coefficient matrices across time (updating), one can also use it to adjust coefficient matrices across space (regionalization). To the extent that a national table, A(N), reflects an average of I–O relationships in various regions of the nation, the minimization of differences inherent in the RAS technique may also be appropriate at the regional level. Similarly, if there is an I–O coefficient table for a region, R', that is thought to be economically similar to the region in question, R, then this characteristic of the RAS procedure is possibly an attractive one. In this study, we use the RAS procedure to make both temporal and spatial adjustments in coefficients.

The last adjustment that needs to be made to these coefficients before applying them to our analysis, is for the household sector. The above derivation of the closed regional input coefficient matrix must be adjusted to exclude household savings before being applied to the household sector. This can be done by applying one last formula, based on the exclusion of household savings from household income as described above, using the equation: total (raw vector) = 1 – savings rate. The household regional input coefficients (less savings) can then be defined as:

{A(s) [household sector]} * (1 – savings rate) / {A(s) [household sector] total}

The derived RAS results for household sector must be adjusted accordingly, which then produces the final closed regional input coefficient matrix for the Ulchin region, shown in Tables A-3.9–A-3.14.

TABLE A-3.9. CLOSED REGIONAL INPUT COEFFICIENT MATRIX IN ULCHIN REGION, 1990

Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.0828	0.0026	0.0884	0	0.0065	0	0.0863	0	0	0	0.0003	0.0012	0.0002	0.0261	0.0152	0.0315
2	0	0	0.0284	0	0.0024	0	0.0001	0	0	0	0	0	0	0	0.0503	0
3	0.0458	0.0207	0.1349	0.0349	0.1221	0.0108	0.0669	0.0472	0.0183	0.0073	0.0115	0.0512	0.0108	0.161	0.0622	0.3442
4	0.0015	0.019	0.0097	0.0346	0.0018	0.0110	0.0073	0.0024	0.0121	0.0048	0.0099	0.0177	0.0053	0.0186	0.0109	0.0038
5	0.0008	0.0019	0.0007	0.1110	0.0005	0.0027	0.0039	0.0006	0.0072	0.0014	0.075	0.0142	0.0032	0.0082	0.0143	0
6	0.0088	0.0043	0.0255	0.005	0.0296	0.0339	0.0299	0.0074	0.0072	0.0030	0.0029	0.0144	0.005	0.0544	0.0288	0.1061
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0288	0.0044
8	0.0037	0.0051	0.0059	0.0014	0.007	0.0115	0.0034	0.084	0.0058	0.0088	0.0034	0.0127	0.0016	0.0075	0.0107	0.0486
9	0.0007	0.0009	0.0013	0.0013	0.0015	0.0163	0.0014	0.0018	0.0884	0.0093	0.0088	0.0055	0.0013	0.0049	0.0055	0.0104
10	0.0082	0.0178	0.0086	0.0188	0.0112	0.0145	0.0036	0.0082	0.0151	0.0864	0.0265	0.0097	0.0047	0.0225	0.0108	0.0348
11	0.0090	0.0152	0.0095	0.0092	0.0363	0.0396	0.0155	0.0172	0.0363	0.0326	0.022	0.0213	0.0053	0.0536	0.0224	0.0979
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.0004	0.0013	0.0170	0.0397	0.0124	0.0057	0.0005	0.0035	0.0190	0.0051	0.008	0.0057	0.0193	0.0043	0.0043	0.0358
14	0.0005	0.0001	0.0005	0.0014	0.0007	0.0005	0.0009	0.0005	0.0004	0.0006	0.0007	0.0017	0.0004	0.007	0.0006	0.0299
15	0.0056	0.0162	0.0107	0.0113	0.0091	0.0205	0.0078	0.0087	0.0676	0.0235	0.0156	0.0482	0.0170	0.0494	0.0499	0.0857
16	0.1579	0.2106	0.1146	0.0921	0.4902	0.3196	0.2504	0.3506	0.3711	0.7418	0.206	0.8055	0.5212	1.1944	0.5885	0

TABLE A-3.10. CLOSED REGIONAL INPUT COEFFICIENT MATRIX IN ULCHIN REGION, 2001

Sector	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1	0.0302	0.0012	0.0255	0	0.0007	0	0.0011	0	0	0	0.0002	0.0004	0.0001	0.002	0.0142	0.0507
2	0	0	0.0488	0	0.0110	0	0	0	0	0	0	0.0003	0	0	0.0432	-0.0001
3	0.0186	0.0122	0.0387	0.005	0.027	0.0035	0.0117	0.0180	0.0023	0.0015	0.0039	0.0115	0.0072	0.0106	0.0191	0.2582
4	0.0006	0.0098	0.0027	0.0125	0.0003	0.0023	0.0062	0.0014	0.0020	0.0010	0.0024	0.0027	0.0022	0.0015	0.0019	0.0038
5	0.0007	0.003	0.0004	0.0488	0.0002	0.0016	0.0022	0.0005	0.0017	0.0004	0.0497	0.0250	0.0028	0.0007	0.0064	0
6	0.0015	0.0009	0.0038	0.0004	0.0033	0.0013	0.0017	0.0020	0.0003	0.0002	0.0003	0.0014	0.0012	0.0016	0.0043	0.0713
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.284	0.0807
8	0.0017	0.0029	0.0015	0.0002	0.0015	0.0026	0.0008	0.0169	0.0007	0.0016	0.0008	0.0017	0.0007	0.0004	0.0017	0.0396
9	0.0022	0.0033	0.0022	0.0024	0.0016	0.0407	0.0121	0.0044	0.0210	0.0119	0.0195	0.0086	0.0033	0.0022	0.0073	0.0361
10	0.0176	0.0133	0.0145	0.0059	0.0174	0.0213	0.0195	0.0204	0.0082	0.0398	0.0208	0.0029	0.0053	0.0026	0.0042	0.0633
11	0.0090	0.0276	0.0065	0.0035	0.0197	0.0285	0.0603	0.0284	0.0087	0.0186	0.0251	0.0065	0.0058	0.0130	0.0105	0.1336
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.0004	0.0016	0.0083	0.0133	0.003	0.0012	0.0006	0.0027	0.0029	0.0004	0.0003	0.0007	0.0171	0.0004	0.0093	0.0534
14	0.0011	0.0003	0.0005	0.0004	0.0002	0.0008	0.0040	0.0012	0.0002	0.0008	0.0006	0.0010	0.0006	0.002	0.0004	0.0721
15	0.0031	0.0144	0.0052	0.0078	0.0026	0.0093	0.0119	0.0056	0.0070	0.0084	0.0067	0.0128	0.0132	0.0065	0.0140	0.0572
16	0.1505	0.2358	0.0950	0.0456	0.2627	0.2071	0.2573	0.3361	0.2200	0.3589	0.1106	0.3446	0.5780	0.3752	0.2476	0

TABLE A-3.11. CLOSED REGIONAL INPUT COEFFICIENT MATRIX IN ULCHIN REGION, 2002

Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.028	0.0012	0.0231	0	0.0006	0	0.0010	0	0	0	0.0002	0.0004	0.0001	0.0016	0.0124	0.0496
2	0	0	0.0517	0	0.0114	0	0	0	0	0	0	0.0003	0	0	0.0440	-0.0001
3	0.0170	0.0114	0.0346	0.0043	0.0235	0.0031	0.0106	0.0165	0.0020	0.0013	0.0034	0.0099	0.0067	0.0086	0.0164	0.2487
4	0.0006	0.0095	0.0025	0.0112	0.0003	0.0021	0.0059	0.0014	0.0018	0.0009	0.0022	0.0024	0.0021	0.0013	0.0017	0.0038
5	0.0007	0.0030	0.0004	0.0457	0.0002	0.0016	0.0022	0.0005	0.0016	0.0004	0.0477	0.0233	0.0028	0.0007	0.0060	0
6	0.0013	0.0008	0.0034	0.0003	0.0028	0.0012	0.0015	0.0018	0.0003	0.0001	0.0003	0.0012	0.0011	0.0013	0.0036	0.0671
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3354	0.1071
8	0.0015	0.0027	0.0013	0.0002	0.0013	0.0023	0.0008	0.0155	0.0006	0.0014	0.0007	0.0015	0.0006	0.0003	0.0015	0.0383
9	0.0023	0.0036	0.0023	0.0024	0.0016	0.0423	0.0129	0.0047	0.0210	0.0120	0.0202	0.0086	0.0036	0.0021	0.0073	0.0408
10	0.0178	0.0138	0.0143	0.0056	0.0168	0.0209	0.0197	0.0207	0.0077	0.0380	0.0203	0.0027	0.0055	0.0023	0.0040	0.0676
11	0.0088	0.0278	0.0062	0.0032	0.0184	0.0271	0.0591	0.028	0.0080	0.0172	0.0238	0.0060	0.0058	0.0115	0.0097	0.1384
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.0004	0.0016	0.0078	0.0121	0.0027	0.0011	0.0005	0.0026	0.0026	0.0003	0.0003	0.0007	0.0168	0.0004	0.0085	0.0544
14	0.0012	0.0003	0.0005	0.0003	0.0002	0.0008	0.0040	0.0012	0.0002	0.0007	0.0005	0.001	0.0006	0.0018	0.0004	0.0773
15	0.0029	0.0137	0.0047	0.0069	0.0023	0.0084	0.0110	0.0052	0.0061	0.0074	0.0060	0.0111	0.0125	0.0054	0.0122	0.0562
16	0.1494	0.2392	0.0922	0.0426	0.2484	0.1992	0.2548	0.3340	0.2041	0.3357	0.1059	0.3203	0.5841	0.3341	0.2306	0

TABLE A-3.12. CLOSED REGIONAL INPUT COEFFICIENT MATRIX IN ULCHIN REGION, 2003

Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.0259	0.0011	0.0209	0	0.0005	0	0.0010	0	0	0	0.0002	0.0003	0.0001	0.0014	0.0108	0.0459
2	0	0	0.0549	0	0.0118	0	0	0	0	0	0	0.0003	0	0	0.0448	-0.0001
3	0.0155	0.0106	0.0309	0.0037	0.0205	0.0027	0.0097	0.0151	0.0017	0.0011	0.0030	0.0084	0.0062	0.0071	0.0141	0.2273
4	0.0005	0.0093	0.0023	0.0100	0.0003	0.0019	0.0056	0.0013	0.0016	0.0008	0.0020	0.0021	0.0020	0.0011	0.0015	0.0036
5	0.0007	0.0030	0.0004	0.0427	0.0002	0.0015	0.0022	0.0005	0.0015	0.0004	0.0457	0.0217	0.0028	0.0006	0.0056	0
6	0.0012	0.0007	0.0029	0.0003	0.0024	0.0010	0.0014	0.0016	0.0002	0.0001	0.0002	0.001	0.001	0.0010	0.003	0.0598
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3960	0.1347
8	0.0014	0.0025	0.0012	0.0002	0.0012	0.0020	0.0007	0.0142	0.0005	0.0012	0.0007	0.0013	0.0006	0.0003	0.0013	0.0351
9	0.0025	0.0039	0.0025	0.0025	0.0016	0.0440	0.0138	0.0051	0.0211	0.0121	0.0209	0.0086	0.0039	0.0020	0.0074	0.0437
10	0.018	0.0143	0.0142	0.0053	0.0162	0.0205	0.0199	0.0210	0.0073	0.0363	0.0198	0.0026	0.0056	0.0021	0.0038	0.0684
11	0.0087	0.0279	0.006	0.0030	0.0173	0.0258	0.0580	0.0275	0.0073	0.0160	0.0226	0.0055	0.0058	0.0101	0.0089	0.1361
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.0003	0.0015	0.0074	0.011	0.0025	0.0010	0.0005	0.0025	0.0024	0.0003	0.0003	0.0006	0.0165	0.0003	0.0077	0.0525
14	0.0012	0.0003	0.0005	0.0003	0.0002	0.0008	0.0041	0.0012	0.0002	0.0007	0.0005	0.0010	0.0007	0.0017	0.0003	0.0786
15	0.0027	0.0131	0.0043	0.0060	0.0020	0.0076	0.0102	0.0049	0.0053	0.0065	0.0054	0.0097	0.0118	0.0045	0.0106	0.0523
16	0.1484	0.2426	0.0895	0.0398	0.2349	0.1917	0.2522	0.3319	0.1893	0.3141	0.1014	0.2977	0.5903	0.2975	0.2148	0

TABLE A-3.13. CLOSED REGIONAL INPUT COEFFICIENT MATRIX IN ULCHIN REGION, 2004

Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.0241	0.0011	0.0189	0	0.0005	0	0.0009	0	0	0	0.0001	0.0003	0.0001	0.0011	0.0094	0.0420
2	0	0	0.0582	0	0.0122	0	0	0	0	0	0	0.0003	0	0	0.0456	-0.0001
3	0.0142	0.0099	0.0276	0.0032	0.0178	0.0024	0.0088	0.0138	0.0015	0.0010	0.0026	0.0072	0.0058	0.0058	0.0120	0.2048
4	0.0005	0.0090	0.0022	0.0090	0.0002	0.0018	0.0053	0.0012	0.0014	0.0007	0.0018	0.0019	0.0020	0.0009	0.0013	0.0034
5	0.0007	0.0031	0.0004	0.0400	0.0002	0.0014	0.0022	0.0005	0.0014	0.0003	0.0438	0.0202	0.0029	0.0005	0.0052	0
6	0.0011	0.0007	0.0025	0.0002	0.0021	0.0009	0.0012	0.0014	0.0002	0.0001	0.0002	0.0008	0.0009	0.0008	0.0026	0.0526
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4675	0.1672
8	0.0013	0.0023	0.0011	0.0001	0.0010	0.0018	0.0006	0.0130	0.0004	0.0010	0.0006	0.0011	0.0006	0.0002	0.0011	0.0318
9	0.0027	0.0043	0.0026	0.0025	0.0017	0.0457	0.0148	0.0054	0.0211	0.0122	0.0216	0.0087	0.0042	0.0020	0.0074	0.0462
10	0.0183	0.0147	0.0140	0.0051	0.0156	0.0201	0.0201	0.0213	0.0069	0.0346	0.0193	0.0024	0.0058	0.0019	0.0036	0.0683
11	0.0085	0.028	0.0057	0.0028	0.0162	0.0246	0.0569	0.0271	0.0067	0.0148	0.0214	0.0051	0.0059	0.0089	0.0082	0.1320
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.0003	0.0015	0.0070	0.0100	0.0023	0.0010	0.0005	0.0024	0.0021	0.0003	0.0002	0.0005	0.0163	0.0003	0.0070	0.0500
14	0.0012	0.0003	0.0005	0.0003	0.0002	0.0008	0.0041	0.0012	0.0002	0.0007	0.0005	0.0009	0.0007	0.0015	0.0003	0.0789
15	0.0025	0.0124	0.0039	0.0053	0.0018	0.0068	0.0095	0.0045	0.0046	0.0057	0.0048	0.0084	0.0112	0.0038	0.0093	0.0480
16	0.1473	0.2461	0.0868	0.0372	0.2221	0.1845	0.2497	0.3299	0.1756	0.2938	0.0971	0.2767	0.5965	0.2650	0.2001	0

TABLE A-3.14. CLOSED REGIONAL INPUT COEFFICIENT MATRIX IN ULCHIN REGION, 2005

Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.0223	0.0010	0.0172	0	0.0004	0	0.0008	0	0	0	0.0001	0.0003	0.0001	0.0009	0.0081	0.0388
2	0.0001	0	0.0618	0	0.0126	0	0	0	0	0	0	0.0003	0.0001	0	0.0465	-0.0001
3	0.0129	0.0093	0.0246	0.0027	0.0155	0.0021	0.0081	0.0126	0.0012	0.0008	0.0023	0.0062	0.0054	0.0048	0.0103	0.1867
4	0.0005	0.0087	0.002	0.0080	0.0002	0.0016	0.0050	0.0012	0.0013	0.0006	0.0017	0.0017	0.0019	0.0008	0.0012	0.0032
5	0.0007	0.0031	0.0004	0.0374	0.0002	0.0014	0.0021	0.0005	0.0013	0.0003	0.0420	0.0188	0.0029	0.0005	0.0049	0
6	0.0010	0.0006	0.0022	0.0002	0.0017	0.0008	0.0011	0.0012	0.0002	0.0001	0.0002	0.0007	0.0008	0.0007	0.0021	0.0469
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5520	0.2098
8	0.0012	0.0022	0.0009	0.0001	0.0009	0.0016	0.0006	0.0120	0.0004	0.0009	0.0005	0.0009	0.0005	0.0002	0.001	0.029
9	0.0029	0.0047	0.0027	0.0025	0.0017	0.0475	0.0158	0.0058	0.0211	0.0124	0.0223	0.0087	0.0046	0.0019	0.0074	0.0494
10	0.0185	0.0153	0.0139	0.0049	0.0151	0.0198	0.0203	0.0216	0.0065	0.033	0.0189	0.0023	0.0060	0.0018	0.0034	0.0690
11	0.0084	0.0282	0.0055	0.0026	0.0151	0.0235	0.0557	0.0267	0.0062	0.0137	0.0203	0.0047	0.0059	0.0079	0.0076	0.1295
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.0003	0.0015	0.0066	0.0091	0.0021	0.0009	0.0005	0.0024	0.0019	0.0002	0.0002	0.0005	0.0160	0.0002	0.0063	0.0481
14	0.0012	0.0003	0.0004	0.0003	0.0002	0.0008	0.0042	0.0013	0.0002	0.0006	0.0005	0.0009	0.0007	0.0014	0.0003	0.0801
15	0.0023	0.0118	0.0035	0.0046	0.0016	0.0062	0.0088	0.0042	0.0040	0.0050	0.0043	0.0074	0.0106	0.0032	0.0081	0.0446
16	0.1463	0.2497	0.0842	0.0348	0.2100	0.1775	0.2471	0.3278	0.1629	0.2748	0.0930	0.2571	0.6029	0.2360	0.1864	0

Annex IV
CURRENT ENERGY EFFICIENCY POLICIES

	Policy Name	Policy Type	Sector
1	2000 Blueprint	Policy/Institutional Framework	Crosscutting
2	Building Standards (existing buildings)	Auditing/Benchmarking Fiscal/Financial/Tariff	Commercial Residential
3	Building Standards (new buildings)	Mandates/Standards	Commercial Residential
4	Car pooling	Information/Education/ Motivation	Transport
5	Certification of Energy Efficient Appliance Programme	Fiscal/Financial/Tariffs	Commercial Residential Industry
6	Demand-Side Management	Auditing/Benchmarking	Commercial Industry
7	Energy Audits	Auditing/Benchmarking	Commercial Industry Transport
8	Energy Conservation Guideline for Public Institutions	Assessment/Monitoring Mandates/Standards	Public
9	Energy Efficiency Labelling	Labelling	Residential
10	Energy Efficiency Standards	Mandates/Standards	Commercial Residential Industry
11	Energy Information Service	Information/Education/ Motivation	Crosscutting
12	Energy-Saving Office Equipment and Home Electronics Programme	Labelling Voluntary Agreements	Commercial Public Residential
13	Energy Service Companies	Information/Education/ Motivation Third Party Financing Fiscal/Financial/Tariffs	Commercial Industry
14	Energy Utilisation Planning Consolation Programme	Assessment/Monitoring	Commercial Public CHP/DH
15	Five-Year Conservation Programme	Policy/Institutional Framework	Crosscutting

(continued)

	Policy Name	Policy Type	Sector
16	Fuel Efficiency Labelling	Labelling	Transport
17	Fuel Efficiency Targets	Mandates/Standards	Transport
18	Green Energy Family Movement	Voluntary Agreements	Commercial Industry
19	Integrated Energy Supply	Policy/Institutional Framework Fiscal/Financial/Tariffs	CHO/DH
20	KEMCO	Policy/Institutional Framework	Crosscutting
21	Promotion of Small Car Ownership	Fiscal/Financial/Tariffs	Transport
22	Public Information	Information/Education/ Motivation	Crosscutting
23	Regional Energy Programme	Fiscal/Financial/Tariffs Information/Education/ Motivation	Public

Source: IEA, 2006b.

Annex V
CURRENT RENEWABLE ENERGY POLICES AND MEASURES

	Policy Name	Policy Type	Technology
1	CDM coordination	Capital Grants	All technologies simultaneously
2	Renewable Power Generation Subsidy	3rd Party Finance	All technologies simultaneously
3	Integrated Energy Policy	3rd Party Finance Regulatory and administrative rules	All technologies simultaneously
4	Introduction of a domestic ETS	Public awareness	All technologies simultaneously
5	Research Funding for the Development of Renewable Energy Sources	RD&D	Solar PV Solar Thermal Hydrogen (from renewables) Off and onshore wind
6	Ten-Year Energy Technology Development Plan	Obligations	All technologies simultaneously
7	New and Renewable Energy RD&D Basic Plan	RD&D 3rd Party Finance Investment Tax Credits Net Metering Obligations	All technologies simultaneously
8	Integrated Energy Act	3rd Party Finance Investment Tax Credits	Waste (organic)
9	Local Energy Plan (as part of the Ten-Year Plan)	RD&D 3rd Party Finance Investment Tax Credits	All technologies simultaneously
10	Promotion Law of New and Renewable Energy Development	RD&D	All technologies simultaneously
11	Rational Energy Utilisation Act	RD&D	All technologies simultaneously
12	Special Accounts for Energy Resources	RD&D 3rd Party Finance	All technologies simultaneously
13	Mid- and Long-Term Goal of New and Renewable Energy Supply with Detailed Plan	RD&D 3rd Party Finance Investment Tax Credits Capital Grants Guaranteed Prices / Feed-in	All technologies simultaneously
14	Electricity Business Law	Regulatory and administrative rules Guaranteed Prices / Feed-in	All technologies simultaneously
15	The Promotional Law of New and Renewable Energy Development, Use and Dissemination	Public Awareness Tradable Certificates	All technologies simultaneously

Source: IEA, 2006c.

Annex VI
CURRENT CLIMATE CHANGE POLICIES

	Policy Name	Type	Sector	Energy	Year
1	Tax Incentives	Fiscal	Energy Production	Renewables	2004
2	Amendment to the Alternative Energy Act	Regulatory Instruments	Energy Production	Renewables	2003
3	Extension of Renewable Energy Subsidy	Fiscal	Energy Production	Renewables	2003
4	Hydrogen and Fuel Cell Automobiles	RD&D	Transport	Hydrogen	2003
5	International Thermonuclear Experimental Reactor Project	RD&D	Energy Production	Nuclear	2003
6	New and Renewable Energy Facilities Certification	Policy Processes and Outreach Regulatory instruments	Energy Production	Renewables	2003
7	Research Funding for Energy Efficiency Technology and CO_2 sequestration	RD&D	Energy Production	Fossil Fuels	2002
8	Research Funding for the Development of Renewable Energy Sources	RD&D	Energy Production	Renewables	2002

Source: IEA, 2006d.

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