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The Role of Nuclear Power Considering Environmental Impacts in Korea by Using DECPAC

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1. Introduction

The world has taken an increasingly great interest in the global environment in recent years, because of environmental degradation at global level through the environmental impacts such as global warming, acid rain and etc. The Framework Convention on Climate Change, enacted in March 1994, is expected to influence the industrial structure and energy consumption pattern, because its main objective is to regulate the emission of greenhouse gases. The IAEA also recognized the importance of environmental problems bringing about by consuming fossil fuels such as coal and oil in energy sector including electricity sector. In this regard, DECADES project, Inter-agency joint project on Database and mEthodologies for Comparative Assessment of Different Energy Sources for electricity generation, was initiated in 1992 by the IAEA, in co-operation with the eight international organizations(EC, ESCAP, IBRD, IIASA, OECD/NEA, OPEC, UNIDO, WMO). The objective of this project was to enhance capabilities, particularly in developing countries, for comparative assessment of different energy sources in the process of planning and decision-making for the electricity sector. In this project, 15 countries including Korea, were carrying out the case studies under the CRP contract with the Agency.

The purpose of this study is to derive an optimal electric system in Korea under the consideration of environmental impacts. To do so, this study used DECPAC(DECADES Software Package), which was developed by IAEA for the analysis of the Electric System Expansion Plan(ESEP) considering pollutant emissions.

2. Input data

2.1 Economic data

Table 1 shows general economic parameters for this study. Most of these values are cited from the official input data used in the country's ESEP. However, the discount rate of 8% was assumed in this study, instead of 8.5% used in the official ESEP, because DECPAC only permits integer numbers for the discount rate. It is also assumed that there would be no escalation in fuel costs. All costs are expressed in constant dollars in the year of 1995. The study period is assumed to be from 1995 to 2010.

Table 2 Economic Parameter

Cost reference date	1995. 1
Exchange rate (Korean Won/US $)	790
Discount rate (%)	8.0
Fuel escalation rate (%)	0.0
Study period	1995 ~ 2010

2.2 System load data

Table 2 shows the basic assumptions used for system load data. The input data are cited from the country's official ESEP.

Table 2 Basic assumption for producing electric system load data

		Periods		
		1995 ~ 2000	2001 ~ 2005	2006 ~ 2010
Economic Growth (%)	GDP	7.3	6.0	4.9
	Mining & Industry	8.6	7.0	5.1
	Service	7.1	6.0	5.1
Housing Supply Rate (%)		83.8	97.5	101.4
Industrial Structure	Mining & Manufacturing	30.4	33.4	33.6
	Service	63.1	62.8	63.3
Manufacturing (%)	Petroleum & Chemical	17.4	16.8	15.7
	Basic metals	9.4	9.3	9.4
	Machinery and Equipment	44.2	52.1	55.0

Note) Percentage ratios of manufacturing represent the ratio at the years of 1995, 2005 and 2010, respectively.

Based on these assumptions, the country's system load data are forecasted as shown in Table 3. The peak load of 29,878MWe in 1995 is expected to reach 66,478MWe in 2010, which is twice as high as that of 1995. The estimated average system load factor appears to keep about 69% for the study period. 30 numbers of cosine term are used for the fourier approximation to the inverted load duration curve.

Table 3 System load data

Year	Peak load (MWe)	Electricity (GWh)	Load Factor (%)
1995	29,878	181,529.3	69.36
2000	43,694	265,978.3	69.49
2005	56,001	339,649.3	69.24
2010	66,478	405,509.3	69.63

2.3 Others

Other data for DECPAC are shown in Table 4. As for reserve margin, it is divided into 3 stages to effectively get an optimal solution. The pumped storage power plant option, having been charged of peak load in Korea, cannot be considered in DECPAC. The guideline number of LOLP(Loss of load probability) is 0.5days/year in the ESEP in Korea and determined by considering the pumped storage option. This study, however, used 2.1days/year LOLP, because DECPAC does not reflect the role of the pumped storage option which can contribute to the stable system reliability by combining with nuclear option. This study also used a fixed number of 1$/kWh as a energy-not-served cost.

Table 4 Other data for running DECPAC

Reserve margin (%)	0 ~ 40 (1995)
	5 ~ 40 (1996 ~ 1999)
	10 ~ 40 (2000 ~ 2010)
Loss of load probability (%) constraint	0.58
Energy not served cost ($/kWh)	$1/kWh (Fixed number)

3. Scenarios and Candidate Plants

3.1 Scenarios

A scenario approach is adopted in examining the role of PWR 1300MW and COAL 800MW, respectively, in the ESEP in terms of generation mix, system cost, and environmental emissions volume provided by DECPAC.

Scenario A assumes that PWR 1300MW is permitted to be candidates after 2001, while COAL 800MW is excluded. Conversely, Scenario B assumes that COAL 800MW is permitted to be candidates after 2001, PWR 1300MW is excluded.

However, other options in Table 5 remain as available candidates for the entire study period.

3.2 Candidate Plants

The pumped storage option was excluded in this study. Although pumped storage is a one of strong options in actual planning in Korea, this study does not allow to expand the option because ELECSAM module, which is one of major module in DECPAC, is not able to reflect the pumped storage option. This study, however, reflected existing and planned pumped storage plants by including them into hydro power in FIXSYS module.

Table 5 shows major characteristics on candidate plants in this study.

Table 5 Major characteristics on candidate plants

			Nuclear			Coal				Combin-
		Unit	PWR 1000	PWR 1300	PHWR 700	Coal 500	Coal 800	Coal 1000	Oil 500	ed Cycle 400
Technical Data	Capacity	MWe	1000	1300	700	500	800	1000	500	400
	Minimum load	MWe	900	1170	630	250	400	650	200	100
	Base load heat rate	kcal/kWh	2322	2309	2509	2187	2175	2400	2253	1940
	Average incremental heat rate	kcal/kWh	2309	2286	2484	2098	2080	2080	2098	1620
	Spinning reserve	%	0	0	0	10	10	10	10	10
	Forced outrage rate	%	6.3	6.3	5.5	5.6	9.7	9.7	5.5	4.9
	Scheduled maintenance days	days	60	60	39	44	55	55	36	45
Economic Data	Capital costs	$/kW	1920.3	17038	1858.2	1287.3	1164.6	1137.3	1012.7	639.2
	Interest during construction	%	16.60	22.09	21.34	14.13	16.60	16.39	13.44	9.39
	Construction time	years	5.50	5.50	5.30	3.70	4.30	5.30	3.50	2.50
	Life time	years	25	25	25	25	25	25	25	20
	Fixed O&M cost	$/kW-months	5.00	4.38	6.60	4.25	3.44	3.44	2.28	1.74
	Fuel costs	cents/10^6 kcal	178.0	178.0	96.0	682.0	682.0	682.0	1173.0	1987.0

4. Comparison of Scenario A with Scenario B

4.1 Newly added installed capacities and power plant options by scenarios

The optimal electric systems resulted from both scenarios are presented and compared in Table 6. Scenario A yields a nuclear dominant system, by the nature of the assumption. The results show that 12 units of PWR 1300MW and one unit of PHWR 700MW are added to the system during the study period. On the other hand, total 33 units of coal fired plants are added during the study period in Scenario B, of which 12 units are Coal 800MW and the remaining 21 units are coal 500MW.

Table 6 Results of the ESEP in Korea by Scenarios

	RM (%)	Added Capacity (MW)	CC 400	Oil 500	Coal 500	Coal 800	Coal 1000	PWR 1000	PWR 1300	PHWR 700
1995	6.1	900	1	-	1	-	-	-	-	-
	(6.1)	(900)	(1)	(-)	(1)	(-)	(-)	(-)	(-)	(-)
1996	11.2	900	1	-	1	-	-	-	-	-
	(11.2)	(900)	(1)	(-)	(1)	(-)	(-)	(-)	(-)	(-)
1997	16.0	900	1	-	1	-	-	-	-	-
	(16.0)	(900)	(1)	(-)	(1)	(-)	(-)	(-)	(-)	(-)
1998	24.2	1,800	2	-	2	-	-	-	-	-
	(24.2)	(1,800)	(2)	(-)	(2)	(-)	(-)	(-)	(-)	(-)
1999	28.0	900	1	-	1	-	-	-	-	-
	(28.0)	(900)	(1)	(-)	(1)	(-)	(-)	(-)	(-)	(-)
2000	27.0	900	1	-	1	-	-	-	-	-
	(27.0)	(900)	(1)	(-)	(1)	(-)	(-)	(-)	(-)	(-)
2001	24.4	-	-	-	-	-	-	-	-	-
	(24.4)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
2002	22.5	-	-	-	-	-	-	-	-	-
	(22.5)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
2003	20.7	700	-	-	-	-	-	-	-	1
	(21.3)	(1,000)	(-)	(-)	(2)	(-)	(-)	(-)	(-)	(-)
2004	20.8	1,800	-	-	1	-	-	-	1	-
	(20.6)	(1,400)	(1)	(-)	(-)	(-)	(-)	(1)	(-)	(-)
2005	21.5	3,000	1	-	-	-	-	-	2	-
	(21.3)	(3,000)	(3)	(-)	(2)	(2)	(-)	(-)	(-)	(-)
2006	21.6	3,500	1	-	1	-	-	-	2	-
	(21.2)	(3,400)	(2)	(-)	(2)	(2)	(-)	(-)	(-)	(-)
2007	21.7	3100	-	-	1	-	-	-	2	-
	(21.2)	(3,000)	(1)	(-)	(2)	(2)	(-)	(-)	(-)	(-)
2008	22.7	2,900	4	-	-	-	-	-	1	-
	(22.1)	(2,800)	(1)	(-)	(-)	(3)	(-)	(-)	(-)	(-)
2009	22.7	3,100	-	-	1	-	-	-	2	-
	(22.7)	(3,500)	(1)	(-)	(3)	(2)	(-)	(-)	(-)	(-)
2010	22.4	3,600	-	-	2	-	-	-	2	-
	(22.2)	(3,500)	(1)	(-)	(3)	(2)	(-)	(-)	(-)	(-)
Total	-	28,000	13	-	13	-	-	-	12	1
		(27,900)	(17)	(-)	(21)	(12)	(-)	(1)	(-)	(-)

Note) Figures represent the results of Scenario A, while figures in parenthesis represent the results of Scenario B.

4.2 Generating installed capacities

The generating installed capacities resulted from both scenarios are shown in Table 7. The results of Scenario A show that 41% of total generating installed capacities are provided by nuclear, 28% by coal, and 21% by combined cycle, while the remaining 10% are provided by hydro and oil by the end of 2010. Looking at the results of Scenario B, 22% of the total generating installed capacities are provided by nuclear, 45% by coal, 23% by combined cycle with the remaining 10% by hydro and oil by the end of 2010.

Table 7 Comparison of generating installed capacities by Scenarios

	Nuclear		Bituminous Coal		Anthracite Coal		Oil		Combined Cycle		Hydro Power		Total	
	MW	%	MW	%	MW	%	MW	%	MW	%	MW	%	MW	%
1995	8,616	27	5,800	18	1,020	3	4,674	15	8,491	27	3,105	10	31,706	100
	(8,616)	(27)	(5,800)	(18	(1,020)	(3)	(4,674)	(15)	(8,491)	(27)	(3,105)	(10)	(31,706)	(100)
2000	13,716	25	16,300	29	1,225	2	4,140	8	16,216	29	3,982	7	55,489	100
	(13,716)	(25)	(16,300)	(29)	(1,225)	(2)	(4,140)	(8)	(16,216)	(29)	(3,982)	(7)	(55,489)	(100)
2005	22,316	33	19,400	28	1,125	2	4,140	6	16,051	24	4,494	7	68,026	100
	(18,716)	(28)	(21,700)	(32)	(1,125)	(2)	(4,140)	(6)	(17,251)	(25)	(4,494)	(7)	(67,426)	(100)
2010	33,429	41	21,900	27	800	1	2,210	3	17,511	21	5,494	7	81,344	100
	(18,129)	(22)	(35,500)	(44)	(800)	(1)	(2,210)	(3)	(19,111)	(23)	(5,494)	(7)	(81,244)	(100)

Note) Figures represent the results of Scenario A, while figures in parenthesis represent the results of Scenario B.

4.3 Electricity generation

Table 8 shows the electric power generation by energy sources resulted from both scenarios. Results of Scenario A indicate that 57% of total electricity generation comes from nuclear, 33% from coal in 2010. The situation is reversed in Scenario B, showing that 31% of total electricity generation comes from nuclear and 57% from coal in 2010.

Table 8 Comparison of electricity generation by Scenarios

	Nuclear		Bituminous Coal		Anthracite Coal		Oil		Combined Cycle		Hydro Power		Total	
	GWh	%	GWh	%	GWh	%	GWh	%	GWh	%	GWh	%	GWh	%
1995	59,481	33	42,296	24	6,122	3	31.614	18	32.972	18	7.338	4	179,823	100
	(59,481)	(33)	(42,296)	(24)	(6,122)	(3)	(31.614)	(18)	(32.972)	(18)	(7.338)	(4)	(179.823)	(100)
2000	95.524	36	111.665	42	4,234	1	23.402	9	23,378	9	7,770	3	265,973	100
	(95.524)	(36)	(111.665)	(42)	(4,234)	(1)	(23.402)	(9)	(23.378)	(9)	(7.770)	(3)	(265.973)	(100)
2005	154.795	46	126.686	37	3.733	1	21.020	6	25.179	8	8,217	2	339,630	100
	(129.741)	(38)	(145.231)	(43)	(4,113)	(1)	(22,578)	(7)	(29.752)	(9)	(8,217)	(2)	(339,632)	(100)
2010	230.726	57	130.249	32	2,264	1	9.729	2	24,194	6	8,327	2	405,489	100
	(125.717)	(31)	(228,080)	(56)	(2,626)	(1)	(11,214)	(3)	(29,531)	(7)	(8,327)	(2)	(405,495)	(100)

Note) Figures represent the results of Scenario A, while figures in parenthesis represent the results of Scenario B.

4.4 System costs

Table 9 presents total system costs, which are consisted of capital cost, O&M cost, and fuel cost and are derived from both scenarios. The results show that Scenario A, nuclear dominant system, has some cost advantages over Scenario B, coal dominant system. The total system costs in Scenario A can be saved by about 1% (1,800million $) compared with that of Scenario B during the study period.

Table 9 Comparison of system cost(capital cost + O&M cost + fuel cost) by Scenarios

(Unit : million dollars)

	Nuclear	Coal	Oil	Combined Cycle	Hydro	Total Cost
1995	1,136.7 (1,136.7)	2,665.9 (2,665.9)	1,834.3 (1,843.3)	3,189.6 (3,189.6)	1,845.1 (1,845.1)	10,671.6 (10,671.6)
2000	1,723.2 (1,723.2)	5,061.3 (5,061.3)	1,379.3 (1,379.3)	2,430.1 (2,430.1)	161.7 (161.7)	10,755.6 (10,755.6)
2005	6,850 (2,301.1)	4,953.7 (7,765.9)	1,253.0 (1,336.3)	2,463.8 (3,317.2)	198.4 (196.3)	15,718.9 (14,616.8)
2010	8,014.9 (2,194.2)	5062.2 (12,187.3)	565.4 (644.0)	2,133.3 (2,793.5)	207.7 (203.2)	15,983.5 (18,022.2)
Total	62,972.8 (32,380.9)	76,039.2 (104,460.2)	20,823.5 (21,374.8)	42,642.2 (46,124.7)	5,010 (4,992.9)	207,487.7 (209,333.5)

Note) Figures represent the results of Scenario A, while figures in parenthesis represent the results of Scenario B.

4.5 Pollutant Emissions

The volume of pollutant emissions were derived from DECPAC by using the mass balance and the emission coefficients. Total volume of system's pollutant emissions were estimated during the period 1995 and 2010. The estimated volume of pollutant emissions of the particulate, SOx, and NOx did not show significant differences in both scenarios. However, in case of CO_2, related closely to the global warming, there was a great difference and the results are shown in Table 10. It can be found that additional introduction of nuclear power plants has a great contribution to the reduction of the total volume of CO_2 emissions. The CO_2 emissions in Scenario A are reduced by 14% compared with that of Scenario B.

Table 10 Comparison of pollutant emissions by Scenario

(Unit : 1,000 Ton)

	Scenario A				Scenario B			
	Particulate	SOx	NOx	CO2	Particulate	SOx	NOx	CO2
1995	7.8	390.5	212.1	76.175.3	7.8	390.5	212.1	76,175.3
1996	8.4	408.2	232.4	83,171.0	8.4	408.2	232.4	83,171.0
1997	8.9	438.7	257.8	92,020.1	8.9	438.7	257.8	92,020.1
1998	10.4	468.3	277.9	101,370.8	10.4	468.3	277.9	101,371.8
1999	11.2	481.6	289.9	106,541.5	11.2	481.6	289.9	106,541.5
2000	12.6	529.4	323.5	118,959.7	12.6	529.4	323.5	118,959.7
2001	13.0	550.4	338.8	123,827.4	13.0	550.4	338.8	123,827.4
2002	13.5	572.6	354.2	128,986.2	13.5	572.6	354.2	128,986.2
2003	13.7	581.3	359.2	130,773.0	14.3	580.2	371.8	135,706.2
2004	13.8	576.2	359.4	131,472.0	14.4	584.8	373.6	136,438.2
2005	13.6	564.1	351.5	128,695.4	15.5	588.7	402.9	147,030.4
2006	13.4	531.3	345.6	125,962.2	16.9	566.9	435.7	158,370.1
2007	13.2	502.6	338.8	123,201.4	18.1	549.9	467.8	169,796.9
2008	13.2	503.9	345.4	124,897.8	19.2	544.1	498.4	181,171.8
2009	13.2	496.4	345.2	125,054.1	20.9	542.6	538.5	196,383.0
2010	12.8	447.8	339.6	122,161.6	22.0	504.1	572.0	207,687.1
Total	192.7	8,043	5,071.3	1,843,269.5	227.1	8,301	5,947.3	2,163,636.7

5. Summary and Conclusions

To analyze the role of 1300MWe PWR and 800MWe coal-fired plants, expected to be main power generation sources in Korea, two scenarios were assumed and compared in the terms of system costs and volume of pollutant emissions.

Scenario A, nuclear dominant system, has some cost advantages and CO_2 emission reductions over Scenario B, coal dominant system. Scenario A can save about 1,800 million $ of total system costs and reduce 14% of CO_2 emissions, compared with Scenario B during the study period.

Although nuclear power plant has been a most economically competitive option, there also has been a wide anti-nuclear movement in Korea. However, as a concern over global environment is growing in Korea, it is hoped that nuclear energy highly improve public acceptances by its nature of environmentally friendly energy resources.

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