International Journal of Business, Human and Social Sciences
ISSN: 2517-9411
Vol:3, No:6, 2009

Nuclear Power Generation and CO_2 Abatement Scenarios in Taiwan

Chang-Bin Huang, and Fu-Kuang Ko

Abstract**—**Taiwan was the first country in Asia to announce "Nuclear-Free Homeland" in 2002. In 2008, the new government released the Sustainable Energy Policy Guidelines to lower the nationwide CO_2 emissions some time between 2016 and 2020 back to the level of year 2008, further abatement of CO_2 emissions is planed in year 2025 when CO_2 emissions will decrease to the level of year 2000. Besides, under consideration of the issues of energy, environment and economics (3E), the new government declared that the nuclear power is a carbon-less energy option. This study analyses the effects of nuclear power generation for CO_2 abatement scenarios in Taiwan. The MARKAL-MACRO energy model was adopted to evaluate economic impacts and energy deployment due to life extension of existing nuclear power plants and build new nuclear power units in CO_2 abatement scenarios. The results show that CO_2 abatement effort is expensive. On the other hand, nuclear power is a cost-effective choice. The GDP loss rate in the case of building new nuclear power plants is around two thirds of the Nuclear-Free Homeland case. Nuclear power generation has the capacity to provide large-scale CO_2 free electricity. Therefore, the results show that nuclear power is not only an option for Taiwan, but also a requisite for Taiwan's CO_2 reduction strategy.

Keywords**—**Energy model, CO_2 abatement, nuclear power, economic impacts.

I. Introduction

A complete analysis of carbon dioxide (CO_2) reduction strategies in the power sector must consider the feasibility of a nation's technology portfolio and their impacts. The advanced CO_2 reduction technologies in the power sector are found in renewable energy, nuclear power and fossil power plants with CO_2 capture and storage (CCS) technology. This study evaluates from a technical perspective, the potential for reducing CO_2 emissions in the power sector. Our study is based on the deployment of a portfolio of current and advanced technologies. The MARKAL-MACRO model was adopted to analyze the lowest cost combination of technologies and economic impacts in meeting specified CO_2 emission constraints.

Ranking 20th in the world, Taiwan released 216.8 million tons of CO_2 in 2000 and 267.9 million tons in 2006, which is a substantial increase. The CO_2 emissions in the domestic power sector accounts for an average of 59 percent of total CO_2 emissions. The Kyoto Protocol, which aims to slow down global warming effects, came into effect in 2005. Annex I countries have agreed to adopt legally binding commitments with the goal of reducing emissions of greenhouse gases. Although Taiwan is not a member of Annex I countries, it is still its responsibility, as a member of the global village, to reduce CO_2 emissions.

Fuel combustion is usually the most important origin of greenhouse gas emission inventories, and typically contributes over 90 percent of CO_2 emissions and 75 percent of total greenhouse gas emissions in developed countries [1]. At the end of 2006, total installed capacity in Taiwan was 45.7 GWe where 39% consisted of coal-fired power plants, 28% came from gas-fired power plants, 10% were from oil-fired power plants, 11% were from nuclear power plants, 6% were from renewable power plants, and 6% came from pump-storage power plants [2]. Moreover, 78% of electricity was generated from fossil fuel power plants, 17% came from nuclear power plants, 3% were from renewable energy, and 2% came from pump storage power plants [2]. The capacity and electricity allocations are shown in Fig.1.

Taiwan was the first country in Asia to announce a plan to build "Nuclear-Free Homeland" through the Environment Basic Law in 2002. Based on the law, the government established a Nuclear-Free Homeland Promotion Commission to publicize its policy. The Bureau of Energy drew up a statute to bring forward the phasing out of the three existing nuclear power plants. The energy policy, and national CO_2 reduction target and strategies in Taiwan were addressed in the White Paper on Energy in 2005 [3]. The White Paper was based on the conclusions of the National Energy Conference in 2005 which included the development of renewable energy, the increase in natural gas usage, the usage of only the Lungmen nuclear power plant with no further construction of new ones, the 40-years operation of existing nuclear power plants and the promotion of cogeneration.

The Executive Yuan released the Sustainable Energy Policy Guidelines in June 2008. The purpose of these guidelines is to promote the sustainable use of energy, following the principles of "high efficiency", "high value-added", "low emissions," and "low dependency (on imported energy)". By deploying clean energy with low or zero carbon emissions, the government's demanding reduction target is to lower the nationwide emissions back to year 2008 levels some time between 2016 and 2020, and back to year 2000 levels by 2025. The government hoped that Taiwan can create a new "low-carbon"

Chang-Bin Huang is an Engineer at Institute of Nuclear Energy Research (INER), Taiwan, R.O.C. (phone: +886-3-4711400#3429, fax: +886-3-471409, e-mail: cb.huang@iner.gov.tw)

Fu-Kuang Ko is an Associate Research Fellow at Institute of Nuclear Energy Research (INER), Taiwan, R.O.C. (e-mail: fkko@iner.gov.tw).

economy that balances economic development, environmental protection and social justice by following the new energy policy. However, under the "nuclear-free homeland" policy, Taiwan cannot construct new nuclear power plants nor extend the operation life of existing ones. In order to create a "win-win-win" situation for energy security, the environment protection and economic growth, the government declared that the nuclear power is a carbon-less energy option. The government held the National Energy Conference in April, 2009 to discuss energy policy of the future. However, the issue of new nuclear power plant is still under dispute.

A number of studies have attempted to address the issue of energy policy in Taiwan. For example, the Industrial Technology Research Institute (ITRI), Hsinchu, Taiwan, investigated end use demands and established energy technology databases to study Taiwan's energy policy with the standard MARKAL model. ITRI simulated CO_2 reduction scenarios and suggested feasible CO_2 reduction target and strategies [4]. Their results were available for further research in energy policy. However, the time period selected for the study was 1990 to 2030 which renders it inadequate for long-term energy policy evaluation.

TAIGEM-III (Taiwan General Equilibrium Model - III), which was developed by the Center for Sustainable Development at the National Tsing Hua University, Hsinchu, Taiwan, is a multi-sectoral, computable general equilibrium (CGE) model of Taiwan's economy derived from ORANI [5]. TAIGEM-III was developed specifically to analyze climate change issues, such as baseline forecasting and climate change response policies. The most significant features of TAIGEM-III are the inclusion of inter-fuel substitute, technology bundles and dynamic mechanism capable of projecting the development of the economy through time. The CO_2 emissions, GDP growth rate, and other economic variables can also be estimated by TAIGEM-III model. TAIGEN-III is a top-down economic model. The technologies are mainly the present technologies. New and advanced technologies are not detailed description in this model. All technologies should progress with time in the energy economics model. This means that TAIGEM-III is not suitable to forecast the long-term technology allocation.

Taiwan Power Company (Taipower) is the only power company who takes over all power facilities in Taiwan. Taipower's long-term load forecasting model provides important information for energy policy decisions, future power development, network programming, energy price structures, and demand-side management. Meanwhile, long-term power development programming considers several factors including feasible plans, existing generation structures, the percentage of reserve margin, and CO_2 emissions that are based on the outcome of long-term load forecasting. Long-term power development programming allows for the power development plan that ensures the reliability of long-term power supply. [6]. However, the forecasting year of Taipower's "long-term load" is only up to 2027. It is still not enough for a country's long-term energy policy plan.

This study analyses scenarios of nuclear power generation to achieve CO_2 emissions targets in Taiwan. The MARKAL-MACRO energy model, demands altered endogenously, was adopted to evaluate economic impacts, optimal energy deployment and CO_2 reduction scenarios. The time period of the model covers years 2000 to 2050 and is adequate to evaluate mid and long-term energy policies. CO_2 emissions in years 2000 and 2005 were calibrated with the Taiwan's energy balance sheet. The purpose of this study is to suggest feasible mid-term and long-term CO_2 reduction strategies, especially for the nuclear power generation, and evaluate the economic impacts caused by the CO_2 reduction.

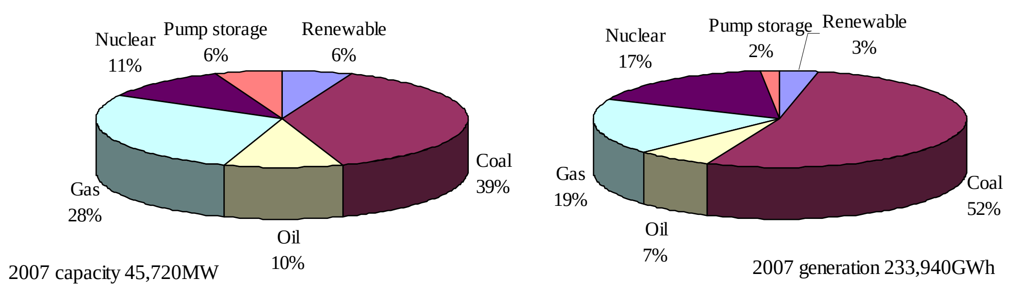

Fig. 1 Electricity capacity and generation of 2007

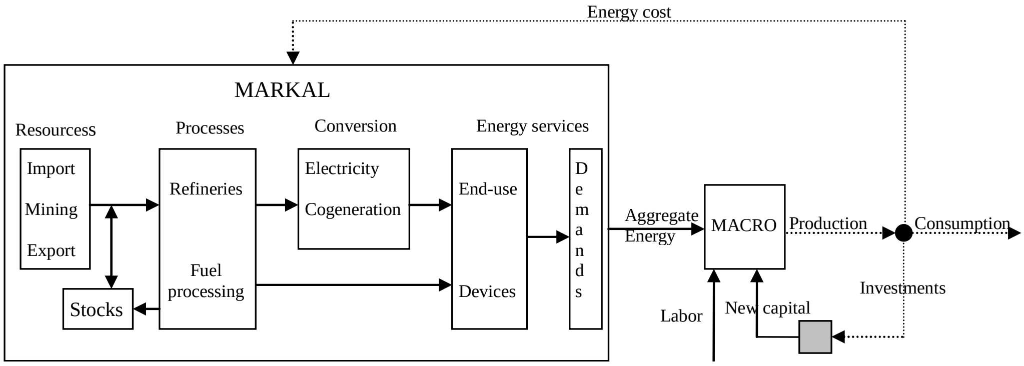

Fig. 2 Flowchart of MARKAL-MARCO model

II. Modeling Methodology

A. *MARKAL-MACRO*

MARKAL, a well-known dynamic energy model, is built on the concept of a Reference Energy System (RES) [7]. The standard MARKAL model is a bottom-up technology-based linear optimization model, which identifies the least-cost combinations of technological processes and improvement options, satisfying a specified level of demand for goods and services under certain policy constraints. It incorporates a full range of energy processes, e.g. exploitation, process, conversion, transmission, distribution and end-use. The model can consider existing as well as advanced technology that may be deployed in the future. The objective function includes the capital costs of energy technologies, fuel costs, infrastructure costs, and fixed and variable operating and maintenance costs. However, there is no feedback between energy service demand and energy system costs in standard MARKAL. This means that the demands in standard MARKAL model are specified exogenously and the model is not suitable for economic impacts evaluation.

MACRO is a top-down macroeconomic model with an aggregated view of long-term economic growth [7]. MARKAL-MACRO is the result of merging two existing model approaches, MARKAL and MACRO, into a single, self-contained model, as shown in Fig. 2. The basic input factors of production are capital, labor and energy, which are aggregated from variable energy service demands. The economy's outputs are used for investment, consumption and inter-industry payments for the cost of energy. Investment is used to build up the stock of capital. MARKAL-MACRO adds elasticity of substitution on energy service demands and links changes in the energy system to the level of economic activity while maintaining the technological richness and flexibility of MARKAL.

III. Assumptions of Scenarios and Data Calibation

A. *INER's MARKAL-MACRO Model*

The Institute of Nuclear Energy Research (INER) developed MARKAL-MACRO model for Taiwan in 5-year intervals extending from 2000 through 2050 with ANSWER MARKAL 6.2.15 and MARKAL-MACRO modeling framework. The model provides detailed description for Taiwan's energy system, covering from energy resource mining, energy import/export, conversion, transmission and distribution to end-use. The energy conversion technologies consider not only the use of conventional fossil fuel power plants such as coal, oil and natural gas, but also new and renewable energy technologies like IGCC, fossil fuel power plants with CCS technologies, the construction of advanced nuclear reactors, as well as hydro, wind, solar, ocean, geothermal and biomass energy. About 70 conversion technologies, including both existing and advanced technologies, are defined in the model to convert primary energy into final energy.

Demand sectors are divided into industry, commercial, residential, transportation and others (agriculture and non-energy use). For each sub-sector, the choice of technologies includes those that are commercially available today, as well as technologies that might be commercially introduced in the future. In total, around 90 end-use technologies are presented in the model. All technologies in this model will progress with time. The detail description and assumption for resource availability, technical and economic parameters for each technologies, and etc. can be found in other literatures [8] [9].

The basic assumptions of future social and economic development for BAU scenario are displayed in Table 1. The energy service demand projection approaches as well as results can also be found in above-mentioned literatures. The costs in this study are discounted back to year 2001 with a discount rate of 6% and prices are given in 2001$US unless otherwise stated.

B. *Assumptions of Scenarios*

A series of analyses were performed to examine the electricity deployment and economic impacts in each scenario. The BAU scenario in this study is based on the assumptions of the National Energy Conference in 2005 and the designed emphases are shown in Table II. The usage of natural gas will be increased from 10 million tons in 2010 to 16 million tons in

2025; the capacity of renewable energy will be increased from 5139 MW in 2010 to 6500 MW in 2025; and the target improvement in energy intensity in 2020 is 28% according to the conclusions of the National Energy Conference in 1998 [3]. However, due to the postponement of wind turbine constructions, the capacity of renewable energy in 2010 is adjusted to 3960MW. The Lungmen nuclear power plant is planed to be operated commercially at 2011. There is no more construction of nuclear power plant after Lungmen power plant. From a technical view point, CCS may become a mature technology for fossil-fuelled power plants by 2020 [10]. Consider the postponement of implementing new technology in Taiwan, CCS technology is assumed to be ready at 2030 in the model.

Table III gives an overall picture of the main differences among the analyzed scenarios. N1 to N3 scenarios are the CO_2 constraint scenarios. The CO_2 constraints of reduction scenarios are based on the Sustainable Energy Policy Guidelines as shown in Fig. 3.

C. Data Calibration

One of the features of INER's MARKAL-MACRO is to calibrate energy use in each sector with the Energy Balance Sheet of Taiwan from years 2000 and 2005. Table IV shows the comparison of CO_2 emissions between results of INER's MARKAL-MACRO and historical statistics. The historical statistics of CO_2 emissions was calculated based on the Energy Balance Sheet of Taiwan [11] [12] and the 2006 IPCC Guidelines for National Greenhouse Gas Inventories [1]. From Table II, CO_2 emissions of INER's MARKAL model are 217.1 million tons in 2000 and 258.6 million tons in 2005, and the deviations are 0.2% and -0.3% respectively.

IV. Results and Discussion

A. Electricity Deployment

Taiwan's BAU scenario was mainly designed according to the assumption of the Energy Conference in 2005, and the time period covers up to 2025. However, in order to project long-term CO_2 reduction impacts and technology development, the time period is extended from 2000 to 2050 in this study. Fig. 4 and Fig. 5 show the allocation of electricity capacity and generation respectively for the BAU and reduction scenarios in 2025 and 2050. The BAU results show that, if there would be no CO_2 reduction targets, PC/SCPC power plants will be dominant since the coal price is much lower relative to other fossil fuels. The share of PC/SCPC in electricity generation will be 60.2% at 2050. NGCC comes in second, with a 30.8% ratio in total electricity generation in 2050 due to the policy of increasing the usage of natural gas, despite higher natural gas prices relative to coal. The share of NGCC in capacity is larger than in generation because of high fuel cost. The share of nuclear power will be phased out gradually from 2020 onwards. In 2050, the rest nuclear power units are in the Lungmen nuclear power plant which is operated since 2011. Generally, the cost of renewable energy is higher than traditional power plants and the capacity factor is lower. However, renewable energy is promoted by an interim measure of purchasing renewable energy power at the guaranteed price (US$0.06 KWh). Furthermore, fossil power plants with CCS do not appear in the BAU scenario.

The government expects to lower CO_2 emissions back to year 2000 levels by 2025. However, by 2025, CCS technology will still not be available in this model. The renewable generations are low-carbon technologies, but due to restrictions in natural resources, high electricity cost and undeveloped technology, the electricity generated from renewable energy will be limited. For CO_2 reduction scenarios in Fig. 4 and Fig. 5, the share of NGCC in electricity generation will be dominant in N1 and N2 scenarios. Coal-fired power plants have the most CO_2 emissions, so generation from coal-fired power plants is avoided. There are most nuclear power plants in N3 scenario. The share of nuclear power in electricity generation is 41.8% in 2025. The total electricity generation in N3 is also the highest among the CO_2 reduction scenarios.

By 2050, because of the strict CO_2 reduction target, the progress of technology and decrease of investment cost, the electricity capacity of renewable energy has an obvious growth compare to 2025. However, due to the low capacity factor of renewable energy, the share of electricity generation of renewable energy is lower than the share of capacity. Besides, CCS is a mature technology in 2050. All the coal-fired and NGCC power plants which build by 2030 will be integrated with CCS technology. In N2 and N3 scenarios, the nuclear power plants which built in the 1980s with 20 years life extension will be phased out before 2050. The capacities of nuclear power plants in N1 and N2 are the same in 2050, so the allocations of electricity generation in N1 and N2 scenarios are similar. The fossil-fuel power plants generate more than 50% of electricity in N1 and N2 scenarios due to less nuclear power plants. In N3 scenario, the capacity of nuclear power plants is 21.6 GW (26.3%) and generates 159 TWh (49.5%) of electricity. Due to enough electricity from nuclear power, there is no need to generate electricity from NGCC with CCS.

Table V shows the share of generation of fossil fuel power plants and nuclear power plants of total electricity. In 2025, renewable technologies are still not mature enough, fossil fuel power plants and nuclear power plants have the ratio more than 85%. In 2050, due to the maturity of renewable technologies, fossil fuel power plants and nuclear power plants have the ratio around 60%. In N3 scenario, nuclear power plants constrict the development of fossil fuel power plants obviously.

TABLE I
BASIC ASSUMPTIONS FOR FUTURE SOCIAL AND ECONOMIC DEVELOPMENT TO GENERATE ENERGY SERVICE DEMANDS

	Annual GDP growth rate(%)[13]	Annual population growth rate(%)[14]	Annual household growth rate(%)[15]	Annual GDPP growth rate(%)
2001~2005	3.216	0.439	1.766	2.764
2006~2010	2.274	0.308	1.653	1.961
2011~2015	4.588	0.306	1.592	4.269
2016~2020	3.637	0.208	1.472	3.422
2021~2025	3.148	0.092	1.370	3.053
2026~2030	2.955	-0.047	0.688	3.003
2031~2035	2.752	-0.235	0.231	2.994
2036~2040	2.575	-0.451	-0.262	3.040
2041~2045	2.420	-0.637	-0.760	3.077
2046~2050	2.283	-0.771	-1.240	3.078

Note: The GDP and household growth rate after 2025, and GDPP growth rate from 2006 to 2050 are our own calculation.

TABLE II
OUTLINES OF BAU SCENARIO

	Assumptions of BAU
LNG	2010: 10 million tons 2020: 13 million tons 2025: 16 million tons
Renewable energy	2010: 5,139MW 2015: 5,820 MW 2020: 6,500MW 2025: 6,500MW
Energy intensity	Improvement in energy intensity in 2020 is 28% according to the conclusions of the National Energy Conference 1998.
Nuclear policy	No new nuclear construction and no life extension of existed plants. Lungmen nuclear power plant will be operated commercially at 2011.
CCS technology	CCS will be ready at 2030.

Source: [3]

TABLE III
LIST OF SCENARIOS

Name	Description
BAU	Increase LNG usage; develop renewable energy; improvement of energy efficiency and intensity; Nuclear-Free Homeland policy
N1	1. CO_2 emissions return 2000 levels by 2025, 50% of 2000 levels by 2050. 2. No new construction of nuclear power plants. 3. No life extension of existed nuclear power plants.
N2	Same as N1, except 20 years of life extension and power uprate of existed nuclear power plants.
N3	Same as N2, except new nuclear power units will be constructed after 2021. Five nuclear power units will be operated commercially from 2021 to 2025. After 2026, two new units will be operated commercially in every five years until 2040. One new unit will be operated commercially by 2045. By 2050, there will be two new units constructed at the sites of two retired nuclear units.

TABLE IV
COMPARISON OF CO_2 EMISSIONS RESULTS OF INER'S MARKAL-MACRO AND HISTORICAL STATISTICS

CO2 emissions	2000		2005	
	Mton	Deviation	Mton	Deviation
Historical statistics (without power generation from wastes)	216.8	—	259.3	—
INER's MARKAL (without power generation from wastes)	217.1	0.2%	258.6	-0.3%
INER's MARKAL (including power generation from wastes)	219.5	—	262.1	—

Note: CO_2 emissions from waste CHP is not included in Taiwan's historical statistics.

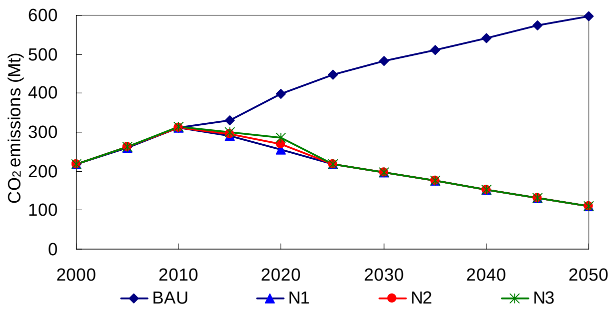

Fig. 3 Trajectories of constrained CO_2 emissions

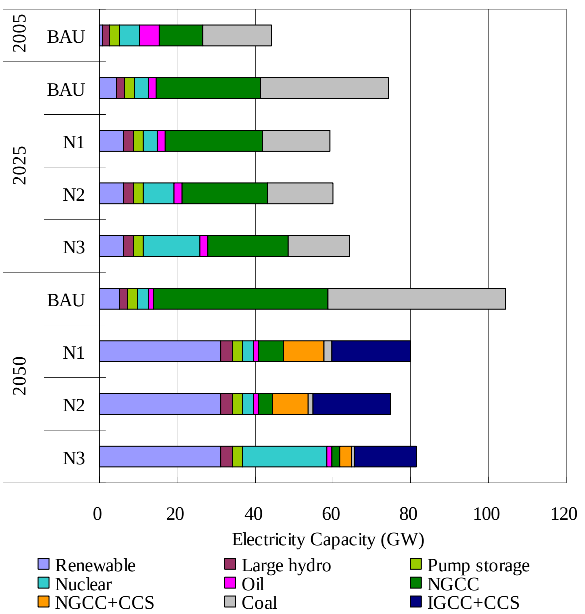

Fig. 4 The allocation of electricity capacity in 2025 and 2050

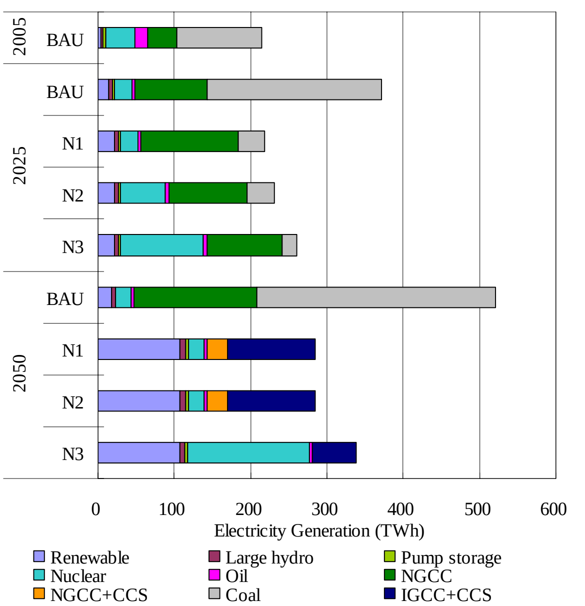

Fig. 5 The allocation of electricity capacity in 2025 and 2050

TABLE V

THE SHARE OF GENERATION OF TOTAL ELECTRICITY

	2025		2050	
	Fossil fuel power plants	Nuclear power plants	Fossil fuel power plants	Nuclear power plants
BAU	88.1%	6.2%	91.8%	3.8%
N1	76.0%	10.5%	51.4%	7.0%
N2	61.6%	25.5%	51.3%	7.0%
N3	46.8%	41.8%	18.2%	47.0%

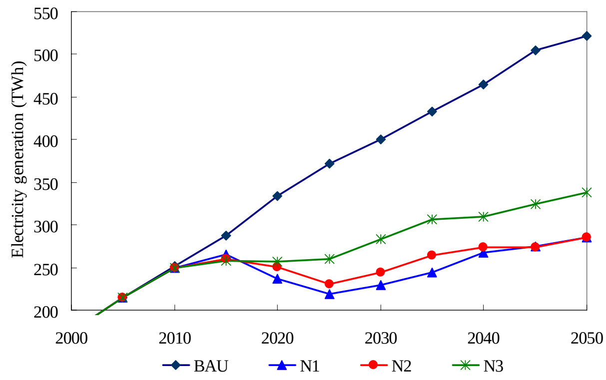

Fig. 6 Energy demand of BAU and CO_2 reduction scenarios

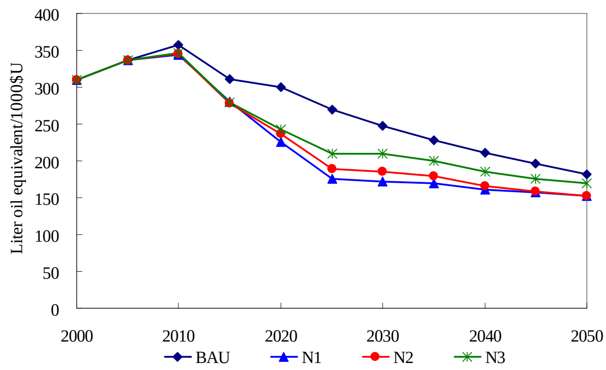

Fig. 7 Energy intensity of BAU and CO_2 reduction scenarios

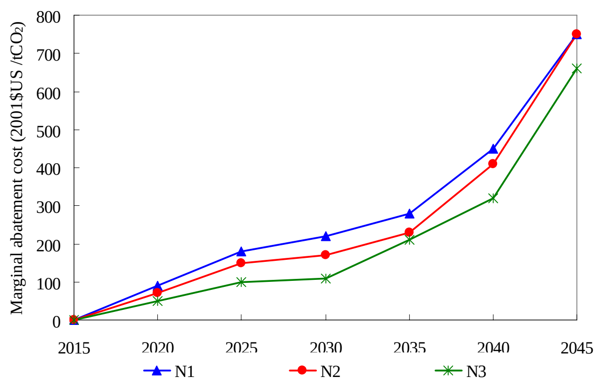

Fig. 8 Marginal abatement costs of CO_2 reduction scenarios

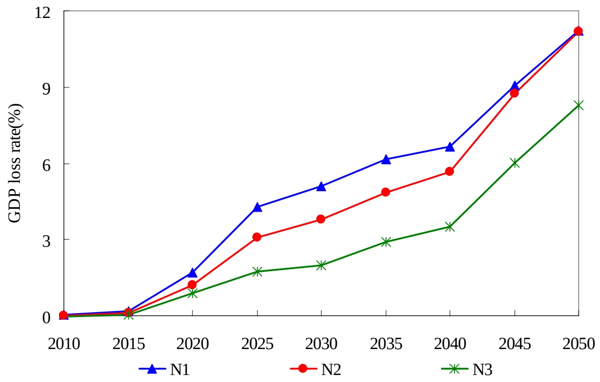

Fig. 9 GDP loss rate of CO_2 reduction scenarios

B. *Electricity Generation and Energy Intensity*

Fig. 6 shows the electricity generation of each scenario. In 2025, because there are not enough low CO_2 emissions power plants, the electricity generation is decreased to meet the CO_2 reaction target. After 2030, due to CCS technology is implemented, the reduction stress is released. The electricity generation of N1 and N2 scenario is increased again. In N3 scenario, due to plenty of CO_2 free electricity from nuclear plants, it is not necessary to decrease electricity generation in 2025. The electricity of N3 scenario is 18.9% higher than N1 scenario in 2025, and is 18.5% higher than N1 scenario in 2050. Fig. 7 shows the energy intensity of BAU and CO_2 reduction scenarios. The decrease of energy intensity implies the improvement of energy efficiency or reduction of energy demand per GDP produced. Energy intensity curves in CO_2 constraint cases drop rapidly once CO_2 emissions start to be constrained. In Fig. 7, the difference of energy intensity between the 3 CO_2 reduction scenarios is distinct obviously. In comparison N3 with N1 scenario, the energy intensity is much higher than N1 scenario. This means we have much more energy for N3 scenario to develop economic.

C. *Economic Impacts*

Marginal abatement cost (MAC) is a useful parameter to characterize the response of a model to emission constraints. MAC represents the costs of abating the final ton of CO_2 to meet a given constraint. The higher marginal costs are associated with those runs where constraints are more stringent or where technologies to reduce emissions are unavailable or costly [16].

Three CO_2 reduction scenarios, N1, N2 and N3, were analyzed with MAC curves as shown in Fig. 8. In scenario N1, highest costs are observed primarily due to the lack of available low carbon abatement technologies in the electricity generation sector. There is no new nuclear plant and no life extension of existing nuclear plant in scenario N1, the MAC is the highest during 2020 to 2040. In scenario N2, during the year 2020 to 2040, the life of existing nuclear power plants built in 1980's will be extended. The nuclear power generation of N2 scenario is more than N1 scenario during this period. N1 scenario needs to build more IGCC with CCS and NGCC with CCS. CCS is not an efficient technology, and the electricity cost of fossil fuel power plants with CCS technology is expensive than the electricity cost of nuclear power plants. However, when all of these existing power plants are phased out after 2045 in N2 scenario, the MAC after 2045 is similar with N1 scenario. In order to meet the CO_2 reduction target in 2045, N2 scenario needs to build more fossil fuel power plants with CCS technology and renewable power plants.

Within a closed economy, a constraint on carbon emissions will reduce available choices in energy. As a result, fuel prices will rise, energy costs in the economy will increase, and both consumption and investment will be reduced. Fig. 9 shows the GDP loss rate of CO_2 reduction scenarios. GDP loss rate in N1 scenario, without new nuclear plants and life extension, is the highest among all scenarios. Also, it is important to mention that GDP loss rate in N2 scenario is lower than N1 scenario during the period year 2020 to 2045. By 2050, due to the allocation of electricity generations of N1 and N2 scenarios are similar, and the GDP loss rate is almost the same.

In Comparison of the economic impacts of CO_2 reduction scenarios, N3 scenario has the lowest economic impacts among the 3 scenarios. The economic impacts of N2 scenario are lower than N1 during the period of life extension of existing nuclear power plants. After the existing nuclear power plants are phased out, the economic impacts will be the same with N1 scenario.

V. Conclusion

Taiwan is still a developing country, thus, projected continuous economic growth will lead to more CO_2 emissions if no CO_2 reduction activities are taken. Nuclear power generation has the capacity to provide large-scale and CO_2 free electricity. Under the "Nuclear-Free Homeland" policy, the GDP losses are considerably high. The GDP loss rate in the case of building of new nuclear power plants is around two thirds of the Nuclear-Free Homeland case in 2050. In order to create a "win-win-win" situation for energy security, the environment protection and economic growth, nuclear power generation is not only an option for Taiwan, but also a requisite for Taiwan's CO_2 reduction strategy.

References

[1] A. Garg, K. Kazunari and T. Pulles, 2006. 2006 IPCC Guidelines for National Greenhouse gas Inventories, Chapter 1: Introduction. The Intergovernmental Panel on Climate Change (IPCC).
[2] Bureau of Energy, Energy Statistical Hand Book 2007. Bureau of Energy, R.O.C., 2008.
[3] Bureau of Energy, White Paper on Energy in 2005. Bureau of Energy, R.O.C., 2005.
[4] ITRI, Taiwan'S Future Energy Planning - Application and Maintenance of the Energy Engineering Model (in Chinese). Bureau of Energy / ITRI, R.O.C., 2005.
[5] P. C. Li, S. H. Hsu, C. H. Huang and H. H. Lin, Baseline Forecasting for Greenhouse Gas Reduction in Taiwan: A Dynamic CGE Analysis, 2003. http://csd.hss.nthu.edu.tw
[6] S. P. Hung, et al., Project of Long-Term Load Forecasting and Power Development Planning of Taiwan (in Chinese). Bureau of Energy / Taipower, 2008.

[7] R. Loulou, G. Goldstein and K. Noble, Documentation for the MARKAL Family of Models. ANSWER MARKAL Manual, 2004.
[8] C. B. Huang, P. Y. Tseng, H. M. Chiu, B. Y. Zheng, F. K. Ko, and C. H. Lin, INER MARKAL-MACRO Model Establishment– BAU Scenario Analysis and Validation of Electricity Scetor Submodel (INER-5241R). INER, R.O.C., 2008.
[9] C. B. Huang, P. Y. Tseng, C. H. Lin, B. Y. Zheng, H. M. Chiu, F. K. Ko, INER's MARKAL-MACRO Data Base (INER-5228R). INER, R.O.C., 2008.
[10] International Energy Agency (IEA), Energy Technology Prospectives 2008. IEA, 2008.
[11] Bureau of Energy, Energy Balance Sheet of Taiwan. Bureau of Energy, R.O.C., 2001.
[12] Bureau of Energy, Energy Balance Sheet of Taiwan. Bureau of Energy, R.O.C., 2006
[13] Bureau of Energy, Database of Taiwan's MARKAL model for 2006 simulation (in Chinese). Bureau of Energy, R.O.C., 2006.
[14] Council for Economic planning and development, Population Evaluation of Republic of China, Taiwan from 2006 to 2051 (in Chinese). R.O.C., 2006.
[15] C. M. Lee, et al., The Baseline of CO_2 Emissions and Estimation Method of Taiwan (in Chinese). Center for Sustainable Development of National Tsing Hua University, 2005.
[16] Defra, MARKAL Macro analysis of long run costs of climate change mitigation targets. Defra, UK, 2007.

Chang-Bin Huang, Taiwan, R.O.C., was born in June 15, 1975. This Author got the Ph.D. degree in Mechanical Engineering, Yuan-Ze University, Taiwan, (1999~ 2006). His major field is energy and CFD.

He is an engineer in Institute of Nuclear Energy Research (INER), Taiwan since 2006. His major publishers which relative to this paper are:

1. **C. B. Huang**, P. Y. Tseng, H. M. Chiu, B. Y. Zheng, F. K. Ko, and C. H. Lin, INER MARKAL-MACRO Model Establishment– BAU Scenario Analysis and Validation of Electricity Scetor Submodel (INER-5241R). INER, R.O.C., 2008.
2. Fu-Kuang Ko, **Chang-Bin Huang**, Pei-Ying Tseng, Chung-Han Lin, Bo-Yan Zheng, Hsiu-Mei Chiu, Long-Term CO_2 Reduction Target and Scenarios of Power Sector in Taiwan, 2nd IAEE Asian Conf. November 5-7, 2008, Australia.

Fu-Kuang Ko, Taiwan, R.O.C., was born in May 25, 1966. This Author got the Master degree in Nuclear Engineering, Tsing Hua University, Taiwan, (1988~1990). His major field is energy modeling, energy policy planning and nuclear engineering.

He is an associate researcher and leads IGCC group since 2007 and energy modeling since 2005 in Institute of Nuclear Energy Research (INER), Taiwan. His major publishers which relative to this paper are:

1. C. B. Huang, P. Y. Tseng, H. M. Chiu, B. Y. Zheng, **F. K. Ko**, and C. H. Lin, INER MARKAL-MACRO Model Establishment– BAU Scenario Analysis and Validation of Electricity Scetor Submodel (INER-5241R). INER, R.O.C., 2008.
2. **Fu-Kuang Ko**, Chang-Bin Huang, Pei-Ying Tseng, Chung-Han Lin, Bo-Yan Zheng, Hsiu-Mei Chiu, Long-Term CO_2 Reduction Target and Scenarios of Power Sector in Taiwan, 2nd IAEE Asian Conf. November 5-7, 2008, Australia.
3. Shih-Mo Lin, Jin-Shiun Chou, **Fu-Kuang Ko**, Pei-Ying Tsing, Le-Ren Lu, Economic Impacts and Mitigation Costs of CO_2 Emission Reduction in Taiwan- A MARKAL-MACRO Model Analysis, The 1st IAEE Asian Conference, November 5-6, 2007, CPC, Taipei, Taiwan, ROC.