**Measuring the Contribution of New and Renewable Energy R&D to Slowing Down $CO_2$ Emissions in Taiwan with an Integrated Modelling Approach**

Shih-Mo Lin, Chung-Chiang Feng, Jin-Xu Lin, Han-Pang Su, and Fu-Kuang Ko

ABSTRACT

Energy and environmental issues have become increasingly important over the past decade. Concerns over the security of fossil fuel supply have accelerated the pace of exploring alternative energies among major energy-consuming countries. However, research and development (R&D) in new and renewable energy technologies inevitably engages in all the stages of life cycle of new product or technology development, meaning that uncertainty involves and tremendous investment that crowds out other expenditures might result in disappointing returns. As such, comprehensive assessment on the potential costs and benefits of a new or renewable energy technology investment project is necessary. This paper refines the new-energy data and updates the input-output data based on the most recent input-output tables for the top-down economic analysis model developed specifically for Taiwan's energy and environmental policy analysis. The linking of the top-down model to the MARKAL energy-engineering model is also explored to take advantage of the strengths of both kinds of model. Cost and benefit analysis for the development of new and renewable energies as well as specific policy analyses based on the constructed integrated modeling system is then performed to justify the development of certain new and renewable energy technologies in Taiwan. Our analysis results indicate that with a reasonable level of R&D investment and learning process, new and renewable energy technology development is cost-effective and shall have significant environmental benefit.

Keywords: Renewable energy, R&D, CGE model, integrated modelling

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## 1. Introduction

Taiwan has very limited indigenous conventional energy resources and thus over 97% of its energy supply has been imported from foreign countries (Bureau of Energy, 2010). The overdependence on foreign sources of energy has raised concerns over the security of energy supply in the past decades. Beside the energy security concerns, rapidly increased $CO_2$ emissions due to the burning of fossil fuels have also caught the eyes of policy makers, as carbon emissions may have a profound and perhaps irreversible effect on the environment. Nations throughout the world now have started to impose ever stricter carbon reduction requirements, and sooner or later Taiwan will be asked to reduce its $CO_2$ emission levels.

To reduce the reliance on imported energy and the level of $CO_2$ emission, developing new and renewable energies has become one of the primary energy policies of the Taiwanese government. Over the past decade, Taiwan has implemented many measures subsidizing the installation of renewable energy apparatus and providing incentives for developing renewable energy technology, such as investment deduction and accelerating depreciation. In addition, to further establish the promoting mechanism, the Bureau of Energy has pushed the legislation of "Renewable Energy Development Bill". According to the Bill, the capacity of renewable energies will be 12% share of the national power installation capacity by 2020.[1]

It is widely believed that the government has a vital role to play in the development of renewable energy technology, and that whatever investments the government makes now should have significant returns in the future (Wiser, 2000). This is to say that, a virtuous cycle could be created with government's active participation in the development process. With the government's support on basic research and development (R&D) in renewable energy, Taiwan's dynamic and enterprising private sector will be able to make use of the knowledge to create advanced technology. This, in turn, would generate income for the companies and for the economy as a whole as well. Other than that, a second virtuous cycle could also be created. That is, Taiwan could eventually break it's reliance on foreign energy suppliers. Additionally, as the cost of renewable energy gets cheaper, more demand will be generated; and as demand increases, more and more companies will join to

[1] However, the share of the power capacity of renewable energy to the national power installation capacity is less than 7% currently. There are still a lot of rooms for the development of renewable energy in Taiwan.

help supply this need, which will help lower energy prices further.

Although government plays a very important role in researching and developing renewable energy technologies, research and development in new and renewable energy technologies inevitably engages in all the stages of life cycle of new product or technology development, meaning that uncertainty involves and tremendous investment that crowds out other expenditures might result in disappointing returns. As such, comprehensive assessment on the potential costs and benefits of a new or renewable energy technology investment project is necessary. This paper refines the new-energy data and updates the input-output data based on the most recent input-output tables for the top-down economic analysis model developed specifically for Taiwan's energy and environmental policy analysis. The linking of the top-down model to the MARKAL energy-engineering model is also explored to take advantage of the strengths of both kinds of model. Cost and benefit analysis for the development of new and renewable energies as well as specific R&D policy analyses based on the constructed integrated modeling system is then performed to justify the development of certain new and renewable energy technologies in Taiwan. We would like to see whether with a reasonable level of R&D investment and the learning process associated with the production and adoption of renewable energy technology, renewable energy technology development is cost-effective and has significant environmental benefit.

## 2. New and renewable energy development in Taiwan

Before 1998, rapid development of the economy has led to a rapid increase in energy demand in Taiwan. Year 1998 and 2001 are the two years exhibiting downturn energy demand, which can be largely attributed to the poor performance of the global and local economy in those periods. The slowdown in economic growth in recent years, however, has depressed the demand for energy.

Oil and coal are the two energies that form the most part of energy demand in Taiwan (Figure 1). Demand for these two types of energy exhibits a fast growing trend over the past several decades. LNG, which has been used mostly for generating electricity, has also shown a growing trend, but with a slower rate than that of oil and coal.

In 2001, total production of renewable energy was about 2200 MW, which is mostly from hydro power and biomass sources, including municipal solid waste, animal waste and agricultural by-products. Current government policies for the promotion of renewable energy, however, have turned to decrease the use of biomass wastes and other combustible wastes, and progressive promote the development of solar and wind energy. According to the "Renewable Energy Development Bill", the cumulative installation capacity is expected to reach at least 6,500 MW by the end of 2020.

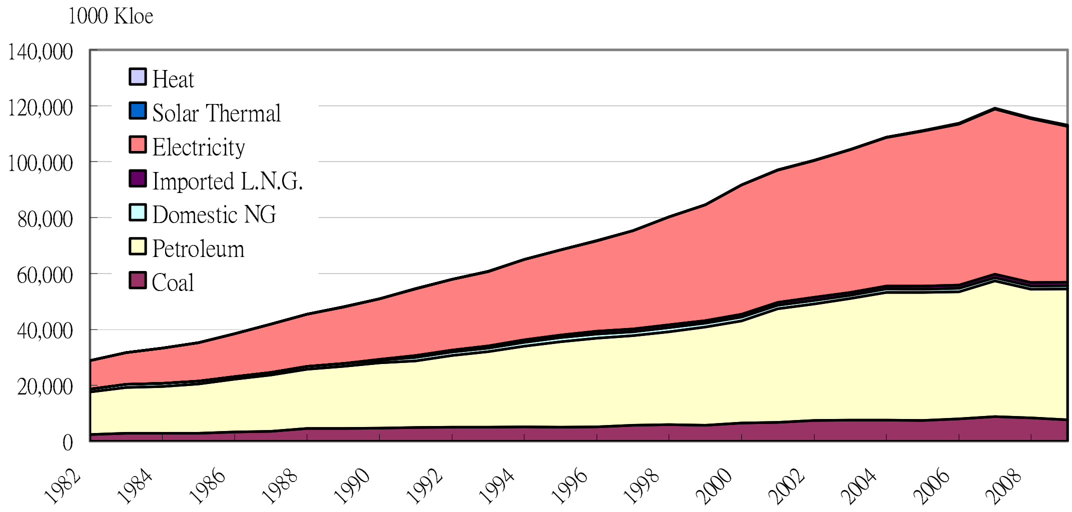


Figure 1. Energy demand by energy form (1982-2009)

Source: Bureau of Energy, MOEA

Table 1 shows the actual and expected installed capacity for most forms of renewable energies in Taiwan (BOE, 2008). It can be seen from the table that the installed capacity for renewables is expected to reach 8,450 MW, representing around 15% of the energy capacity in Taiwan. Without counting the so-called "big-hydro", the capacity will be around 6,500 MW, meaning the capacity will maintain at least the 2020 level.

Table 1. Targets of renewable energy promotion in Taiwan

| | 2007 | | 2010 | | 2025 | |
|---|---|---|---|---|---|---|
| | Installed Capacity (MW) | Ratio (%) | Installed Capacity (MW) | Ratio (%) | Installed Capacity (MW) | Ratio (%) |
| 1. Hydropower | 1922 | 5.0 | 2168 | 5.7 | 2500 | 4.4 |
| 2. Wind power | 281.6 | 0.7 | 980 | 2.6 | 3000 | 5.3 |
| 3. Solar Photovoltaic | 2.1 | 0.0 | 31 | 0.1 | 1000 | 1.8 |
| 4. Geothermal | — | — | — | — | 150 | 0.3 |
| 5. Biomass | 637 | 1.7 | 741 | 1.9 | 1400 | 2.5 |
| 6. Fuel Cell | — | — | — | — | 200 | 0.4 |
| 7. Marine Current | — | — | — | — | 200 | 0.4 |
| **Total** | **2843** | **7.5** | **3920** | **10.3** | **8450** | **15.1** |

Source: Bureau of Energy, MOEA

Table 2 shows the installed capacity for power generation in 2009, and Table 3 illustrates the energy production with the installed capacity in 2009. As shown in the tables, although the share of renewable energy in total capacity (including pumped and storage hydo) has reached the set target of 12%, the total energy produced is still far from a level that can significantly contribute to the reduction of $CO_2$ emission.

Table 2. Installed Capacity in Taiwan (2009)

| Item | Installed Capacity (MW) | | (%) | Growth Rate (%) |
|---|---|---|---|---|
| **Pumped Storage Hydro** | **2,602.0** | | **6.5** | **0.0** |
| **Thermal** | **30,194.3** | | **75.0** | **5.2** |
| Taipower | | 22,487.2 | 55.9 | 4.7 |
| IPP | | 7,707.1 | 19.1 | 6.8 |
| **Nuclear** | **5,144.0** | | **12.8** | **0.0** |
| **Renewable** | **2306.8** | | **5.7** | **5.6** |
| Conv. Hydro | | | | |
| Taipower | | 1,647.8 | 4.1 | -0.1 |
| IPP | | 39.1 | 0.1 | 0.0 |
| Hydro Entrusted to Taipower | | 250.0 | 0.6 | 0.0 |
| Wind Power | | | | |
| Taipower | | 179.8 | 0.4 | 36.4 |
| IPP | | 190.1 | 0.5 | 66.5 |
| **Total Installed Capacity** | **40,247.0** | | **100.0** | **4.2** |

Source: Taiwan Power Company, http://www.taipower.com.tw/indexE.htm

Table 3. Energy Production in Taiwan (2009)

| Item | Energy Production & Purchased (billion KWh) | | (%) | Growth Rate (%) |
|---|---|---|---|---|
| **Pumped Storage Hydro** | **3.3** | | **1.7** | **-4.9** |
| **Thermal** | **145.8** | | **75.3** | **-4.5** |
| Taipower | | 96.8 | 50.0 | -10.5 |
| IPP | | 37.7 | 19.5 | 8.6 |
| Cogen | | 11.3 | 5.8 | 15.6 |
| **Nuclear** | **40.0** | | **20.7** | **1.8** |
| **Renewable** | **4.6** | | **2.4** | **-6.3** |
| Conv. Hydro | | | | |
| Taipower | | 3.0 | 1.5 | -13.3 |
| IPP | | 0.1 | 0.1 | 2.3 |
| Hydro Entrusted to Taipower | | 0.6 | 0.3 | -14.2 |
| Wind Power & Photovoltaic | | | | |
| Taipower | | 0.4 | 0.2 | 36.3 |
| IPP | | 0.5 | 0.2 | 44.7 |
| **Total Installed Capacity** | **193.6** | | **100.0** | **-3.3** |

Source: Taiwan Power Company, http://www.taipower.com.tw/indexE.htm

## 3. The model

The model used to conduct analyses of the potential of renewable energy in reducing $CO_2$ emissions in the current paper is denoted GEMEET, which is the abbreviation of General Equilibrium Model for Energy, Environment and Technology analysis. Being a CGE model, GEMEET's core describes the operation of the economy based on the optimisation theory and applies it to most agents. Weakly separability assumptions are also adopted to simplify agent's optimisation problem.

GEMEET is jointly developed by the Center of Applied Economic Modeling at Chung Yuan Christian University, Taiwan and the Institute of Nuclear Energy Research (INER), Taiwan. It embraces the basic features of the dynamic TAIGEM model with several important extensions that distinguish it from its predecessors. These include 1) detailed specification of major new and renewable energies, such as bio-ethanol, bio-diesel, solar photovoltaic (PV) products, wind power equipment, PV power equipment, SIGCC (sustainable integrated-gasified combined cycle) equipment, etc.; 2) inclusion of PV generation technology, wind power technology, and SIGCC technology in the power generation technology mix; 3) taking into account the learning effect that exists especially for new and renewable energy sectors and specifying functions that link cumulative production with total factor productivity; and 4) econometrically estimation of some of the key parameter values in the model. In addition to the above, when generating benchmark solutions, GEMEET also makes use of some of the important technology information, especially the power generation technology information, from the Taiwan MARKAL model.[2] This has greatly reduced the possibility of generating unrealistic production results in the power sector (Lin et al., 2009).

Following Miketa and Schrattenholzer (2004), Klaassen and Miketa (2002), Kobos (2002a, b, c), Criqui et al. (2000), Kouvaritakis et al. (2000), Cory et al. (1999) and others, GEMEET explicitly incorporates R&D expenditures into a two-factor experience curve.

## 4. Scenario simulation and analysis

### 4.1 Scenario design

In this paper, three scenarios have been specified and simulated. They are (all with a crowding out of other government expenditures):

(1) RD20 – Government invests a total of 60 billion NT$ between 2010 and 2020 for renewable energy technology development.

(2) RD30 -- Government invests a total of 220 billion NT$ between 2010 and 2030 for renewable energy technology development.

(3) RD30_LAG – Same as RD30, but the effect of R&D investment on productivity growth will take effect three years after the investment.

### 4.2 Simulation results and analysis

Our simulation results are shown in Figures 2 to 6. Figure 2 indicates that shifting the original government expenditure to new and renewable energy development will generate positive effects for real GDP. Figure 3 reveals that the investment multipliers (defined as the additional GDP created per one dollar of R&D investment) for different scenarios are between 5 and 8, suggesting that investing in new and renewable energy technology development should be repaid well in the long term.

With respect to the environmental benefit of R&D in renewables, as shown in Figure 4, might not be so significant, suggesting that renewable energy may not be the sole solution to CO2 emission reduction. Other measures or incentives are required to

[2] See Ko et al. (2008) for more detailed description of the model.

support a designated reduction scheme.

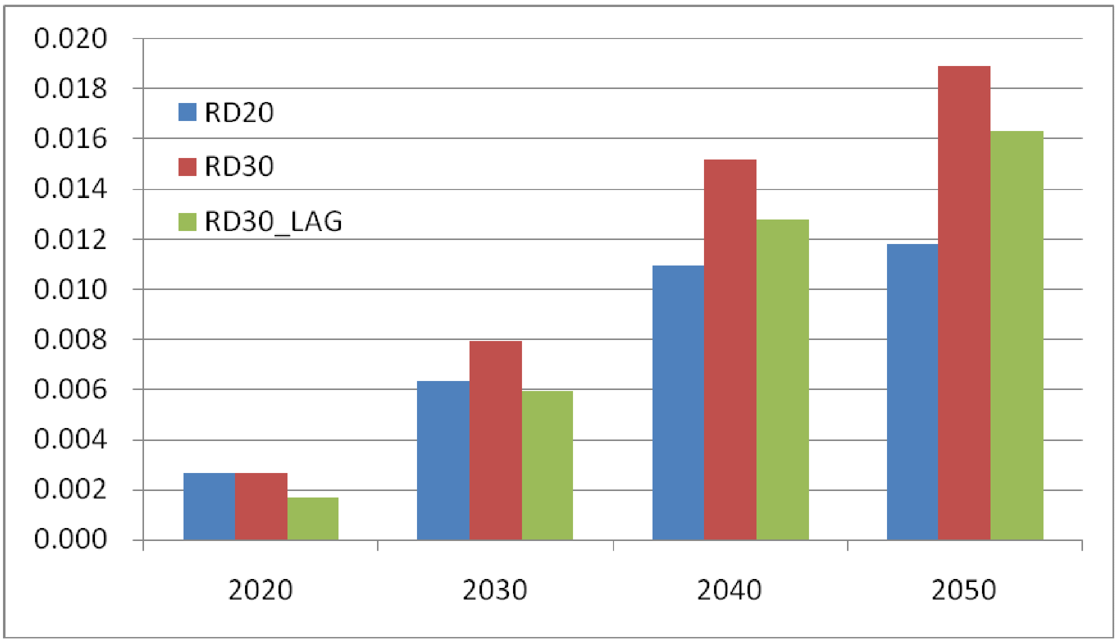


Figure 2. Real GDP change rate (relative to baseline)

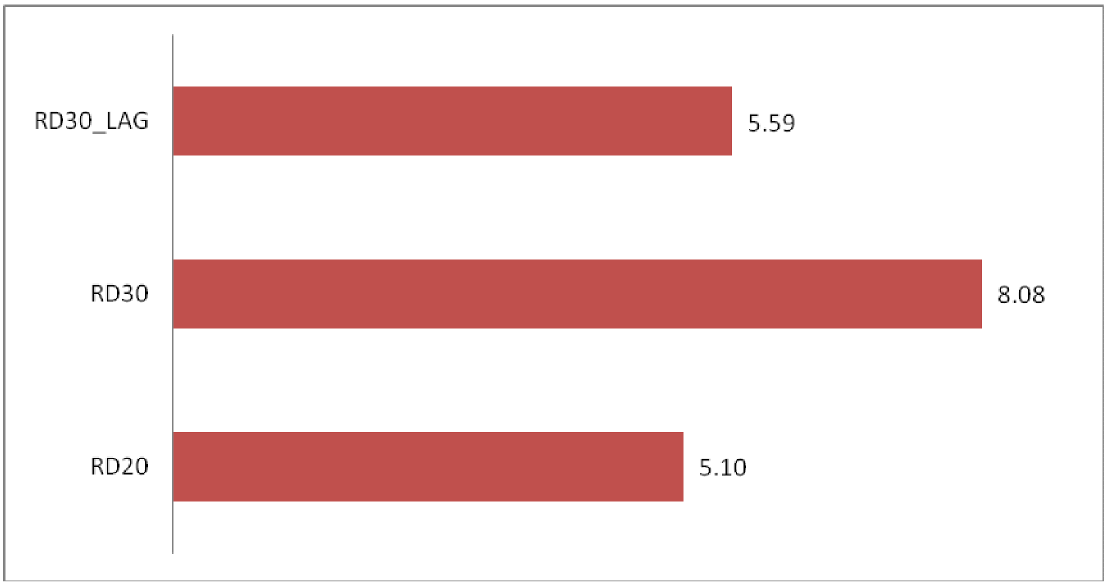


Figure 3. Investment multiplier under different scenarios


Figure 4. CO2 emission change rate (relative to baseline)

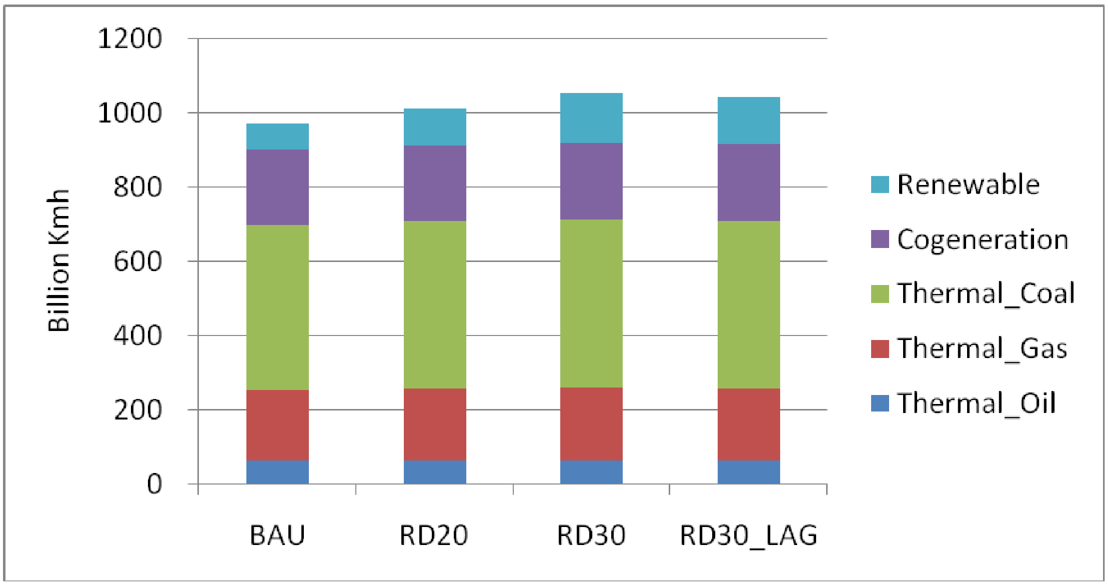


Figure 5. Changes in power generation mix between 2006 and 2050

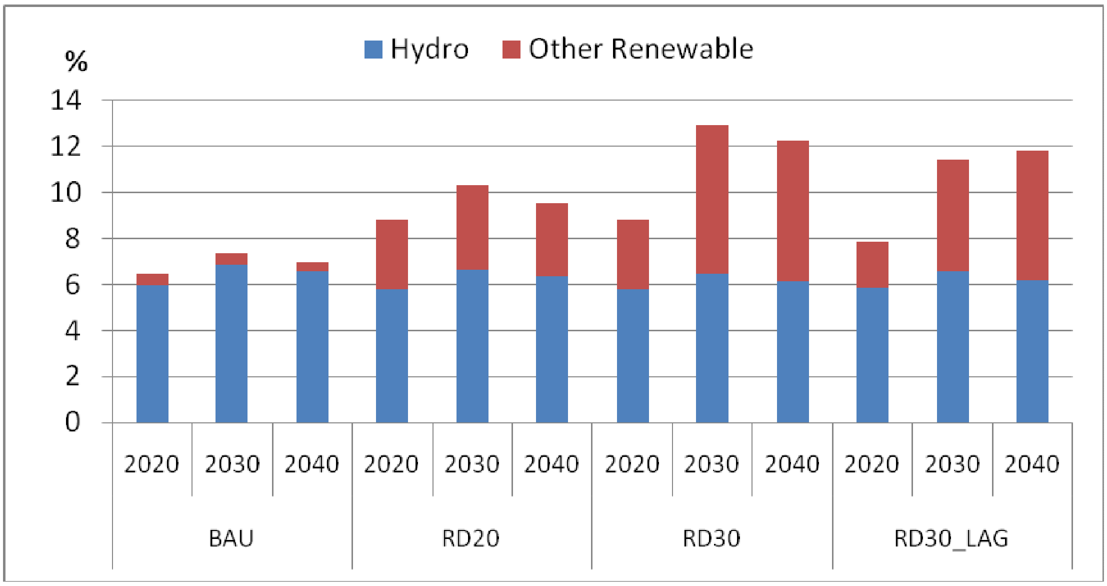


Figure 6. Share of renewable in power generation for selected years

## 5. Concluding remarks

Energy and environmental issues have become increasingly important over the past decade. Concerns over the security of fossil fuel supply have accelerated the pace of exploring alternative energies among major energy-consuming countries. This paper makes use of the newly developed top-down model GEMEET and refines the new-energy data and updates the input-output data based on the most recent input-output tables. In addition, we link the top-down model to the MARKAL energy-engineering model to take advantage of the strengths of both kinds of model. Cost and benefit analysis for the development of new and renewable energies as well as specific policy analyses based on the constructed integrated modeling system is then performed to justify the development of certain new and renewable energy technologies in Taiwan. Our analysis results indicate that with a reasonable level of R&D investment and technology learning process, new and renewable energy technology development is cost-effective and shall have positive environmental benefit. However, the environmental benefit of R&D in renewables might not be so significant, which suggests that renewable energy may not be the sole solution to $CO_2$ emission reduction. Other measures or incentives are required to support a designated reduction scheme

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**Shih-Mo Lin***
Center for Applied Economic Modeling
Chung Yuan Christian University
Chung-Li 32023
Taiwan
Fax: (+886)3-2655299
Email: shihmo@cycu.edu.tw
*Corresponding author

**Jin-Xu Lin**
Department of Economics
National Cheng-chi University
Taipei, Taiwan
Email: g1258503@nccu.edu.tw

**Han-Pan Su**
Department of International Trade
Chung Yuan Christian University
Chung-Li 32023
Taiwan
Email: hpsu@cycu.edu.tw

**Fu-Kuang Ko**
Institute of Nuclear Research
Lungtan, Taiwan
Email: fkko@iner.gov.tw

**Biographical notes:** Shih-Mo Lin is currently a Professor of the Department of International Trade at Chung Yuan Christian University, Taiwan. He is also the Director of Center for Applied Economic Modeling at CYCU. He received his PhD. in Energy Economic from West Virginia University in 1991, and spent 1 and a half years at Penn Sate University for post-doctoral research. His research interest includes energy modeling, computable general equilibrium modeling, input-output analysis, integrated modeling for bottom-up and top-down models, renewable energy development, etc.

Jin-Xu Lin is currently a Ph.D. candidate of the Department of Economics at National Cheng-chi University. He holds a Masters degree in International Trade from CYCU. His doctoral thesis topic has been centered on outsourcing, vertical integration and FDI among Asian economies.

Han-Pang Su is currently an Assistant Professor of the Department of International Trade at CYCU. He received his Ph.D. from National Taiwan University in 2005. His research interest includes public finance, economic modeling and econometrics.

Fu-Kuang Ko is currently an Associate Research Fellow at the Institute of Nuclear Research, Taiwan. He holds a Masters degree in Nuclear Engineering from National Tsing Hua University, Taiwan. He has been in charge of the development of the Taiwan MARKAL model since 2005.