Evaluations of Efficiency Investments in Taiwan – Applications with an Integrated Model for Energy, Economic, and Environmental Analysis

Yi-Hua Wu[1,*] Chia-Hao Liu[1], Ming-Lung Hung[1], Tzu-Yar Liu[1], Toshihiko Masui[2]

Abstract

The promotion of energy efficiency investments has been an important strategy to reduce energy demand and carbon emissions. Through investments in energy efficiency, more efficient machines, motors, vehicles are applied for production, transportation, and farming. A new investment in energy efficiency might produce the same level of output using less energy. In addition to energy reduction, the sectoral investments boost up not only its output growth but also demand for other commodity and service – such as steel, transportation, and wholesale service. Economic growth, therefore, might perk up due to energy efficiency investments. Numerous studies in the literature have found that the improvements of energy efficiency not only reduce energy demand but also enhance the economic growth. However, most papers adopt either top-down or bottom-up approach to investigate the issue of energy efficiency improvement.

In this paper we adopt the integration of these two approaches – a soft-link procedure between Asia-Pacific Integrated Model/Computable General Equilibrium (AIM/CGE) for Taiwan (top-down) and Taiwan 2050 Calculator (bottom-up) labeled as Taiwan Integrated Sustainable MOdel (TISMO) – to study the impacts of energy efficiency investments. Our contributions are as follows: (1) We provide evidence that investments in energy efficiency not only reduce energy demand and CO_2 emissions, but also spur economic growth. (2) Even though the energy efficiency improvements bring multiple benefits, the subsidies on energy efficiency investments crowd out private consumption. We propose that the government could adjust its fiscal policy by lowering its expenditure; therefore, the crowding-out effects on consumption could be mitigated. (3) We propose a new strategy, the Bayesian technique, to estimate the elasticity parameters of a CGE model. Such an estimation strategy combines the prior as well as data information; therefore, we can shrink the elasticity toward a reasonable parameter space. (4) The hybrid of bottom-up and top-down models for the investigation of energy efficiency investments, to our knowledge, is relatively scant in the literature. A hybrid model such as TISMO could provide more insights for the energy efficiency improvements.

Keywords: AIM/CGE; Taiwan 2050 Calculator; Energy Efficiency Investments; TISMO; Taiwan

1. Industrial Technology Research Institute, 195, Sec. 4, Chung Hsing Rd., Chutung, Hsinchu, Taiwan 31057, R.O.C.
2. Center for Social and Environmental Systems Research, National Institute for Environmental Studies (NIES), 16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan.
*: Corresponding Author, itriA00031@itri.org.tw. Telephone: +886-35915438.

1. Introductions

The United Nations Framework Convention on Climate Change (UNFCCC) launched the 21st Conference of the Parties (COP21) in Paris in 2015 with the purpose of tackling the problem of climate change. The conclusions of COP21 proposed that global temperature in this century should not rise 2 degrees Celsius above pre-industrial levels. Together with global efforts, Taiwan set an ambitious goal to reduce greenhouse gas (GHG) emissions. In order to share the responsibility to combat global warming, Taiwan announced its Nationally Determined Contributions (NDCs) to reduce its GHG emissions in 2030 by 50% from the business-as-usual (BaU) level of 428 million tonnes of CO_2 equivalent (Mt CO_2e) to 214 Mt CO_2e. Several strategies have been proposed in order to achieve the NDC target, such as 20% of power generation from renewables in 2025, carbon trading system, and energy demand saving plan. The energy efficiency improvement, therefore, could be one of the strategies to achieve the NDC goal.

The improvements of energy efficiency have been an important strategy to reduce energy demand and carbon emissions. The energy efficiency investments are the key factors to enhance energy efficiency. The government of Taiwan has subsidized purchase of high-efficient electronic devices such as pumps, motors and freezers in 2015, 2016 and 2017.[1] Through investments in energy efficiency, more efficient machines, motors, vehicles are applied for production, transportation, and farming. A new investment might produce the same level of output using less energy. In addition to energy reduction, a new investment of a sector boosts not only its output growth but also demand for other commodity and service – such as steel, transportation, and wholesale service. Economic growth, therefore, might perk up due to energy efficiency investments. Numerous studies in the literature have found that investments in energy efficiency not only reduce energy demand but also enhance the economic growth. For example, International Energy Agency (IEA, 2012) proposes that investments in energy efficiency can raise asset price, improve health quality of employees, boost productivity, and provide safe working environment. Neves et al. (2008) suggest that the energy efficiency improvements can increase social welfare and create employment.

However, most papers in literature adopt either top-down or bottom-up approach to investigate

[1] See, for instance: http://www.ecct.org.tw/News/Show?id=5d6d47d177dd4e64be51b02e48890d1b; http://news.ltn.com.tw/news/business/breakingnews/1606143 (in Chinese).

the issue of investments in energy efficiency. The top-down approach, such as a computable general equilibrium (CGE) model, investigates the impacts of energy efficiency investments in the economy. The bottom-up approach, such as the 2050 Energy Calculator originated from Department of Energy and Climate Change (DECC) in the United Kingdom, considers the detail specifications on individual technology development, energy production activity and energy demand. In this paper we adopt the hybrid of these two approaches – a soft-link procedure between CGE and the 2050 Energy Calculator – to study this issue for Taiwan.

The CGE model in this paper, Asia-Pacific Integrated Model (AIM/CGE), was originally developed by National Institute for Environmental Studies (NIES) in Japan. NIES collaborated with Kyoto University for the development of AIM in 1991. The major modules of the AIM model were completed after three years. In 1994, the project expanded with an international collaborative program to jointly develop national models with leading research institutes in several Asian countries. These national models then integrated with the regional and global models. This collaboration program extended for a further three years from 1997 and expanded to provide more detail evaluations on a broader range of impacts and policy options. In 2015, Industrial Technology Research Institute (ITRI) in Taiwan collaborated with NIES to build AIM/CGE for Taiwan. Such a model considers consumers, producers, government policy, and foreign trade, using local data and the official projections for the scenario settings. AIM/CGE for Taiwan is based upon a small open economy framework and suitable for economic analysis.

2050 Energy Calculator is a generic simulation model built by DECC. The purpose of 2050 Energy Calculator is to provide a decision making tool for energy policy. DECC launched the U.K. 2050 Calculator in 2010. Since then many countries including Australia, Belgium, China, India, Indonesia, Japan, Mexico, South Africa, South Korea, Taiwan, Thailand and Vietnam have developed 2050 Calculators following the footstep of the DECC. The Calculator – a model based upon Microsoft Excel (MS-Excel) and open to the public – allows a user to input their scenarios for energy demand and supply; in addition, it also simulates how the scenario settings affect the GHG emissions. The Calculator is based on an energy-balancing model, which uses a number of sectoral projections to calculate possible energy pathways to 2050. The model helps a user to understand what type of technology to use, and what kind of changes is needed in 2050 in order to reduce emissions.

ITRI devotes a lot of efforts to construct the hybrid of AIM/CGE for Taiwan and Taiwan 2050

Calculator. Such a hybrid model – labeled as Taiwan Integrated Sustainable MOdel (TISMO) – adopts a soft-link procedure between top-down and bottom-up approaches. National Development Council in Taiwan announced future economic outlook and population up to 2025. The hybrid of Taiwan 2050 Calculator and AIM/CGE for Taiwan is based upon the same economic and population projections. Not only Taiwan 2050 Calculator adopts official projections of GDP growth and sectoral value added as business as usual (BaU), but also AIM/CGE for Taiwan is calibrated to these projections. The energy analysis relies on Taiwan 2050 Calculator and simulation of economic impacts counts on AIM/CGE for Taiwan. In the energy demand side, most sectors adopt the ambitious actions for efficiency improvements. We establish the supply side scenarios such that at least 20% of power supply is generated by renewable energy in 2025, consistent with the energy policy goal in Taiwan. Using this information as BaU, Taiwan 2050 Calculator simulates energy demand based upon the official projections of economic and population growths. Moreover, the energy supply mix ensures that energy demand is satisfied. Therefore, AIM/CGE Taiwan and Taiwan 2050 Calculator assume the same BaU scenarios for the analysis of energy efficiency investments.

The purpose of this paper is to investigate the effects of improvements on energy efficiency. Multiple benefits on energy, economy and environment (3E) emerge following such improvements. After the sectors switch from BaU (Level 2) to the very ambitious scenario (Level 3) to improve energy efficiency, the simulation of hybrid model indicates that energy demand drops, the CO_2 emissions reduces, and GDP grows. As a consequence, the energy efficiency improvements reduce energy demand, decrease CO_2 emissions, and increase GDP growth in Taiwan. However, higher subsidies on energy investments crowd out consumption. An appropriate scheme for the fiscal policy adjustment could mitigate the negative effects on consumption.

Our contributions to this field are as follows: (1) We provide evidence that energy efficiency improvements not only reduce energy demand and CO_2 emissions, but also spur economic growth. Such findings are consistent with previous findings in the literature and reconfirm the importance of energy efficiency improvements. The promotion of energy efficiency, therefore, is one important strategy for carbon reduction. (2) Even though the energy efficiency improvements bring multiple benefits, the subsidies on energy efficiency investments crowd out private consumption. To maintain the fiscal budget balance, the lower government transfer to household reduces consumption. The crowding out effect is similar to Leeper et al. (2010a) – they find that the U.S.

government spending crowds out private consumption.[2] Galí et al. (2007) argues that an increase in government purchases could be financed by current or future lump-sum taxes. The higher tax induces a negative wealth effect which is reflected in lower consumption. We propose that the government could adjust its fiscal policy by lowering its expenditure; therefore, the crowding-out effects on consumption are mitigated. The literature does not emphasize the costs or burdens of more investments in energy efficiency. The side effects could be useful references for a policy decision. (3) We propose a new strategy to estimate the elasticity parameters of a CGE model. In the literature, Go et al (2016), Jorgenson and Yun (2013), Jorgenson (2011), and Arndt et al. (2002) have estimated parameters in a CGE model. The elasticity values are crucial to determine the simulation results. We adopt the Bayesian technique, which is widely applied for a dynamic stochastic general equilibrium (DSGE) model, for the estimation of CGE elasticity. Conditional on the structural equations of CGE model, we estimate the elasticity values using Taiwan's times series data. The Bayesian estimation combines the prior information as well as data property; therefore, we can shrink the elasticity parameters toward a reasonable parameter space. Our results are robust to alternative elasticity values. (4) The hybrid of bottom-up and top-down models for the investigation of energy efficiency investments, to our knowledge, is relatively scant in the literature.[3] We propose a new soft-link procedure to integrate the top-down and bottom-up models. TISMO possesses the advantage of economic analysis as well as energy policy simulation. Therefore, a hybrid model could provide more insights for the energy efficiency improvements. Despite of multiple benefits from energy efficiency investments, how to induce private investments in energy efficiency is essential to succeed.

The remainder of this paper is structured as follows. The next section provides a survey of literature reviews. Section 3 shows the model specifications. Section 4 presents scenario settings and simulation results. Section 5 discusses our findings and policy implications. The final section concludes.

2. Literature Reviews

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[2] Leeper et al. (2010b) and Bouakez et al. (2017) propose the crowding out effect of fiscal expansion on consumption.

[3] Barker et al. (2007) and Barker et al. (2009) adopt a top-down model with a submodel less detailed than bottom-up. Their models, therefore, are closer to top-down approach with partial extend to a bottom-up model.

The energy efficiency improvement/investment is an important strategy to reduce energy demand. There are numerous studies in the literature investigating the importance of energy efficiency. We summarize previous findings in the literature in order to illustrate the importance of energy efficiency improvements.

Table 1 offers a survey for the previous studies on energy efficiency improvement/investment. The literature has emphasized the multiple benefits from the improvement of energy efficiency. Allan et al. (2007) propose that the energy production sector in the United Kingdom improves the energy efficiency during 2000-2020. The higher energy efficiency has positive effects on GDP, consumption, export, and employment both in the short run and long run. Investments and imports, however, fall in the short run but increase in the long run. Barker et al. (2009) find that current and committed energy efficiency policy can increase global GDP by 0.28% in 2030. Barker et al. (2007) show that the energy efficiency policy in the United Kingdom increases GDP by 0.1% and decreases prices by 3% during 2000-2010. As shown by Bataille and Melton (2017), the improvement of energy efficiency in Canada during 2002-2012 significantly increases GDP, employment, and welfare. Grepperud and Rasmussen (2004) argue that the energy productivity in Norway improves during 1992-2050 and such an improvement has positive effects on industrial sectors. Hanley et al. (2006) find that the energy efficiency of energy production sectors in Scotland improves 5% during 1999-2050. The energy efficiency improvement triggers economic growths in Scotland in the short run and long run. IEA (2012) proposes that the improvement of energy efficiency has multiple effects on health, asset values, and safety conditions. Lilly and Pearson (1999) suggest that higher energy efficiency reduces air emissions, wear and tear, and operation maintenance expenses. Neves et al. (2008) claim that energy efficiency initiates welfare improvements and has positive effects on other resources. Mills et al. (2008) also find that the higher energy efficiency not only improves productivity, process control, and reliability, but also reduces operation and maintenance costs. The proposition of Rasmussen (2017) shows that energy efficiency investments could be more attractive with the elaboration of non-energy benefits. Skumatz et al. (2000) propose that the improvement of energy efficiency has multiple positive effects, such as lower costs, higher air quality and fewer water loses. In the study of Vikström (2008), the energy efficiency improvements of all sectors in Switzerland increases GDP during 1957-1962.

As a consequence, the literature has emphasized the importance of energy efficiency improvements or the energy efficiency investments. Such efficiency improvements bring multiple benefits, such as high economic growth, lower production costs, and fewer CO_2 emissions. The promotion of energy efficiency investments, in particular, is one of the key strategies to improve energy efficiency. The literature, however, adopts either top-down or bottom-up approach to investigate the energy efficiency. As mentioned in the previous section, the top-down model has advantage of economic analysis while the bottom-up model has detail specifications on technology, efficiency, and energy flows. We, therefore, formulate a hybrid procedure to integrate bottom-up and top-down models for the analysis of energy efficiency investments.

Table 1: Previous Studies on Benefits of Energy Efficiency Improvement/Investment

Studies	Findings	Methodology
Allan et al. (2007)	Energy efficiency of energy production sector improves 5% in the United Kingdom during 2000-2020: Short run: GDP +0.11%, consumption +0.06%, investment -0.03%, export -0.23%, import -0.27%, and employment+0.20%. Long run: GDP +0.17%, consumption +0.14%, investment +0.21%, export +0.21%, import +0.23%, and employment +0.21%.	Top down
Barker et al. (2009)	Current and committed energy efficiency policy can increase global GDP by 0.28% in 2030.	Top-down with an energy submodel less detailed than bottom-up
Barker et al. (2007)	The energy efficiency policy in the United Kingdom increases GDP by 0.1% and decreases prices by 3% during 2000-2010.	Top-down with an energy submodel less detailed than bottom-up
Bataille and Melton (2017)	During 2002-2012, the improvement of energy efficiency in Canada significantly increases GDP, employment, and welfare: GDP +2% (annual growth 0.19%), employment 2.5% (annual growth 0.24%), and household welfare 1.5% (annual growth 0.15%).	Top-down
Grepperud and Rasmussen (2004)	The growth rate of energy productivity in Norway doubles relative to baseline during 1992-2050: Pulp and paper +11.3%, metals +31.9%, chemicals & minerals +4.1%, finance & insurance +0.3%, fisheries +2.1%, and road transport +1.9%.	Top-down
Hanley et al. (2006)	Energy efficiency of energy production sectors in Scotland improves 5% during 1999-2050:	Top-down

Studies	Findings	Methodology
	Short run: GDP +0.06%, consumption +0.19%, investment +0.29%, export +0.21%, export +0.03%, and unemployment -0.83%. Long run: GDP +0.88%, consumption +0.79%, investment +1.03%, export +0.96%, import +0.28%, and unemployment 0%.	
IEA(2012)	Improved health, increased asset values, industrial productivity, safer working conditions, improved quality, reduced capital & operating costs, reduced scrap & energy use, and improved competitiveness.	Survey
Lilly and Pearson (1999)	Extended life of equipment, reduced air emissions & related fines, reduced wear & tear, and reduced operation & maintenance expenses.	Top-down
Neves et al. (2008)	Energy efficiency initiates welfare improvements and has positive effects on other resources, such as water supply and employment creation.	Bottom-up
Mills et al. (2008)	Improve productivity, improve process control, enhance reliability, and reduce operation & maintenance costs.	Bottom-up
Rasmussen (2017)	Including non-energy benefits in the investment process can make energy efficiency investments more attractive and increase their priority against other investments. Moreover, non-energy benefits can reinforce drivers as well as counterbalance known barriers to energy efficiency investments.	Survey
Skumatz et al. (2000)	Improved lighting, safety/security, lower maintenance, improved work environment, better aesthetics, reduced glare/eyestrain, improved productivity, better control, longer equipment lifetimes, greater comfort, improved air quality, higher tenant satisfaction, environmental benefits, reduced water losses and bills, improved efficiency, more efficient water use, labor savings, reduced noise, and improved temperature control.	Bottom-up
Vikström (2008)	Energy efficiency of all sectors in Switzerland increases 12-15% in 1957-1962. During this period GDP increases 0.5% and average annual growth is 0.1%.	Top-down

Source: Bataille and Melton (2017) and Rasmussen (2017)

3. Model Specifications

In this section we illustrate framework of AIM/CGE for Taiwan and Taiwan 2050 Calculator, respectively. The details such as model specifications, parameter calibration and elasticity estimation are described in Appendix for reference.

3.1 AIM/CGE for Taiwan

The CGE model is able to simulate the full range of interaction and feedback between different agents in the economic system. Such a model framework has been widely used to assess the economic and environmental impacts of various climate policies at global and national levels. Böhringer and Löschel (2005) and Fujimori et al. (2014), for instance, adopt CGE framework for the application to the global issue. See Zhang (1996) and Ke et al. (2009) for the CGE study on national level and Dai (2012) for regional issues.

We collect data from multiple sources. The following data are gathered from Directorate-General of Budget, Accounting and Statistics, Executive Yuan in Taiwan: the 2011 input-output (IO) table, times series data for sectoral value added and population. The official projections of population, GDP growth, and sectoral value added come from National Development Council. Bureau of Energy, Ministry of Economic Affairs offers the 2011 energy balance table. AIM/CGE for Taiwan in this paper contains 39 sectors. The sectoral export and import data with foreign countries are gathered from Bureau of Foreign Trade, Ministry of Economic Affairs. The sectoral classifications are shown in Table A 1, Appendix.

Figure 1 sketches the structure of AIM/CGE for Taiwan. Capital, labor, and intermediate goods are adopted to produce gross output. Gross output is then distributed to exports and domestic goods. The import and domestic goods constitute the composite goods. The composite goods is distributed to consumption, investment, government expenditure, and intermediate inputs. The CGE model is solved by Mathematical Programming System for General Equilibrium under General Algebraic Modeling System (GAMS/MPSGE) at a one-year time step.[4] We show the detail specifications of AIM/CGE for Taiwan, such as model specifications, parameter calibration and elasticity estimation in Appendix.

We propose a new strategy to estimate the elasticity parameters of a CGE model. The Bayesian technique, which is widely applied for a DSGE model, could be a useful strategy for the estimation

[4] See Rutherford (1999) for details.

of CGE elasticity. We log-linearize particular structural equations of CGE model, using subjective setups on prior distributions and the Kalmen filter to update the likelihood function. The Bayesian estimation combines the prior as well as data information; therefore, we can shrink the elasticity parameters toward a reasonable parameter space. The technical details of Bayesian estimation for elasticity parameters are shown in Appendix.

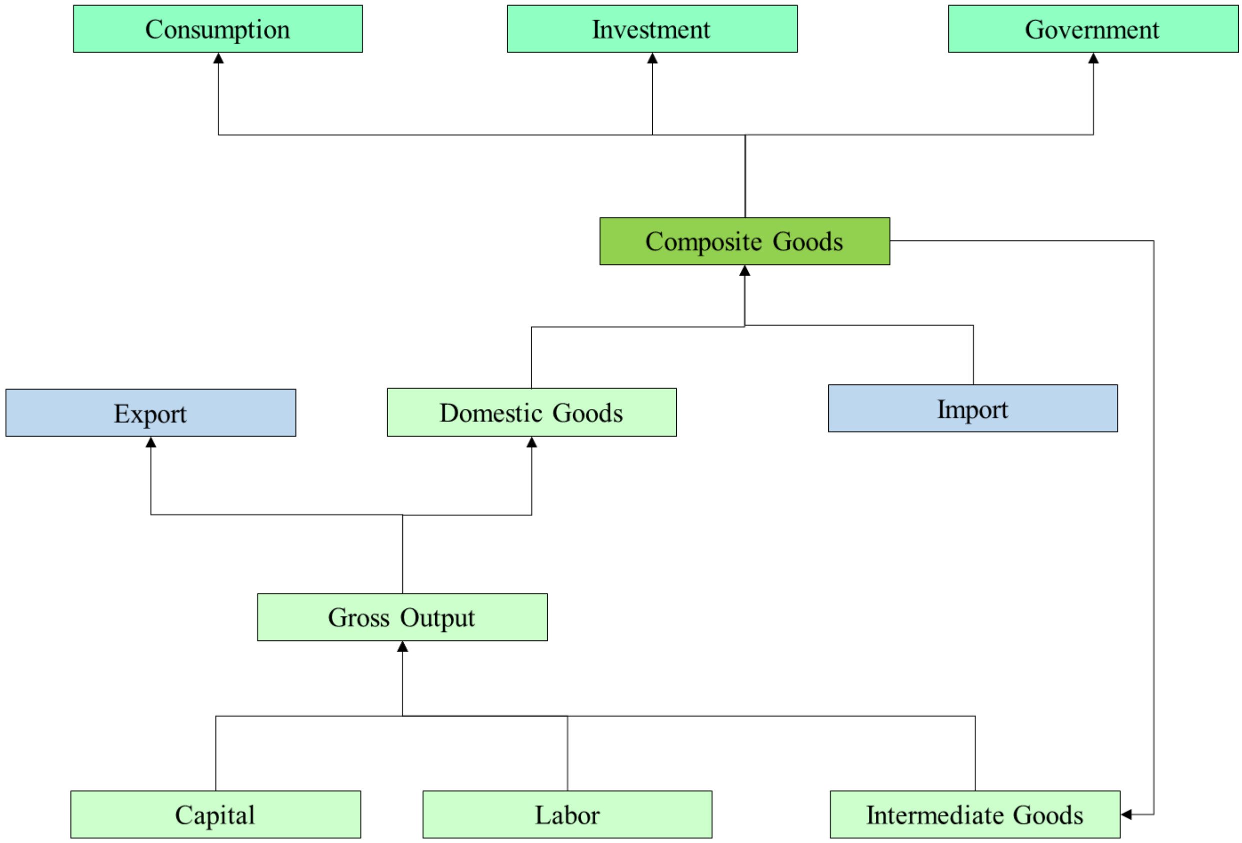


Figure 1: The Structure of AIM/CGE for Taiwan

3.2 Taiwan 2050 Calculator

This subsection demonstrates the structure of Taiwan 2050 Calculator. Appendix offers a description for the construction history of Taiwan 2050 Calculator. The scenario options and framework of Taiwan 2050 Calculator are shown as follows.

3.2.1 Scenarios of Taiwan 2050 Calculator

Based upon the economic and population assumptions, Taiwan 2050 Calculator offers scenario options for energy service demand, energy supply, energy demand, residential, service sector, industrial, transportation and other sectors. The scenario options allow a user to choose assumptions on technology progress, energy efficiency and power generation mix. These assumptions are constructed according to energy expertise in Taiwan. To ensure that subjective views of a user could be fully reflected in available options, Taiwan 2050 Calculator provides at most four levels of scenario options for individual setting. Several workshops took place to ensure the level settings are reasonable according to Taiwan's potentials.[5] Therefore, the scenario settings in Taiwan 2050 Calculator are reasonable according to expertise.

Table 2 describes the general meanings of level options in Taiwan 2050 Calculator. As the level advances from 1 to 4, the efforts to improve energy efficiency become stronger and policy enforcement is stringent. A user inputs the preferred level in the Control Panel of MS-Excel and Taiwan 2050 Calculator simulates the results according to the settings. Similar to the 2050 Calculator of the United Kingdom, Level 1 indicates that there is little or no attempt to take action on decarburization. If a scenario of this level is related to policy, an official strategy devotes scant resources for carbon reduction. In addition, advanced technologies for low carbon society are neither developed nor deployed in such a level. Level 2 – which extends the decarbonization activity, policy enforcement, and energy efficiency in Level 1 – describes the ambitious scenario that most or all experts believe to be reasonably achievable. This level could be reached by successful implementation of the programs or projects in progress. Level 3, furthermore, requires significant breakthroughs in technology. This very ambiguous scenario could not be achieved without significant changes from the current system. The challenge to achieve this level, therefore, is larger than Level 3. Scenarios in Level 4 approach the physical or technical limits. Further extension beyond this level might not be physically possible. In the views of most or all experts, this heroic level might be extremely hard to achieve.

[5] Please refer to Appendix for the contributions of expertise to the construction of Taiwan 2050 Calculator.

Table 2: General Descriptions for Scenarios of Taiwan 2050 Calculator

Level	Brief Meaning	Description
1	Little or No Attempt	Level 1 indicates that little or no attempt to take action on decarbonization. A policy devotes scant resources for carbon reduction. In addition, advanced technologies for low carbon society are neither developed nor deployed in such a level.
2	Ambitious	Level 2 – which extends the decarbonization activity, policy enforcement, and energy efficiency in Level 1 – describes the ambitious scenario that most or all experts believe to be reasonably achievable. This level could be reached by successful implementation of the current programs or projects in progress
3	Very Ambitious	Level 3 requires significant breakthroughs in technology. This scenario could not be achieved without significant changes from the current system. The challenge to achieve this level, therefore, is more difficult than Level 3.
4	Heroic	Level 4 approaches the physical or technical limits. Further extension beyond this level might not be physically possible. In the view of most or all experts, this heroic level might be extremely hard to achieve.

Table 3 demonstrates the scenario options of Taiwan 2050 Calculator for a user. The scenario options, with the maximum four levels of settings described in Table 2, offer a user to alter the assumption according to one’s subjective views. For example, a user can change the power supply scenario. Taiwan 2050 Calculator can simulate the future pathway following such a change. The scenario options with hyphen (-) indicates that a user can not change this level directly in the Control Panel. One must set up the alternative values in the corresponding worksheet.

The global variables provide options to choose GDP and industrial growths. The future economic trend is a key factor to determine energy demand. If a user prefers that the future trend of economic growth is expected to be higher than the default value, one can input the updated information in the appropriate worksheet of MS-Excel.

We have several options to choose the energy supply scenarios, such as installed capacity of coal-fired, cogeneration, and nuclear power. The storage capacity of natural gas, in addition, is also an option for a user. Taiwan 2050 Calculator also provides options for detail specifications on the renewable energy. For example, a user can choose subjective scenarios for onshore wind, offshore wind, and solar PV. Geothermal, which is not matured nowadays in Taiwan, might be an option in the future. Therefore, a user could easily choose the level that corresponds to subjective views.

There are several sectors in Taiwan 2050 Calculator: residential, service, industrial, transportation, and other sectors. Taiwan 2050 Calculator offers multiple options for the setting of energy demand. To be more specific, a user can choose the detail settings for energy efficiency, energy saving rate, and thermal insulation for each sector. If a user sets a level higher than the BaU scenario, Taiwan 2050 Calculator will simulate the effects of such a change. After the simulation, a user can compare the amount of energy changes from a BaU scenario to a new one.

Table 3: The Scenario Options of Taiwan 2050 Calculator

Field	Scenario module	Scenario Options	BaU
Economic Assumptions and Energy Service Demand			
Global Variables	Economic Assumption	GDP Growth	-
		Industrial Growth	-
	Energy Service Demand for Residential Sector		-
	Energy Service Demand for Service Sector		-
	Energy Service Demand for Industrial Sector		-
Energy Supply			
Fossil Fuel Production	Oil Refinery		-
	Coal Refinery, and Shaft Furnace		-
	Self-Produced Natural Gas		-
Thermal Power	Coal-Fired Power	Coal-Fired Power	1
	Gas-Fired Power	Storage Capacity of Natural Gas	4
	Oil-Fired Power		-
	CCS		1
Cogeneration	Cogeneration Power	Cogeneration Power	1
Nuclear Power	Nuclear Power	Nuclear Power	2
Renewable	Wind Power	Onshore Wind	3
		Offshore Wind	4
	Hydro Power		-
	Wave Power	Wave Power	1
	Ocean Current Power	Ocean Current Power	1
	Ocean Thermal Power	Ocean Thermal Power	1
	PV Solar	PV Solar	4

Field	Scenario module	Scenario Options	BaU
	Biomass and Waste	Biomass and Waste	4
	Geothermal	Geothermal	3
Hydrogen and Fuel Cell	Hydrogen		-
	Fuel Cell	Fuel Cell	2
	Residential and Service Sectors		
Residential Sector	Air Conditioning	Thermal Insulation in Buildings	2
		Energy Efficiency	2
	Illumination	Efficiency	2
	Others	Other Electric Devices	2
	Building Energy Management	Residential/Service Energy Saving	2
Service Sector	Air Conditioning	Thermal Insulation in Buildings	2
		Energy Efficiency	2
	Illumination	Efficiency	2
	Others	Other Electric Devices	2
	Building Energy Management	Residential/Service Energy Saving	2
	Industrial Sectors		
	Industrial CCS	Industrial CCS	2
	Semiconductor	Energy Efficiency	2
	Steel	Energy Efficiency	2
	Chemical	Energy Efficiency	2
	Others (Cement, Paper, Fiber, and Medal)	Energy Efficiency	2
	Non-Energy Use		-
	Export of Petroleum Products		-
	Transportation Sectors		
Domestic Transportation	Road Transportation	Public Transportation Rate	A*
		Share of Low Carbon Vehicle	2
		Share of Biomass Energy	2
	Other Transportation		-
	Others		
Import Balance	Balance of Fossil Energy Import		-

Field	Scenario module	Scenario Options	BaU
	Balance of Biomass Import		-
Electricity System	Electricity Import		-
	Power Grid and System		-
	Storage and Demand Management		-

Note: - indicates that a user can not directly change the Control Panel. One must fill in the alternative values in the appropriate worksheet of MS-Excel.

* indicates that there are two options – options A or B – for a user to choose. Through this paper we choose option A for the public transportation rate.

3.2.2 The Framework of Taiwan 2050 Calculator

The execution of Taiwan 2050 Calculator is based upon MS-Excel. Figure 2 depicts the framework of Taiwan 2050 Calculator. Future economic growth and sectoral movements are drivers for future energy demand; therefore, Taiwan 2050 are based upon these economic factors to infer future energy growth. When the economy stimulates during a boom period, more energy – such as coal, gas, and oil – is used to trigger economic activity. In addition, energy demand is related to population and fuel price. We adopt the population projections announced by National Development Council of Taiwan. In addition, because Taiwan imports most energy from abroad, the energy prices are closely related to the world price movements. We use a linear regression model to infer the relationship between Taiwan's energy prices and global energy prices. Based upon the projections of global energy prices from Energy Information Agency (EIA), we infer the future energy prices of Taiwan.

In the Control Panel, a user can set four levels of scenarios for energy demand and supply. The Control Panel locates in one worksheet of MS-Excel. One can easily set up the scenario level and simulate the results quickly. Given the economic information and population trend, the demand side settings – such as energy efficiency, technology progress, cooling temperature, and thermal insulation efficiency – determine the energy demand for Taiwan.

A user can choose Levels 1 to 4 for the specifications on the energy supply side, such as install capacity of power generation and renewable energy. For example, Levels 3 or 4 for the solar PV and onshore wind power is necessary to achieve the target of 20% power generation from renewable energy. Carbon capture and storage (CCS) could be an option for the future.

Taiwan 2050 Calculator also simulates whether the energy supply could satisfy energy demand. The subjective settings of a user might not necessarily ensure the energy demand could be fulfilled. For instance, if the nuclear power is phased out without supports of renewable energy, the energy demand could exceed energy supply. A warning message is provided if energy supply is lower than energy demand. The energy supply and demand balance in our analytical results.

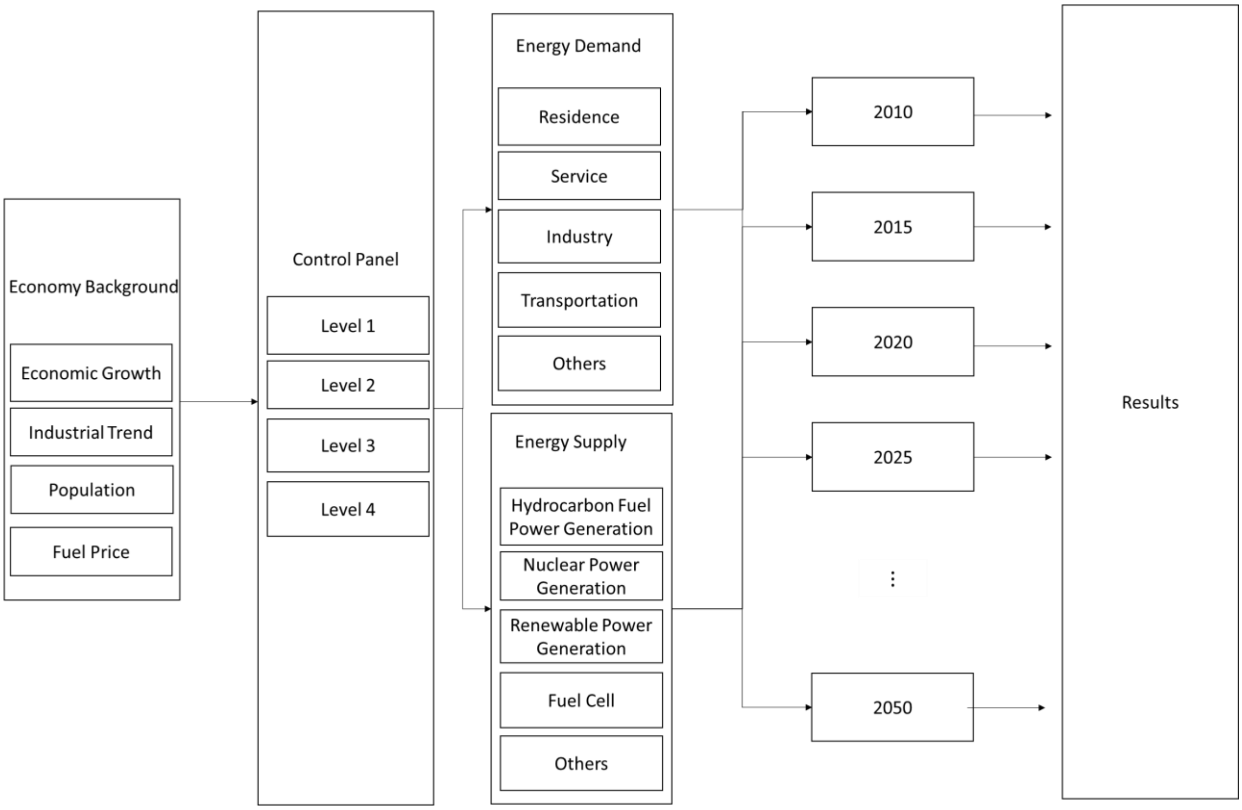


Figure 2: The Framework of Taiwan 2050 Calculator

3.3 The Soft-Link Between AIM/CGE and Taiwan 2050 Calculator

This subsection describes the soft-link strategy between AIM/CGE for Taiwan (top-down) and Taiwan 2050 Calculator (bottom-up). CGE model is constructed according to the IO table and this approach has advantage of economic analysis. Taiwan 2050 Calculator, in contrast, has an advantage over a CGE model in terms of energy analysis. The analytical capability of energy issues, such as energy efficiency and technology progress, have been key features of Taiwan 2050 Calculator. The connection between top-down and bottom-up models could provide more comprehensive implications for energy efficiency investments.

We propose a procedure for the soft-link between AIM/CGE and 2050 Calculator. There are four steps for the integration between the top-down and bottom-up models.

Step 1: Taiwan 2050 Calculator not only adopts the official projection of future GDP and sectoral trends, but also assumes the scenarios in Table 3 as BaU. In addition, the future pathway of AIM/CGE for Taiwan is calibrated to the official economic projections.

Step 2: After the simulation of BaU in Step 1, the energy demand for target sectors shifts to Level 3 and Taiwan 2050 Calculator simulates the energy efficiency investments in the new scenario. The extra investments for energy efficiency improvements transmit to AIM/CGE for the simulation of economic impacts.

Step 3: Taiwan 2050 Calculator resets its GDP and sectoral trends according to economic impacts simulated by AIM/CGE in Step 2. With the adjustment to the new economic scenario, Taiwan 2050 Calculator evaluates energy efficiency investments and energy system.

Step 4: With respect to the new set of energy efficiency investments in Step 3, AIM/CGE simulates the impacts on GDP growth and sectoral trends. If the difference of GDP between Steps 3 and 4 is less than 0.1%, we propose that the soft-link procedure converges. Otherwise the procedure returns to Step 3 until convergence.

Step 1 ensures that Taiwan 2050 Calculator and AIM/CGE for Taiwan are based upon the same economic condition for the further simulation. Step 2 simulates the energy efficiency investments when the sectoral energy demand shifts from Levels 2 to 3. AIM/CGE in Step 3 evaluates the initial economic effects of energy efficiency investments from Step 2; in addition, Taiwan 2050 Calculator simulates the extra investment triggered by the new economic effect. Step 4 simulates the economic effect of new investments using AIM/CGE. If the difference of GDP between Steps 3 and 4 is less than 0.1%, we claim that the top-down and bottom-up models have reached the same economic condition and there is no further force to deviate these two models. Otherwise, we should return to Step 3 with the new economic scenario until convergence occurs. Our integration simulation is efficient: it takes only one round from Steps 1 to 4 to reach convergence.

Technically, the extra investments simulated by Taiwan 2050 Calculator are exogenous information to AIM/CGE for Taiwan. In AIM/CGE, investments are endogenously determined. To evaluate the impacts of energy efficiency investments using AIM/CGE, capital stocks in particular sectors are exogenously determined to the new level. In addition, some exogenous variables must be endogenously determined such that the number of equations equal the number of endogenous variables. In this paper, we assume that the government subsidizes the energy efficiency investments. The sectoral subsidization rates become endogenous variables to AIM/CGE. Therefore, AIM/CGE could be solved for the analysis of energy efficiency investments.

Our purpose of this paper is to investigate the effects of sectoral energy efficiency improvements from the BaU of Level 2 to Level 3. Taiwan 2050 Calculator simulates the increments of energy efficiency investments between these two levels. In addition, AIM/CGE simulates the economic impacts of energy efficiency investments. With the convergence of Taiwan 2050 Calculator and AIM/CGE, we can simulate the 3E effects of energy efficiency improvements.

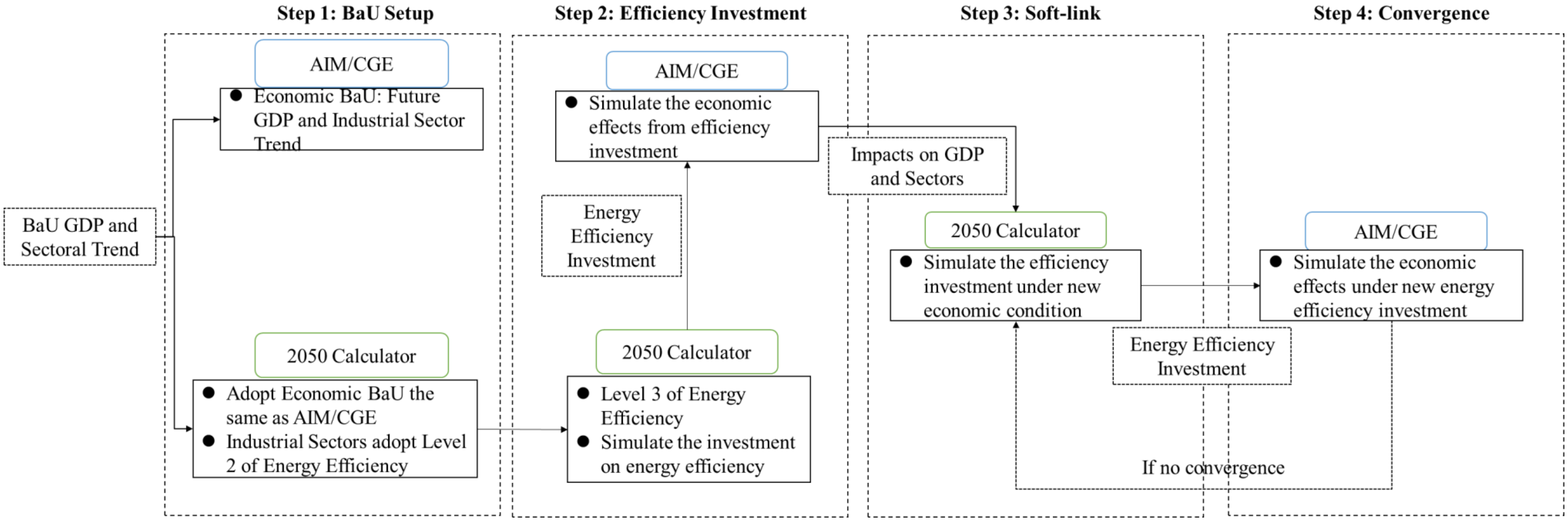


Figure 3: Procedure of Soft-Link Between AIM/CGE and 2050 Calculator

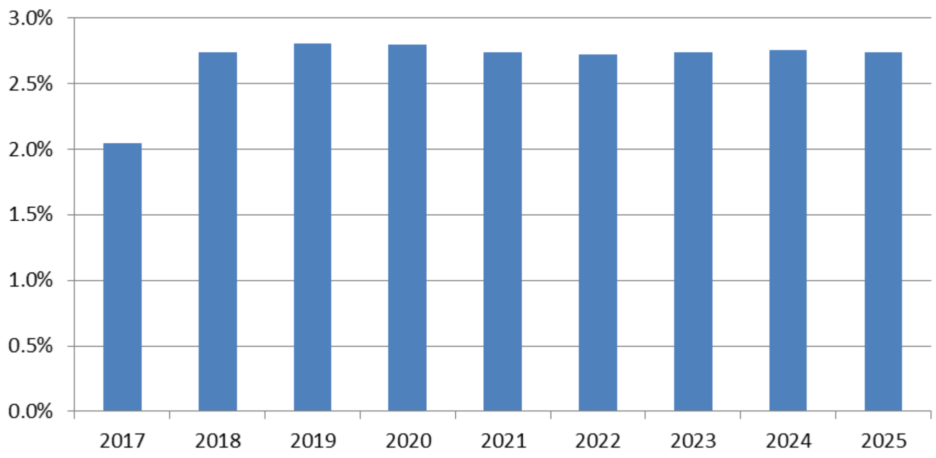
4. Scenarios and Simulation Results

This section shows the scenario setting and simulation results. The scenarios assume the future trend of economic growth and sectoral tendency. In addition, we demonstrate the scenarios for energy demand in Taiwan 2050 Calculator. Then we study the effects of energy efficiency improvements on economy, energy, and environment. Finally the sensitivity analysis shows that the simulation results are robust to elasticity of substitution.

4.1 Economic and Social Scenarios

4.1.1 Economic Growth

In 2017, National Development Council in Taiwan announced long run projections of GDP growth and sectoral value added. These economic projections are common assumptions for Taiwan 2050 Calculator and AIM/CGE for Taiwan. The future economic trend of these two models are based upon the official projections. Therefore, the top-down and bottom-up models are conditional on the same economic background for the analysis of this paper.



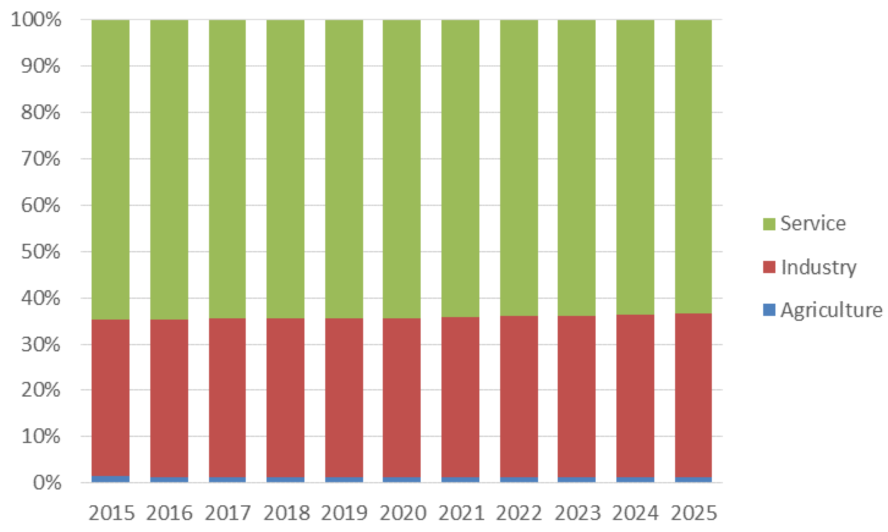
Source: National Development Council in Taiwan

Figure 4: The GDP Projections of Taiwan

Figure 4 depicts the future projections of Taiwan's GDP growth. The export share of Taiwan's nominal GDP was 63% and import share of nominal GDP was 51% in 2015. The economic growth of Taiwan is closely related to the world GDP. The world economic growth, therefore, could be a driving force of Taiwan's future GDP. According to the projections of International Monetary Fund (IMF), the world GDP growth rate increased from 3.2% in 2016 to 3.6% in 2017.[6] The world GDP, in addition, is expected to increase from 3.7% in 2018 to 3.8% to 2022. Because the world economy grows steadily since 2017, Taiwan's GDP growth also follows the rising trend in the short term. The GDP growth in Taiwan reaches the peak level of 2.81% in 2018. In the long term until 2025, Taiwan GDP growth gradually declines to 2.74%. The economy of Taiwan is matured and it is reasonable to assume a steady growth rate.

Figure 5 demonstrates the value added by service, industrial, and agricultural sectors. Given the sectoral trend of Taiwan, AIM-CGE is capable of calibrating its sectoral movements to the external information. Taiwan 2050 Calculator also treats the sectoral trends as global variables for energy simulation. The service sector constitutes the largest share of value added in Taiwan, the industrial sector ranks as the second, and the agricultural sector is the lowest one. Between 2016 and 2025, about 62% to 65% of value added comes from the service sector. In the meantime, the share of industrial value added increases from 34% in 2016 to 35% in 2025. The share of agriculture sector, however, remains steady around 1%. Therefore, the service sector contributes the largest share of value added to Taiwan. The industrial sector contributes the second major share of value added in Taiwan.

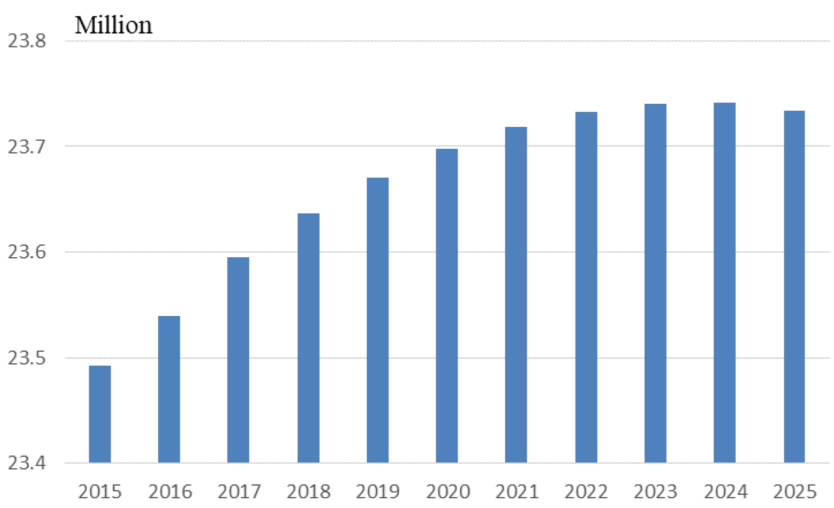
[6] See IMF: http://www.imf.org/external/datamapper/NGDP_RPCH@WEO/OEMDC/ADVEC/WEOWORLD



Source: National Development Council in Taiwan

Figure 5: The Share of Sectoral Value Added

Figure 6 indicates the official projections of population in Taiwan. Taiwan's population is increasing in the next few years. However, the birth rate is declining each year. The projections of Taiwan's total population, therefore, are expected to fall. Total population reaches the peak level in 2023 but starts declining since 2024. Taiwan 2050 Calculator takes into account the future population trend for the simulation of energy supply and demand.



Source: National Development Council in Taiwan

Figure 6: The Population Projections of Taiwan

4.1.2 Scenarios for Sectoral Energy Demand

Given the projections of GDP growth, sectoral value added, and population, Taiwan 2050 Calculator simulates energy demand, energy supply and CO_2 emissions for the future. This subsection describes the scenario settings for sectoral energy demand in Taiwan 2050 Calculator.

Table 4 describes the scenarios for sectoral energy demand in Taiwan 2050 Calculator. Level 2 of energy demand is treated as the BaU scenario for residential and service, transportation and industrial sectors. For residential and service sectors, the government gradually enhances minimum energy performance standards (MEPS) on electric devices, thermal insulation in buildings and energy management. In particular, the government enhances efficiency standard in MEPS by 10% every 5 year. The transportation sectors choose low carbon vehicle, adopt biomass fuel vehicle and increase use rate of public transportation. Additionally, industrial sectors gradually enhance MEPS.

With more aggressive actions toward energy reservation, each sector elevates the energy efficiency to Level 3. In particular, the residential and service sectors elevate current first-tier-efficiency standard by 20% as a reference for MEPS since 2016. The transportation sectors promote the market share of hydrogen-fuel-cell and hybrid vehicles. Additionally, industrial sectors gradually enhance MEPS to other equipment, speeding up the enforcement of MEPS.

As a consequence, the energy efficiency in Level 3 is more aggressive than that in Level 2. The energy efficiency improvement is larger in the former scenario. Sectoral energy demand takes Level 2 as the BaU scenario – this is an ambitious scenario that most or all experts believe to be reasonably achievable. Our purpose is to investigate the effects of shifting industrial sectors to Level 3 as an alternative scenario. As shown in Table 4, Level 3 is more challenging than Level 2.

Table 4: Scenario Descriptions for Sectoral Energy Demand of Taiwan 2050 Calculator

Sectors	Scenarios	Description
Residential and Service	Level 2	Gradually enhance MEPS on electric devices, thermal insulation in buildings, and energy management. Enhance efficiency standards in MEPS by 10% every 5 year.
	Level 3	Elevate current first-tier-efficiency standard by 20% as a reference for MEPS since 2016.
Transportation	Level 2	Promote low carbon vehicles, biomass fuel vehicles, and use rate of public transportation.
	Level 3	Promote the market share of hydrogen-fuel-cell and hybrid vehicles.
Industry	Level 2	Gradually enhance MEPS.
	Level 3	Extend MEPS to other equipment, speeding up the enforcement of MEPS.

Source: Taiwan 2050 Calculator

4.2 Simulation Results for BaU Scenarios

Figure 7 shows the energy demand simulated with the BaU setting, as shown in Table 3. The left panel plots the energy demand in level (unit: 10^3 KLOE) while the right panel depicts the share of energy demand (unit: the share to total level). The industrial sectors, the major sector of energy use in Taiwan, constitute about 36.2% of energy demand in 2025. The second major energy demand comes from non-energy use, which contributes 23.2% of energy demand in the same year. The transportation sector consumes 12.0% of energy demand. The service, residential, and energy sectors are subsequent major demand for energy.

With Level 2 as the BaU scenarios for energy demand, Taiwan's future energy demand remains stable since 2018. The aggressive actions induce energy demand to decline after 2022. The government has launched energy policy and sectors have adopted actions to improve energy efficiency in Level 2. In addition, the population growth is expected to decline in the future. Even though Taiwan's GDP keeps growing, the energy efficiency improvements and declining population growth are strong enough to curtail the energy demand.

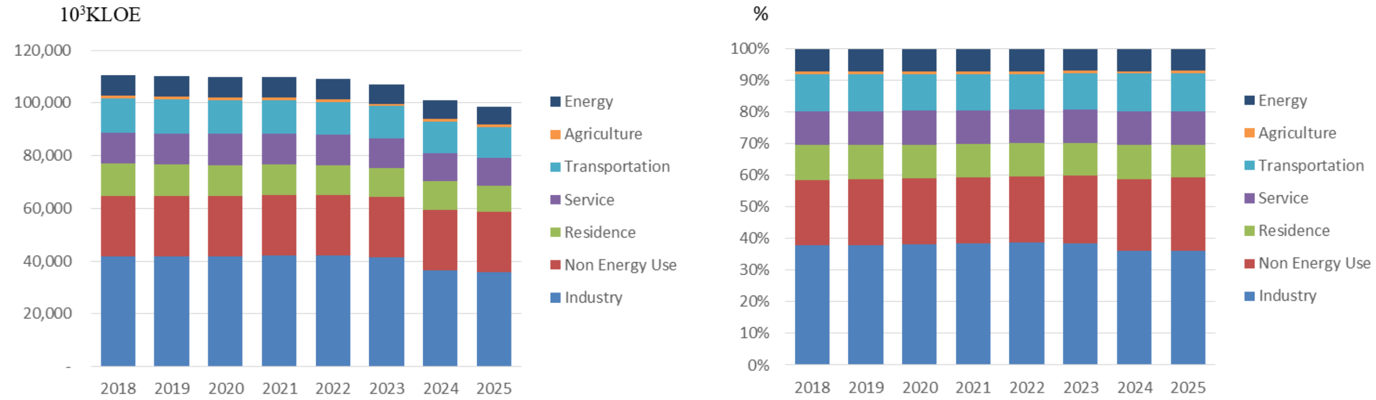


Figure 7: The Energy Demand in the BaU Scenario

Figure 8 presents the power supply mix under the BaU scenarios. The Level 2 scenario of energy demand requires more electronic devices; therefore, electricity supply has to increase steadily until 2025. The renewable power contributes 21% of power supply in 2025, satisfying the energy policy goal in Taiwan. With the BaU settings in Table 3, Taiwan 2050 Calculator simulates that the renewable power reaches 21% of power supply in 2025. In the transition to low carbon society, gas-fired power generates 42% of total power supply. Nuclear power, however, declines gradually until 2025 due to the anti-nuclear power policy of Taiwan’s government. As a consequence, Taiwan is going to transit to clean power supply, increasing renewable and gas-fire power supply.

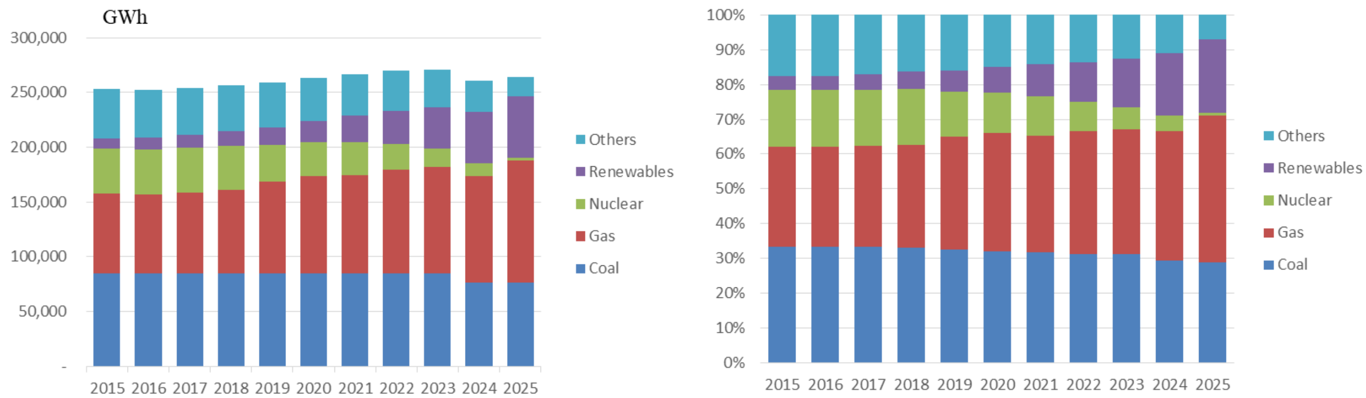


Figure 8: The Power Supply in the BaU Scenario

Figure 9 depicts the simulation of energy supply with the soft-link procedure between top-down and bottom-up models. Fossil energy is the main source of Taiwan's supply. Oil constitutes 40.2%, coal 29.3%, natural gas 22.5% and renewables 7.9% of energy supply in 2018. With falling energy demand, energy supply declines until 2025. The Taiwanese government has proposed to phase out nuclear power in 2025; therefore, the nuclear supply reduces to almost zero in the same year. In the transition to low carbon society, the Taiwanese government has an ambitious goal to decrease coal use. The coal supply, accordingly, shows a declining trend in the future. The shares of gas and renewable supply, therefore, increase. As a consequence, the declining energy demand accompanies not only falling energy supply but also the transition to a low-carbon energy mix. The carbon emissions, therefore, might fall due to the transition to lower carbon energy supply.

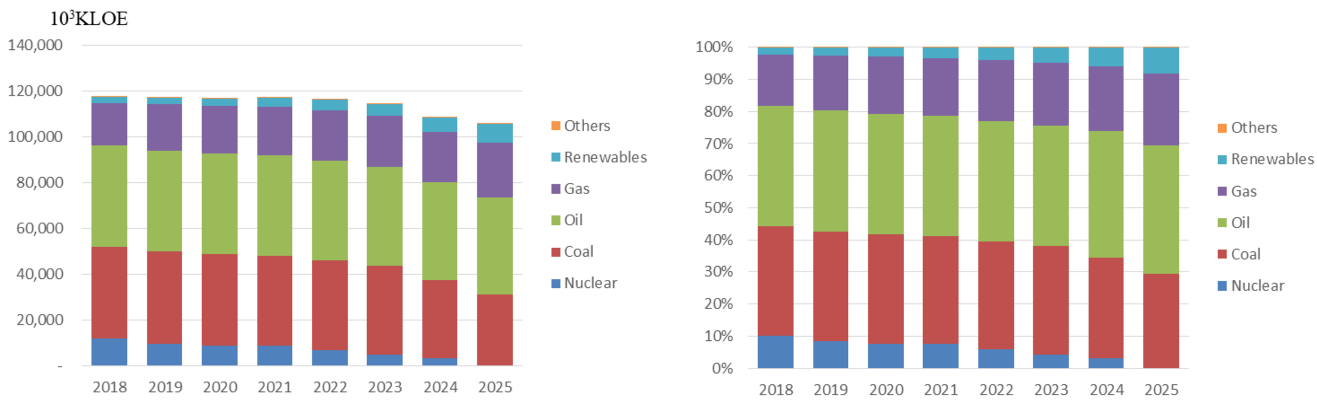


Figure 9: The Energy Supply in the BaU Scenario

Figure 10 demonstrates the CO_2 emissions in the BaU scenario. With the BaU scenarios for energy supply and energy demand, CO_2 emissions remain steadily before 2023. The expansion of renewable energy, the reduction of fossil energy supply and the ambitious action to curtail energy demand curtail CO_2 emissions in 2024 and 2025. Treating the clean energy as the BaU scenarios, the CO_2 emissions remain stable in the short run and begin declining in the long run.

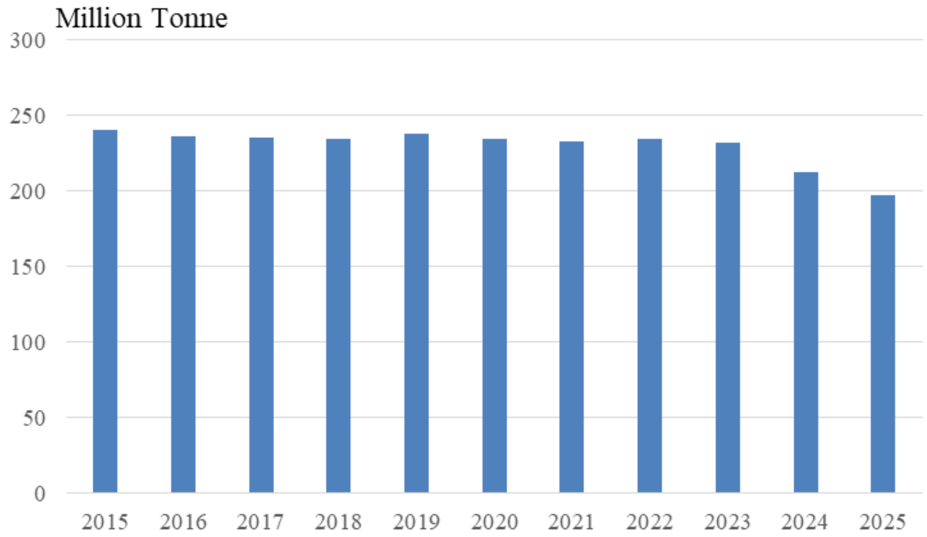


Figure 10: The CO_2 Emissions in the BaU Scenario

4.3 Simulations Results

This subsection demonstrates the simulation results following the soft-link procedure in Section 3.3. The simulation procedures satisfy the convergence criterion between Taiwan 2050 Calculator and AIM/CGE for Taiwan. The hybrid analysis using top-down and bottom-up models provides more comprehensive insights on the effects of energy efficiency improvements.

There are two groups of elasticity of substitution in AIM/CGE for Taiwan. The first group consists of the substitution between the domestic goods and import goods. The second group considers the substitution between the intermediate goods and value-added goods. The Bayesian estimation results are shown in A.2 of Appendix. We adopt the median values in Table A 1 for elasticity of substitution in this subsection, leaving the other values for the sensitivity analysis. The analysis on alternative elasticity values is left in the next subsection.

Level 2 of each sectoral energy efficiency, as described in Table 3, is treated as the BaU scenario. The energy demand scenarios switch from Levels 2 to 3 in order to simulate the effects of energy efficiency improvement. Taiwan 2050 Calculator simulates the energy and emission pathway according to such scenario changes. In addition, AIM/CGE for Taiwan evaluates the economic impacts of energy efficiency investments. The switch to the very ambitious level not only induces a sector to adopt more aggressive action to curtail energy demand but also invest more on energy efficiency improvements. More investments in energy efficiency could not only boost up the production activity but also trigger higher demand for other commodity and service, such as steel, transportation service, and energy demand. As a consequence, the economy growth could increase due to the action to improve energy efficiency.

Table 5 demonstrates increments of energy efficiency investments in terms of energy efficiency improvements on industrial, residential and service, and transportation group, respectively. In particular, we investigate the energy efficiency improvement turning from the BaU scenario of Level 2 to the alternative scenario of Level 3 in three such groups, respectively. For example in 2015, the textile sector shifts from Levels 2 to 3 and induces 33.2 million U.S. dollars of energy efficiency investments. The textile sector chooses a large amount of investments in energy efficiency from 2015 to 2021; however, such a sector reduces its energy efficiency investments in later years. This implies that the textile sector has already invested enough in the early periods. Such a sector, therefore, does not have to invest as much as early periods. Level 3 of energy efficiency, as a consequence, does not necessarily imply higher investments in energy efficiency relative to Level 2. Similarly, the following sectors do not have monotonically higher investments in Level 3 comparing with Level 2: semiconductor, other electronics, solar cell, other manufacturing, hotel and restaurant, education, and wholesale and retails.

Table 5: Increments of Energy Efficiency Investments Between BaU and Alternative Secnarios (Million of U.S. Dollars)

	Industrial Group									
	Textile	Paper	Semiconductor	Cement Products	Steel	Iron	Other Chemicals	Other Electronics	Solar Cell	Other Manufacturing
2015	33.2	0.0	69.4	184.5	0.1	0.2	17.7	21.8	1.8	33.2
2016	23.8	0.0	35.7	246.1	0.7	1.3	26.4	11.2	0.9	23.8
2017	21.0	13.9	18.9	114.7	0.9	1.7	29.2	6.0	0.5	21.0
2018	20.4	9.6	125.1	71.2	10.1	18.8	612.5	39.4	3.2	20.4
2019	20.5	8.3	1.7	57.1	3.5	6.5	222.3	0.5	0.0	20.5
2020	57.1	7.9	29.5	52.9	11.7	21.9	1,386.1	9.3	0.8	57.1
2021	1.8	7.8	17.8	51.9	4.0	7.5	480.8	5.6	0.5	1.8
2022	-17.4	7.9	16.2	52.0	11.9	22.2	777.2	5.1	0.4	-17.4
2023	-24.4	8.0	14.6	52.5	14.1	26.3	226.3	4.6	0.4	-24.4
2024	-69.0	8.0	-18.9	53.1	4.5	8.4	42.2	-6.0	-0.5	-69.0
2025	-19.8	8.2	-19.8	53.8	1.3	2.5	760.7	-6.2	-0.5	-19.8

	Residential and Service Group						Transportation Group	
	Medical Cares	Other Service	Cargo Transportation	Hotel and Restaurant	Education	Wholesale and Retails	Other Passenger Transportation	Cargo Transportation
2015	1.0	533.6	0.0	0.8	4.7	0.6	44.0	0.0
2016	2.1	667.3	24.2	1.3	8.6	1.9	177.1	24.2
2017	2.3	745.8	49.6	2.2	9.1	1.7	267.6	49.6
2018	3.3	1,006.2	77.0	3.1	9.1	2.4	394.1	77.0
2019	6.4	1,032.6	102.3	2.0	12.5	2.2	493.1	102.3
2020	6.8	1,226.2	138.1	1.9	16.9	3.5	566.5	138.1
2021	4.8	1,260.5	193.6	-0.6	-3.3	1.1	658.2	193.6
2022	4.6	1,208.3	258.3	0.8	-5.7	-0.5	706.6	258.3
2023	4.6	1,225.0	284.1	0.9	-6.0	-0.1	726.5	284.1
2024	4.6	1,185.8	297.1	0.9	-4.7	0.0	774.6	297.1
2025	4.6	1,304.3	305.1	1.0	-0.6	0.0	827.7	305.1

Note: The number indicates the energy efficiency investments between alternative scenarios and the BaU. A positive value indicates that the former is higher than the later. The BaU scenarios are set to be Level 2 for all groups. The alternative scenarios are set to Level 3 for industrial, residential and service, and transportation groups, respectively.

4.3.1 Impacts of Energy Efficiency Improvements of Industrial Group

This subsection investigates the effects of energy efficiency improvements on industrial group. The energy efficiency improvements are set to Level 2 for residential and service, industrial, and transportation groups as the BaU scenario. In the alternative scenarios for energy efficiency improvements, the sectors in the industrial group shift to Level 3 while the sectors in the other groups remain at Level 2. Comparing the BaU and the alternative scenarios, we are able to quantify the effects of energy efficiency improvements on Taiwan's industrial sectors.

Table 6 demonstrates the extent to which the efficiency improvements of industrial group affect the economy. To save space of this paper, we show the effects in 2018, 2020, and 2025, respectively. The scenarios in AIM/CGE assume that the government subsidizes the energy efficiency investments in industrial group. Relative to the BaU scenarios, GDP grows 0.19% in 2018, increases 0.34% in 2020, and soars up 0.13% in 2025 due to the energy efficiency investments in industrial sectors in Level 3. To maintain the government budget balance, the fiscal policy adjusts in face of higher subsidies on energy efficiency investments. The government expenditure declines 0.03% in 2018, drops 0.06% in 2020, and decreases 0.02% in 2025. In addition, the government transfer to household also falls 4.16% in 2018, reduces 8.21% in 2020, and shrinks 3.84% in 2025. As shown in Appendix, the household income consists of capital income, labor income, foreign transfer to household, and government transfer to household. The labor income, capital income, and foreign transfer increases in comparison with the BaU scenarios. The consumption, however, declines 0.04%, in 2018, falls 0.07% in 2020, and declines 0.03% in 2025 due to the lower transfer to household. The energy efficiency improvements trigger higher investment, export, and imports relative to the BaU scenarios. We notice that the response of consumption is relatively smaller than the investment change, consistent with most theoretical and empirical findings that investments are more sensitive than consumption.[7]

[7] Friedman (1957), for instance, propose the permanent income hypothesis that agents smooth consumption over their lifetimes. Barsky and Sims (2011), for example, provide empirical evidence that the responses of investment to a total factor productivity (TFP) shock is larger than those of consumption.

Table 6: Economic Impacts of Investments in Energy Efficiency of Industrial Group

	Economic Component	2018	2020	2025
GDP		0.19%	0.34%	0.13%
Household Income	Capital Income	0.59%	1.06%	0.41%
	Labor Income	0.17%	0.30%	0.12%
	Foreign Transfer to Household	0.56%	1.01%	0.38%
	Government Transfer to Household	-4.16%	-8.21%	-3.84%
GDP Expenditure	Consumption	-0.04%	-0.07%	-0.03%
	Investment	0.56%	1.01%	0.38%
	Government Expenditure	-0.03%	-0.06%	-0.02%
	Export	0.22%	0.42%	0.18%
	Import	0.16%	0.29%	0.12%

Note: The simulation results are hybrid of Taiwan 2050 Calculator and AIM/CGE for Taiwan. The impacts of energy efficiency investments satisfy the soft-link procedure described in Section 3.3. The industrial sectors adopts Level 2 of energy demand as BaU and Level 3 as the alternative scenario.

As shown in Figure 11, the very ambitious actions of industrial sectors affect energy efficiency investments, CO_2 emissions, industrial energy demand, and total energy demand. The energy efficiency investments in industrial sectors amounts to 961 million U.S. dollars in 2018, 1,657 million U.S. dollars in 2020, and 783 million U.S. dollars in 2025. The very ambitious actions on energy efficiency improvements reduces CO_2 emissions. Total CO_2 emissions decrease by 0.58% in 2018, decline 0.63% in 2020, and reduce 1.54% in 2025. The industrial energy demand drops 1.22% in 2018, reduces 1.27% in 2020, and falls 2.83% in 2025. Total energy demand – the energy demand of all sectors – also falls following the launch of very aggressive actions on energy efficiency improvements. Total energy demand reduces 1.22% in 2018, drops 1.27% in 2020, and decreases 2.83% in 2025. We emphasize that the soft-link analysis for the investments in the industrial group satisfy the convergence criterion. One the one hand, the energy efficiency improvements reduce energy demand. On the other hand, higher investments not only boost economic growth but also induce more energy demand for production activity. The combination of two effects results in not only energy conservation but also CO_2 emission reduction. As a consequence, the very ambitious actions of industrial sectors reduce energy demand and carbon emissions.

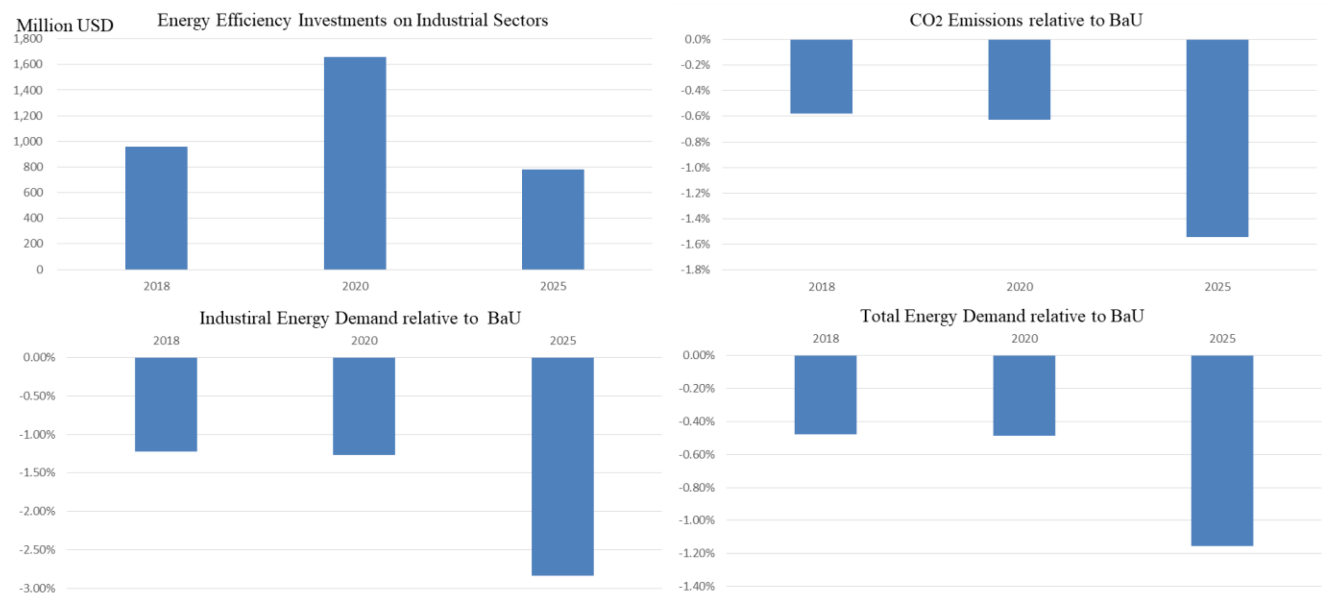


Figure 11: Enviromental and Energy Impacts – Energy Efficiency Improvements on Industrial Group

4.3.3 Energy Efficiency Improvements of Transportation Group

In this subsection, we evaluate the effects of energy efficiency improvements on Taiwan's transportation sectors. The sectors in the transportation group adopt Level 3 for energy efficiency improvements. The other sectors in the industrial and the residential and service groups adopt Level 2 for energy demand. Therefore, the simulation in this subsection demonstrates the effects of energy efficiency improvements of transportation group.

As shown in Table 7Table 6, the investments of transportation sectors on energy efficiency trigger economic growth. Relative to the BaU scenarios, GDP soars up 0.08% in 2018, climbs up 0.10% in 2020, and increases 0.14% in 2025. The government expenditure declines 0.02% in 2018, drops 0.02% in 2020, and decreases 0.03% in 2025. In addition, the government transfer to household also falls 2.20% in 2018, reduces 3.15% in 2020, and shrinks 5.19% in 2025. The labor income, capital income, and foreign transfer increases in comparison with the BaU scenarios with lower energy efficiency improvements. The consumption declines 0.02% in 2018, falls 0.03% in 2020, and declines 0.04% in 2025 due to the lower transfer to household. The energy efficiency investments induce higher investment, export, and imports relative to the BaU scenarios. As a consequence, the energy efficiency improvements boost up GDP and related economic activity comparing with the BaU scenario. The consumption of household, however, drops because of lower transfer from the government.

Table 7: Economic Impacts of Investments in Energy Efficiency of Transportation Group

	Economic Component	2018	2020	2025
GDP		0.08%	0.10%	0.14%
Household Income	Capital Income	0.31%	0.41%	0.56%
	Labor Income	0.09%	0.12%	0.16%
	Foreign Transfer to Household	0.30%	0.39%	0.52%
	Government Transfer to Household	-2.20%	-3.15%	-5.19%
GDP Expenditure	Consumption	-0.02%	-0.03%	-0.04%
	Investment	0.30%	0.39%	0.52%
	Government Expenditure	-0.02%	-0.02%	-0.03%
	Export	0.12%	0.16%	0.24%
	Import	0.09%	0.11%	0.16%

Note: See Table 7 for details.

Figure 12 demonstrates the extent to which the very ambitious actions of transportation sectors affect energy efficiency investments, CO_2 emissions and energy demand. The energy efficiency investments of transportation sectors increase 471 million U.S. dollars in 2018, 705 million U.S. dollars in 2020, and 1,133 million U.S. dollars in 2025. The very ambitious actions significantly improve energy efficiency in 2025: The sectoral energy demand of transportation group falls 0.61% in 2018, drops 1.10% in 2020, and reduces 3.81% in 2025. Total energy demand significantly drops in 2025: it reduces 0.002% in 2018, drops 0.04% in 2020, and decreases 0.37% in 2025. Following the decreasing trend of total energy demand, total CO_2 emissions decline 0.01% in 2018, decrease 0.07% in 2020, and reduce 1.03% in 2025. Similar to the very ambitious efforts of industrial sectors, not only the energy efficiency improves but also CO_2 emissions shrink. In addition, economy perks up due to more energy efficiency investments. As a consequence, the very ambitious actions of transportation sectors reduce energy demand as well as carbon emissions.

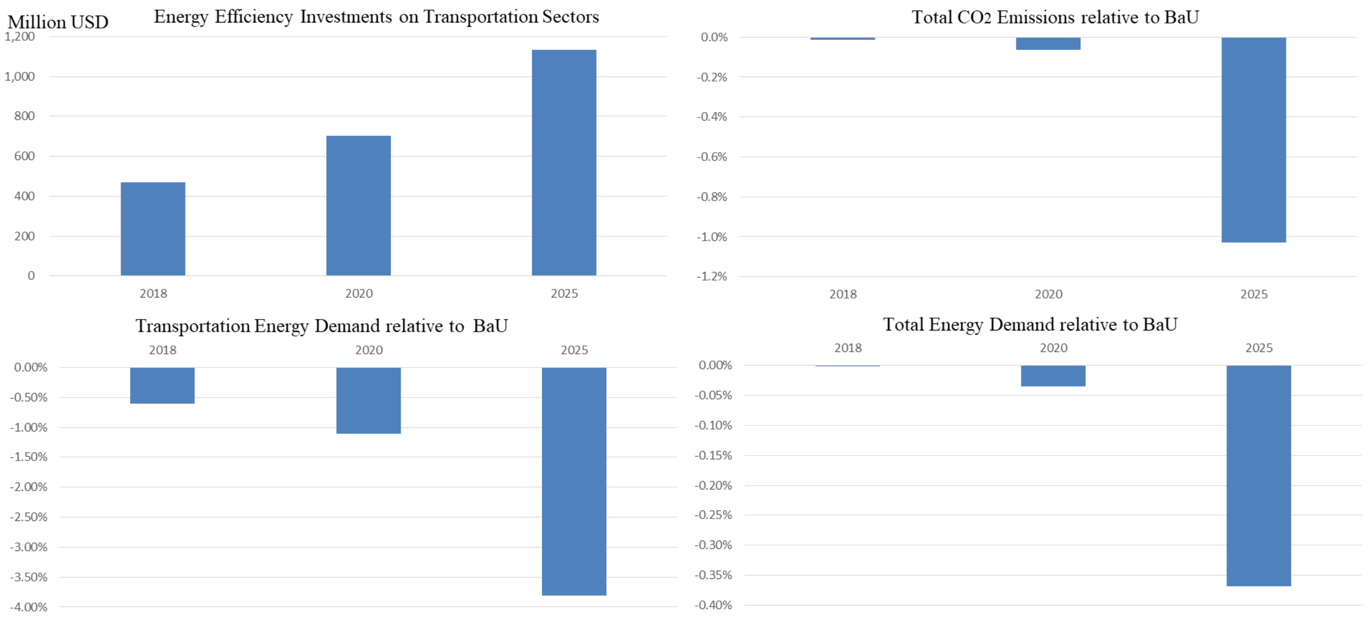


Figure 12: Enviromental and Energy Impacts – Energy Efficiency Improvements on Transportation Group

4.3.4 Impacts of Energy Efficiency Improvements of Residential and Service Group

The efficiency improvements of residential and service group, as shown in Table 8, affect GDP, household income and household expenditure. In comparison with the BaU scenarios, the efficiency investments in Level 3 increase GDP by 0.19% in 2018, 0.34% in 2020, and 0.13% in 2025. The subsidy on efficiency investments crowds out the government expenditure by 0.03% in 2018, by 0.04% in 2020, and by 0.03% in 2025. With more investment subsidies in Level 3, the government transfer to household declines 4.27% in 2018, falls 5.37% in 2020, and shrinks 5.91% in 2025. The labor income, capital income, and foreign transfer, however, increases in comparison with the BaU scenarios. The lower transfer from government reduces the consumption by 0.04%, in 2018, 0.07% in 2020, and 0.03% in 2025. The efficiency investments trigger higher investment, export and imports relative to the BaU scenarios. Similar to the sectors in industrial and transportation groups, the energy efficiency improvements increase GDP, reduce energy demand, and mitigate CO_2 emissions. However, the consumption falls due to the lower transfer from the government.

Table 8: Economic Impacts of Investments in Energy Efficiency of Residential and Service Group

	Economic Component	2018	2020	2025
GDP		0.19%	0.22%	0.21%
Household Income	Capital Income	0.60%	0.69%	0.63%
	Labor Income	0.17%	0.20%	0.18%
	Foreign Transfer to Household	0.58%	0.66%	0.59%
	Government Transfer to Household	-4.27%	-5.37%	-5.91%
GDP Expenditure	Consumption	-0.04%	-0.05%	-0.05%
	Investment	0.58%	0.66%	0.59%
	Government Expenditure	-0.03%	-0.04%	-0.03%
	Export	0.23%	0.27%	0.27%
	Import	0.17%	0.19%	0.19%

Note: See Table 7 for details.

Figure 13 demonstrates the extent to which Level 3 of service and residential groups triggers energy efficiency investments, shrinks energy demand and reduces CO_2 emissions. Relative to the BaU scenarios of Level 2, Level 3 triggers 1,024 million U.S. dollars of energy efficiency investments in 2018, 1,255 million U.S. dollars in 2020, and 1,309 million U.S. dollars in 2025. In particular, the sectors in residential and service group reduce 0.52% of energy demand in 2018, 3.73% in 2020, and 7.25% in 2025. Total energy demand, in addition, reduces 0.03% in 2018, drops 0.69% in 2020, and decreases 1.54% in 2025. Following the declining trend of total energy demand, total CO_2 emissions reduce 0.03% in 2018, drop 0.69% in 2020, and fall 1.54% in 2025. Similar to Subsections 4.3.2 and 4.3.3, the economy perks up and efficiency improves. Such improvements result in less energy demand and lower CO_2 emissions. As a consequence, the very ambitious actions of residential and service sectors are accompanied by lower energy demand as well as mitigated carbon emissions.

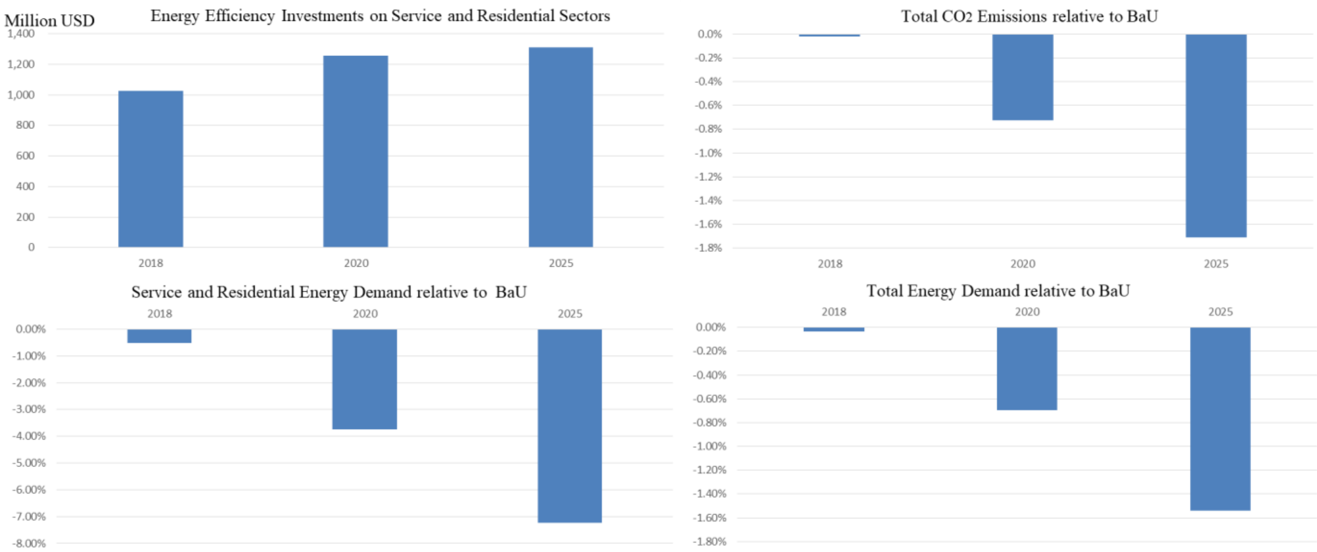


Figure 13: Enviromental and Energy Impacts – Energy Efficiency Improvements on Residential and Service Group

4.4 Sensitivity Analysis: Alternative Elasticity of Substitution

The simulation results might be sensitive to the specifications on elasticity of substitution in AIM/CGE. This subsection considers alternative specifications on elasticity. As shown in Section A.2.3 of Appendix, we adopt the Bayesian technique to estimate elasticity of substitution for AIM/CGE. Therefore, the estimated values are useful references for the specifications on elasticity of substitution.

Table 9 shows the impacts of alternative elasticity of substitution on GDP, energy demand, and total CO_2 emissions. In Table A 1 of Appendix, the Bayesian technique adopts the Markov chain Monte Carlo (MCMC) draws to estimate elasticity of substitution. Section A.2.3 demonstrates the median values as well as the 90% error bands for elasticity values. The "High" label in Table 9 indicates the adoption of the upper bound of 90% error bands using the Bayesian technique, the "Low" label indicates the choice of lower bound of MCMC draws, and the "Median" label indicates the choice of median of draws.

Table 9: Sensitivity Analysis with Respect to Elasticity of Substitution

	Industrial Sectors			Service and Residential Sectors			Transportation Sectors		
				GDP					
Elasticity	Low	Median	High	Low	Median	High	Low	Median	High
2018	0.18%	0.19%	0.19%	0.19%	0.19%	0.19%	0.10%	0.10%	0.10%
2020	0.33%	0.34%	0.34%	0.21%	0.22%	0.22%	0.13%	0.13%	0.13%
2025	0.13%	0.13%	0.14%	0.20%	0.21%	0.21%	0.17%	0.18%	0.18%
				Energy Demand					
Elasticity	Low	Median	High	Low	Median	High	Low	Median	High
2018	-0.48%	-0.48%	-0.48%	-0.04%	-0.03%	-0.03%	0.00%	0.00%	0.00%
2020	-0.49%	-0.48%	-0.48%	-0.70%	-0.69%	-0.69%	-0.04%	-0.04%	-0.03%
2025	-1.16%	-1.16%	-1.15%	-1.55%	-1.54%	-1.54%	-0.38%	-0.37%	-0.36%
				Total CO_2 Emissions					
Elasticity	Low	Median	High	Low	Median	High	Low	Median	High
2018	-0.59%	-0.58%	-0.58%	-0.03%	-0.02%	-0.02%	-0.02%	-0.01%	-0.01%
2020	-0.64%	-0.63%	-0.62%	-0.73%	-0.72%	-0.72%	-0.07%	-0.07%	-0.06%
2025	-1.54%	-1.54%	-1.54%	-1.72%	-1.71%	-1.71%	-1.04%	-1.03%	-1.02%

Note: The "High" label in indicates the adoption of the upper bound of 90% error band using the Bayesian technique, the "Low" label indicates the choice of lower bound of MCMC draws, and the "Median" label indicates the choice of median for the elasticity of substitution. The number is the responses in industrial sectors, residential and service sector, and transportation sectors relative to BaU, respectively.

The soft-link between top-down and bottom-up models is robust with respect to alternative specifications on elasticity, as shown in Table 9. The alternative specifications on elasticity of substitution do not significantly change the response of GDP, energy demand, and CO_2 emissions. In AIM/CGE, there are two parameter groups of elasticity of substitution estimated by the Bayesian technique. The First group enables the substitution between the intermediate goods and the value-added goods. The second group controls the substitution between the domestic goods and the import goods. The subsidies on efficiency investments reduce net price of capital goods. Such subsidies increase investment and capital stock, leading to more production of value-added goods. The higher elasticity induces a larger increases of capital stock relative to the intermediate goods, enhancing the effects on production activity. In addition, higher elasticity between domestic goods and import goods implies that the former can replace the later more. The expansion of production activity is accompanied by more sensitive responses of domestic goods which could replace import goods more easily. GDP, therefore, perks up with more intensive use of domestic goods.

The overall effects on energy demand come from two sources. On the one hand, higher elasticity induces not only better GDP growth but also more energy demand in comparison with the scenario with lower elasticity values. On the other hand, the improvement of energy efficiency reduces energy demand. The hybrid of two such effects in the high elasticity scenario, as a consequence, indicates that the reduction of energy demand is less successful than that in the low elasticity scenario. With the low values of elasticity of substitution, total CO_2 emissions reduce a larger extent.

In a nutshell, the effects of energy efficiency investments depends upon the elasticity of substitution. However, the changes of simulation results are negligible across alternative elasticity values. We, therefore, propose that the simulation results are robust to the choice of elasticity of substitution.

4.5 Counterfactual Analysis on the Transmission Channel to Consumption

Following the higher subsidies on efficiency investments, we propose that the reduction of government transfer to household is the main cause of the declines in consumption. More subsidies on efficiency investments reduce the fiscal budget that is available for government transfer to household and government expenditure. By decreasing the real government expenditure, the counterfactual simulation sheds light on the impacts on consumption.

Let $G_t(i)$ denote the government expenditure for the ith commodity. Section A1 in Appendix explains detail specifications on AIM/CGE. The real government expenditure is an exogenous variable in AIM/CGE. We adjust government expenditure to reveal the transmission of efficiency subsidy to consumption. There are four scenarios for simulation: each year real government expenditure on each commodity reduces 0.1%, 0.5%, 1.0% and 2%, respectively.

Table 10: Counterfactual Analysis on Industrial Investments: Reduction of Government Expenditure

$\Delta G_t(i)$	-0.10%			-0.50%		
	Consumption	Government Transfer to Household	GDP	Consumption	Government Transfer to Household	GDP
2018	-0.02%	-3.58%	0.17%	0.04%	-1.28%	0.12%
2020	-0.06%	-7.61%	0.33%	0.00%	-5.23%	0.28%
2025	-0.02%	-3.21%	0.12%	0.04%	-0.06%	0.08%
$\Delta G_t(i)$	-1.00%			-2.00%		
	Consumption	Government Transfer to Household	GDP	Consumption	Government Transfer to Household	GDP
2018	0.11%	1.61%	0.06%	0.27%	7.36%	-0.06%
2020	0.08%	-2.26%	0.22%	0.23%	3.67%	0.10%
2025	0.11%	2.51%	0.02%	0.25%	8.85%	-0.08%

Table 10 reveals the counterfactual simulation with the adjustment of real government expenditure. The scenario assumes that the government subsidizes energy efficiency investments of industrial sectors – the same scenario as Section 4.3.1. To save space of this paper, the counterfactual analysis on the other sectors are available upon request. In addition to the implement of energy efficiency subsidies, the first scenario assumes that the real government expenditure drops 0.1% on each commodity. With such slight declines of government expenditure, the government has more budget for the transformation to household. The consumption, however, falls 0.02% in 2018, reduces 0.06% in 2020, and declines 0.02% in 2025. The extent of consumption reduction, however, is less than that in Table 6. The lower real government expenditure reduces aggregate demand; therefore, the overall effect reduces GDP to a lower level than that in Table 6.

In the second scenario that the real government expenditure drops 0.1%, the consumption increases 0.04% in 2018 and 2025, respectively. The government transfer to household is higher relative to the BaU scenario. Following the lower government expenditure and higher transfer to household, the consumption increases. Accordingly, the government could reconcile the expenditure and household transfer such that the not only consumption but also GDP increase.

The third scenario proposes that the government expenditure drops 1.00%. The consumption and government transfer to household rise relative to the BaU scenario. However, the government expenditure decreases too much and GDP is lower than the former two scenarios. As a consequence, the lower real government expenditure could increase the transfer to household. However, too much reduction of real government expenditure can not support the same level of GDP in comparison with the BaU scenario.

The government expenditure declines 2% in the last scenario. The reduction of government expenditure is so large that not only the government transfer to household but also consumption soar up. However, such a large decline of government expenditure decrease 0.06% of GDP in 2018 and it falls 0.08% in 2025. As a consequence, we could reduce the crowding-out effect of investment subsidies by shrinking government expenditure. However, too much reduction of government expenditure will reduce the GDP level relative to the BaU scenario.

All in all, the crowding-out effect of investment subsidies on consumption could be mitigated by an appropriate scheme on the fiscal adjustment. The subsidies on efficiency investment could trigger the economic activity; however, the fiscal spending on efficiency subsidies could reduce transfer to household and consumption. Too much reduction of government expenditure could enhance consumption level; nevertheless, the GDP might reduce due to the lower aggregate demand.

5. Discussions and Policy Implications

We find that the energy efficiency investments not only directly reduce energy demand and CO_2 emissions, but also boost GDP growth. Such findings provide several policy implications as follows:

(1) The improvements of energy efficiency induce multiple benefits on economy, energy and environment.

By promoting the energy efficiency from Levels 2 to 3, the energy demand reduces. In addition, CO_2 emissions drop in the later scenarios. The energy efficiency investments, following the adoption of the very ambitious scenarios, significantly rise. The economy prospers due to more investments in energy efficiency. Multiple benefits – higher GDP growth, lower energy demand

and CO_2 emissions – emerge with the promotion of energy efficiency. As a result, a policy that promotes energy efficiency investments could be powerful for energy conservation and carbon emission reduction.

Table 11: Comparison of Efficiency Improvements by Sectors

	Industrial Group				Transportation Group			
	GDP	Consumption	Efficiency Investments	CO_2 Emissions	GDP	Consumption	Efficiency Investments	CO_2 Emissions
2018	0.19%	-0.04%	961	-0.58%	0.08%	-0.02%	471	-0.01%
2020	0.34%	-0.07%	1,657	-0.63%	0.10%	-0.03%	705	-0.07%
2025	0.13%	-0.03%	783	-1.54%	0.14%	-0.04%	1,133	-1.03%

	Residential and Service Group			
	GDP	Consumption	Efficiency Investments	CO_2 Emissions
2018	0.19%	-0.04%	1,024	-0.02%
2020	0.22%	-0.05%	1,255	-0.72%
2025	0.21%	-0.05%	1,309	-1.71%

Note: The unit of efficiency investment is million of U.S. dollars.

Table 11 compares the effects of efficiency improvements by respective groups. The industrial group have a comparative advantage over other groups. Such a group invests intensively before 2020 but the investments reduce to a lower level, 783 million U.S. dollars, in 2025. The residential and service group has the largest reduction of CO_2 emissions in 2025. However, the efficiency investments in such a group have to remain above 1 trillion U.S. dollars. The crowding-out effects on consumption, in addition, are larger with the investment subsidies on the residential and service group. The investment subsidies on the transportation group are moderate and the crowding-out effects on consumption are not the strongest. With the subsidies on the investment of transportation group, the extent of CO_2 emission reduction in 2025 is the lowest among three cases.

(2) How to improve energy efficiency to higher levels is essential for the success to achieve multiple benefits.

The mechanism design to induce energy efficiency improvement is beyond the capability of Taiwan 2050 Calculator. In this paper we assume that the government subsidizes investments in energy efficiency improvements. In practice, unless the government strictly enforces the energy efficiency investments, a private sector might have an option not to apply for the subsidy. There could be other strategies to strictly enforce investments in energy efficiency, such as MEPS. A top-down approach, such as the CGE model in this paper, is not designed for the investigation of MEPS which applies to individual items. As a consequence, a policy maker should be aware of the limitation of the simulation results.

(3) Further studies on investment specifications, such as domestic production ratio and detail elaboration of investment items, could bring simulation results closer to reality.

Taiwan 2050 Calculator can only simulate aggregate investments in a particular sector; moreover, there is neither information of the import shares nor details of investment items. If all investments are imported from other countries, domestic sectors might benefit less from energy efficiency investments. The benefits of investment increments spill over to foreign countries and domestic sectors enjoy less. If most investment goods are domestically produced, production activity could perk up more. Energy efficiency investments that are partially imported, therefore, might have a less effect on economic growth, comparing with the scenario that investments are pure domestically produced.

AIM/CGE for Taiwan is capable of analyzing the effect of sectoral investments. However, in reality, energy efficiency investments might include heterogeneous items such as high efficient machine, new air conditioner, and new electric appliances. If we can decompose the energy efficiency investments to sectoral sources, the simulation scenario could become closer to the reality. The decomposition takes lots of efforts and we leave this issue for future research.

(4) The simulation results are robust to alternative specifications on elasticity of substitution.

Using the Bayesian procedure for the elasticity estimation is a new attempt for the CGE method. The elasticity parameters of a CGE model is crucial to determine the simulation results. Conditional on the structural equations of CGE model, we estimate the elasticity values using Taiwan’s times series data. Therefore, the elasticity of substitution is based upon the structure of CGE and the data in Taiwan.

The Bayesian estimation restrict the elasticity to a prior space. The estimated values are useful references for the choice of elasticity in AIM/CGE for Taiwan. The sensitivity analysis shows that the simulation results are robust to the elasticity choices.

6. Conclusions

The improvements of energy efficiency are important for energy conservation and carbon emission reduction. In addition to energy conservation, energy efficiency improvements boost production activity. Economic growth, therefore, perks up due to higher aggregate demand. Previous studies in the literature use either top-down or bottom-up approach to investigate the effects of energy efficiency investments/improvement. In the literature, the energy efficiency improvements have been proven to provide multiple benefits to economy, environment and energy.

In this paper we adopt the hybrid of these two approaches – a soft-link procedure between AIM/CGE for Taiwan (top-down) and Taiwan 2050 Calculator (bottom-up) – to evaluate the effects of energy efficiency investments in Taiwan. We investigate the impacts of energy efficiency improvements on the industrial, residential and service, and transportation groups. We find that the energy efficiency improvements not only reduce energy demand but also perk up GDP growth. In addition, the CO_2 emissions fall. However, the higher subsidies on investments crowd out consumption. An appropriate scheme on the fiscal balance could reverse the crowding-out effects on consumption, as shown in our counterfactual analysis. The policy for energy efficiency improvement, therefore, is one of important strategies for energy conservation and carbon emission reduction.

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Reference

1. Arndt, C., Robinson, S. and Tarp, F. (2002). Parameter Estimation for a Computable General Equilibrium Model: A Maximum Entropy Approach. *Economic Modelling*, 19(3), 375-398.
2. Allan, G., Hanley, N., McGregor, P., Swales, K. and Turner, K. (2007). The Impact of Increased Efficiency in the Industrial Use of Energy: A Computable General Equilibrium

Analysis for the United Kingdom. *Energy Economics*, 29, pp. 779-798.

3. An, S. and Schorfheide, F. (2007). Bayesian Analysis of DSGE Models. *Econometric Reviews*, 26, pp. 113-172.

4. Barker, T., Ekins, P. and Foxon, T. (2007). The Macroeconomic Rebound Effect and the UK Economy. *Energy Policy*, 35, pp. 4935-4946.

5. Barker, T., Dagoumas, A. and Rubin, J. (2009). The Macroeconomic Rebound Effect and the World Economy. *Energy Efficiency*, 2, pp. 411-427.

6. Barsky, R.B. and Sims, E.R. (2011). News Shocks and Business Cycles. *Journal of Monetary Economics*, 58(3), pp. 273-289.

7. Bataille, C. and Melton, N. (2017). Energy Efficiency and Economic Growth: A Retrospective CGE Analysis for Canada from 2002 to 2012. *Energy Economics*, 64, pp. 118-130.

8. Böhringer, C. and Löschel, A. (2005). Climate Policy beyond Kyoto: Quo Vadis? *Kyklos*, 58(4), pp. 467-493.

9. Bouakez, H., Guillard, M. and Roulleau-Pasdeloup, J. (2017) Public Investment, Time to Build, and the Zero Lower Bound. *Review of Economic Dynamics*, 23, 60-79.

10. Dai, H. (2012). *Integrated Assessment of China's Provincial Low Carbon Economy Development towards 2030: Jiangxi Province as an Example*. PhD. Tokyo Institute of Technology.

11. Friedman, M. (1957). *A Theory of the Consumption Function*. New Jersey: Princeton University Press.

12. Fujimori, S., Masui, T. and Matsuoka, Y. (2014). Development of a Global Computable General Equilibrium Model Coupled with Detailed Energy End-use Technology. *Applied Energy*, 128(3), pp. 296-306.

13. Galí, J., Vallés, J. and López-Salido, J.D. (2007). Understanding the Effects of Government Spending on Consumption. Journal of the European Economic Association, 5 (1), 227-270

14. Grepperud, S. and Rasmussen, I. (2004). A General Equilibrium Assessment of Rebound Effects. *Energy Economics*, 26, pp. 261-282.

15. Go, D.S., Lofgren, H., Ramos, F.M. and Robinson, S. (2016). Estimating Parameters and Structural Change in CGE Models Using a Bayesian Cross-entropy Estimation Approach. *Economic Modelling*, 52, 790-811.

16. Hanley, N.D., McGregor, P.G., Swales, J.K. and Turner, K. (2006). The Impact of a Stimulus to Energy Efficiency on the Economy and the Environment: A Regional Computable General Equilibrium Analysis. *Renewable Energy*, 31, pp. 161–171.

17. International Energy Agency (2012). *Spreading the Net: The Multiple Benefits of Energy Efficiency Improvements*. Paris: OECD/IEA.

18. Jorgenson, D.W. (2011). Innovation and Productivity Growth. *American Journal of Agricultural Economics*, 93(2), 276-296.

19. Jorgenson, D.W. and Yun, K.-Y. (2013). Taxation, Efficiency, and Economic Growth. In: P.B. Dixon and D.W. Jorgenson, ed., *Handboook of Computable General Equilibrium Modeling*,

Massachusetts: North-Holland, pp. 659-741.

20. Ke, W., Wang, C. and Chen, J. (2009). Analysis of the Economic Impact of Different Chinese Climate Policy Options Based on a CGE Model Incorporating Endogenous Technological Change. *Energy Policy*, 37(8), pp. 2930-2940.
21. Leeper, E. M., Plante, M. and Trauma, N. (2010a) Dynamics of Fiscal Financing in the United States. *Journal of Econometrics*, 156, pp. 304-321.
22. Leeper, E. M., Walker, T. B. and Yang, S.-C. S. (2010a) Government Investment and Fiscal Stimulus. *Journal of Monetary Economics*, 57, pp. 1000-1012.
23. Lilly, P. and Pearson, D. (1999). Determining the Full Value of Industrial Efficiency Programs. In: *Proceedings ACEEE Summer Study on Energy Efficiency in Industry*. Washington DC: ACEEE, p. 349-362.
24. Mills, E., Shamshoian, G., Blazek, M., Naughton, P., Seese, R. S., Tschudi, W. and Sartor, D. (2008). The Business Case for Energy Management in High-tech Industries. *Energy Efficiency*, 1(1), pp. 5-20.
25. Mundaca, L. (2008). Markets for Energy Efficiency: Exploring the Implications of an EU-Wide 'Tradable White Certificate' Scheme. *Energy Economics*, 30(6), pp. 3016-3043.
26. Neves, L. P., Martins, A. G., Antunes, C. H. and Dias, L. C. (2008). A Multi-criteria Decision Approach to Sorting Actions for Promoting Energy Efficiency. *Energy Policy*, 36(7), pp. 2351-2363.
27. Rasmussen, J. (2017). The Additional Benefits of Energy Efficiency Investments - A Systematic Literature Review and a Framework for Categorization. Forthcoming in *Journal of Energy Efficiency*.
28. Rutherford, T.F. (1999). Applied General Equilibrium Modeling with MPSGE as a GAMS Subsystem: An Overview of the Modeling Framework and Syntax. *Computational Economics*, 14(1-2), pp. 1-46.
29. Sauter, R., and Volkery, A. (2013). *Review of Costs and Benefits of Energy Savings*. Brussels: IEEP for the Coalition of Energy Savings.
30. Skumatz, L., Dickerson, C. and Coates, B. (2000). Non-energy Benefits in the Residential and Non-residential Sectors – Innovative Measurements and Results for Participant Benefits. In: *Proceedings ACEEE Summer Study on Energy Efficiency in Buildings*. California: ACEEE, p. 8353-8364.
31. Townsend, B. and Ratnayake, R. (2000). *Trade Liberalisation and the Environment: A Computable General Equilibrium Analysis*. World Scientific Pub Co Inc.
32. Vikström, P. (2008). *Energy Efficiency and Energy Demand: A Historical CGE Investigation on the Rebound Effect in the Swedish Economy*. Working Paper, Department of Economic History, Umeå University.
33. Yang, H.Y. (2009) Economic Effects of Energy Taxation: A Computable General Equilibrium Analysis in the Presence of Parameter Uncertainty. *Taiwan Economic Forecast and Policy*, 40(1), pp. 79-125.
34. Zhang, Z.X. (1996). Macroeconomic Effects of CO_2 Emission Limits: A Computable General

Equilibrium Analysis for China. *Journal of Policy Modeling*, 20(2), pp. 213-250.

Appendix

A.1 Model Specifications of AIM/CGE for Taiwan

This section offers a description for the specifications of AIM/CGE for Taiwan. AIM/CGE for Taiwan is set up in a small-open-economy framework. There are producers, consumers, and government in this model. AIM/CGE for Taiwan is a joint work of NIES in Japan and ITRI in Taiwan.

Gross Output Firms

Let j denotes the sectoral indicator, where $j = 1, \dots, 39$. At period t, the jth sector hires labor $L_t(j)$ and rents capital stock $K_t(j)$ for the production of value-added goods $X_{VA,t}(j)$. The production function for value-added goods follows a constant elasticity of substitution (CES) functional form:

$$X_{VA,t}(j) = \left(\left(\boldsymbol{a_{L(j)}}\right)^{\frac{1}{\eta_{va(j)}}} \left(L_t(j)\right)^{\frac{\eta_{va(j)}-1}{\eta_{va(j)}}} + \left(\boldsymbol{a_{K(j)}}\right)^{\frac{1}{\eta_{va(j)}}} \left(K_t(j)\right)^{\frac{\eta_{va(j)}-1}{\eta_{va(j)}}} \right)^{\frac{\eta_{va(j)}}{\eta_{va(j)}-1}}, \quad (1)$$

where $\boldsymbol{a_{L(j)}}$ denotes labor input ratio, $\boldsymbol{a_{k(j)}}$ denotes capital input ratio, and $\eta_{va(j)}$ denotes elasticity of substitution between labor and capital for the jth sector.

We assume that the jth sector adopts the ith intermediate input $IO_t(i,j)$ to produce the jth intermediate output $IO_t(j)$. The production function takes the Leontief functional form:

$$IO_t(j) = \min\left[\frac{IO_t(1,j)}{a_{io}(1,j)}, \frac{IO_t(2,j)}{a_{io}(2,j)}, \dots, \frac{IO_t(i,j)}{a_{io}(i,j)}\right], \quad (2)$$

where $a_{io}(i,j)$ denotes the ith input coefficient for the jth output. The gross output $\boldsymbol{Y_t(j)}$ is a composite function of intermediate output $IO_t(j)$ and value added goods $X_{VA,t}(j)$, taking the functional form:

$$\boldsymbol{Y_t(j)} = \left(\left(\boldsymbol{a_{IO(j)}}\right)^{\frac{1}{\eta_{y(j)}}} \left(IO_t(j)\right)^{\frac{\eta_{y(j)}-1}{\eta_{y(j)}}} + \left(\boldsymbol{a_{VA(j)}}\right)^{\frac{1}{\eta_{y(j)}}} \left(X_{VA,t}(j)\right)^{\frac{\eta_{y(j)}-1}{\eta_{y(j)}}} \right)^{\frac{\eta_{y(j)}}{\eta_{y(j)}-1}} \quad (3)$$

where $\eta_{y(j)}$ denotes the elasticity of substitution between intermediate output and value-added goods in the jth sector. The law of motion of capital stock is:

$$K_t(j) = \left(1 - \delta(j)\right)K_t(j) + I_t(j) \tag{4}$$

where $\delta(j)$ is capital depreciation rate and $I_t(j)$ is investment of sector of jth sector.

We assume that the labor market is frictionless and labor force are mobile in different sectors. Therefore, labor force is homogenous and labor wage $\boldsymbol{P_{L,t}}$ is the same in all sectors. We assume that capital, however, is heterogeneous. Let $\boldsymbol{P_{k,t}(j)}$ denote capital price in the jth sector. The profit maximization problem of the jth sector is:

$$\begin{aligned}\text{Max } & \boldsymbol{P_{Y,t}(j)Y_t(j)} - \sum_{\boldsymbol{i=1}}^{\boldsymbol{39}} \boldsymbol{P_{Q,t}(i)IO_t(i,j)} \\ & - \left(\boldsymbol{1} + \boldsymbol{\tau_t(j)} + \boldsymbol{\tau_t^s(j)}\right)\boldsymbol{P_{k,t}(j)}K_t(j) - \left(\boldsymbol{1} + \boldsymbol{\tau_t(j)}\right)\boldsymbol{P_{L,t}}L_t(j)\end{aligned} \tag{5}$$

where $\boldsymbol{P_{Y,t}(j)}$ denotes the jth gross output price, $\boldsymbol{P_{Q,t}(j)}$ the price of composite goods, and $\boldsymbol{\tau_t(j)}$ the indirect tax rate. Taiwan 2050 Calculator simulates the amount of investments for energy efficiency improvement. According to Equation (4), the increment of investments contemporarily transforms to capital stock. In the simulation that investments rise relative to the BaU scenarios, capital stock is treated as exogenous as explained in Section 3.3. As a consequence, we can simulate the subsidy rate $\boldsymbol{\tau_t^s(j) < 0}$ such that the capital stock change equals the increment of energy efficiency investments. In the BaU scenario, we set $\boldsymbol{\tau_t^s(j) = 0}$**.** The investment sector in IO-Table corresponds to the demand for the intermediate goods, instead of a production factor for a firm. The specifications on subsidy affect the sectoral capital; therefore, such specifications are consistent with the energy efficiency investments. In addition, we have consider the depreciation rates in order to calculate the capital increments.

Gross output is either sold in the domestic or foreign market. The relationship between gross output, domestic goods, and export is:

$$\boldsymbol{Y_t(j) = D_t(j) + EX_t(j)} \tag{6}$$

where $\boldsymbol{D_t(j)}$ denotes the jth domestic goods, and $\boldsymbol{EX_t(j)}$ denotes the jth export goods.

Composite Output Firms

The composite output $\boldsymbol{Q_t(j)}$ is a combination of domestic and import goods. The profit maximization problem is:

$$\text{Max } \boldsymbol{P_{Q,t}(j)Q_t(j) - P_{D,t}(j)D_t(j) - (1+\tau_{IM,t}(j))P_{IM,t}(j)IM_t(j)} \tag{7}$$

where $\boldsymbol{D_t(j)}$ denotes the jth domestic goods, $P_D(j)$ the domestic price, and $IM_t(j)$ the import goods. The composite output takes the CES form:

$$\boldsymbol{Q_t(j)} = \left(\left(\boldsymbol{a_{D(j)}}\right)^{\frac{1}{\eta_{q(j)}}} \left(\boldsymbol{D_t(j)}\right)^{\frac{\eta_{q(j)}-1}{\eta_{q(j)}}} + \left(\boldsymbol{a_{IM(j)}}\right)^{\frac{1}{\eta_{q(j)}}} \left(\boldsymbol{IM_t(j)}\right)^{\frac{\eta_{q(j)}-1}{\eta_{q(j)}}} \right)^{\frac{\eta_{q(j)}}{\eta_{q(j)}-1}}$$

where $\boldsymbol{a_{D(j)}}$ denotes weight on domestic goods, $\boldsymbol{a_{IM(j)}}$ the weight on import goods, and $\boldsymbol{\eta_{q(j)}}$ the elasticity of substitution between domestic goods and import goods.

Households

The utility function of household $\boldsymbol{U_t}$ is:

$$\boldsymbol{U_t} = \mathbf{U}\left(\sum_{i=1}^{39} \boldsymbol{C_t(i)}, \overline{\boldsymbol{Le}_t}\right) \tag{8}$$

where $\boldsymbol{C_t(i)}$ denotes the consumption the ith goods and $\overline{\boldsymbol{Le}_t}$ denotes aggregate leisure. The aggregation leisure consists of individual leisure:

$$\overline{\boldsymbol{Le}_t} = \sum_{i=1}^{39} \boldsymbol{Le_t(i)} \tag{9}$$

where $\boldsymbol{Le_t(i)}$ is leisure for the ith sector.

Households are owners of firms and pay direct tax for capital and labor. The direct tax on capital is:

$$\boldsymbol{(1+\tau_{k,t})P_{k,t}\bar{K}_t} = \sum_{i=1}^{39} \boldsymbol{P_{k,t}(i)K_t(i)} \tag{10}$$

where $\boldsymbol{\bar{K}_t}$ is aggregate capital stock, $\boldsymbol{P_{k,t}}$ is the aggregation capital price, and $\boldsymbol{\tau_{k,t}}$ is the direct capital tax. The direct tax on labor income is:

$$\left(1 + \tau_{L,t}\right) W_t^a \bar{L}_t = \sum_{i=1}^{39} P_{L,t} L_t(i) \tag{11}$$

where $P_{Le,t}$ is the shadow price that determines the transformation of leisure to labor income, $\bar{L}_t$ is aggregate labor, W_t^a is the aggregation labor wage, and $\tau_{L,t}$ is the direct labor tax rate.

Household income comes from several sources. First, households are owners of the production firms. Each period the households get capital return $P_{k,t}(i)K_t(i)$. Second, households provide labor service to production firms and households earn wage income $W_t^a \bar{L}_t$. Third, the government provides lump-sum transfer T^{LG} to household at price $P_{LG,t}$. Fourth, foreign countries provide lump-sum transfer to households at price $P_{TR*,t}$, such as foreign transfer of capital income T^{k*}, foregin transfer of labor income T^{L*}, foreign transfer of household income T^{H*}, and subtract trade balance TB_t. TB_t is a trade surplus (definite) if $TB_t > 0 \ (< 0)$. Household expenditure includes consumption $P_{Q,t}(i)C_t(i)$.

Households maximize utility subject to the budget constraint:

$$\begin{aligned}(1 - s_t^L) W_t^a \bar{L}_t + (1 - s_t^K) P_{k,t} \bar{K}_t + P_{LG,t} T^{LG} + P_{TR*,t}\left(T^{k*} + T^{L*} + T^{H*} - TB_t\right) \\ = \sum_{i=1}^{39} \left(P_{Q,t}(i) C_t(i)\right)\end{aligned} \tag{12}$$

where s_t^L denotes the saving rate of labor income, and s_t^K is the saving rate of capital income.

Importing Firms

We let $P_{IM,t}(j)$ denote the selling price of import goods to the domestic market. The importing firms buy imports goods at price $P_{world,t}(j)$ from foreign countries and sell these goods at price $P_{IM,t}(j)$ to domestic market. We do not consider the nominal exchange rate in this model; therefore, $P_{world,t}(j)$ is denominated in domestic currency. The profit maximization problem of importing firms is:

$$\text{Max } P_{IM,t}(j) IM_t(j) - P_{world,t}(j) IM_t(j) \tag{13}$$

Exporting Firms

The exporting firms buy gross goods at price $P_{Y,t}(j)$ and sell them to foreign countries at price $P_{world,t}(j)$. The profit maximization problem of exporting firms is:

$$\text{Max}\ \boldsymbol{P_{world,t}(j)EX_t(j)} - \boldsymbol{P_{Y,t}(j)EX_t(j)} \qquad (14)$$

Investments

The public saving and private savings constitute the investment $I_t(i)$, inventory $\boldsymbol{I_t^{INV}(i)}$ and domestic investment in foreign countries I_t^*:

$$\boldsymbol{s_t^L W_t^a \bar{L}_t} + \boldsymbol{s_t^K P_{k,t} \bar{K}_t} + \boldsymbol{P_{gs,t} S_t^g} = \boldsymbol{P_{TR*,t} I_t^*} + \sum_{\boldsymbol{i=1}}^{\boldsymbol{39}} \boldsymbol{P_{Q,t}(i)} I_t(i) + \sum_{\boldsymbol{i=1}}^{\boldsymbol{39}} \boldsymbol{P_{Q,t}(i) I_t^{INV}(i)} \qquad (15)$$

where $\boldsymbol{S_t^g}$ denotes the government saving at price $\boldsymbol{P_{gs,t}}$, I_t^* denotes domestic investment in foreign countries, $I_t(i)$ is domestic investment, and $I_t^{INV}(i)$ is inventory.[8]

Government Budget Constraint

The government purchases composite output $G_t(i)$ at price $\boldsymbol{P_{Q,t}(i)}$ for public service. Let G_t denote total government spending and $\boldsymbol{P_{G,t}}$ denote the price of government goods:

$$\boldsymbol{P_{G,t}} G_t = \sum_{\boldsymbol{i=1}}^{\boldsymbol{39}} \boldsymbol{P_{Q,t}(i)} G_t(i) \qquad (16)$$

The government income consists of capital tax income, labor tax income, foreign transfer to domestic government, and import tax income. The government budget constraint is:

[8] The IO table of Taiwan provides information of inventory; therefore, we consider a variable $I_t^{INV}(i)$ in AIM/CGE to match the data. The real inventory is an exogenous variable in all periods.

$$\sum_{i=1}^{39} \boldsymbol{P_{Q,t}(i)} G_t(i) + \boldsymbol{P_{gs,t}} S_{g,t} + \boldsymbol{P_{LG,t}} T^{LG}$$
$$= \sum_{j=1}^{39} \boldsymbol{\tau_t(j) P_{k,t}} K_t(j) + \sum_{j=1}^{39} \boldsymbol{\tau_t(j) P_L} L_t(j)$$
$$+ \sum_{j=1}^{39} \boldsymbol{\tau_{IM,t}(j) P_{IM,t}(j) IM_t(j) + \tau_{k,t} P_{k,t} \bar{K}_t + \tau_{L,t} W_t^a \bar{L}_t + P_{TR*,t}} T^{G*} \tag{17}$$

where the right hand side of Equation (17) denotes government income while the left hand side denotes the fiscal spending as well as government saving.

International Transaction

The foreign transaction balance is determined by:

$$\boldsymbol{I_t^*} + \sum_{j=1}^{39} \boldsymbol{P_{world,t}(j) IM_t(j)}$$
$$= \sum_{j=1}^{39} \boldsymbol{P_{world,t}(j) EX_t(j) + P_{TR*,t}\left(T^{k*} + T^{L*} + T^{H*} - TB_t - T^{G*}\right)} \tag{18}$$

and the net export is defined as:

$$\boldsymbol{P_{TR*,t} NX_t} = \sum_{j=1}^{39} \boldsymbol{P_{world,t}(j) EX_t(j)} - \sum_{j=1}^{39} \boldsymbol{P_{world,t}(j) IM_t(j)} \tag{19}$$

Resource Constraint

The resource constraint is:

$$\sum_{j=1}^{39} \boldsymbol{P}_{Y,t}(\boldsymbol{j})\boldsymbol{Y}_t(\boldsymbol{j}) = \sum_{j=1}^{39}\sum_{i=1}^{39} \boldsymbol{P}_{Q,t}(\boldsymbol{i})\boldsymbol{IO}_t(\boldsymbol{i},\boldsymbol{j}) + \sum_{i=1}^{39}\left(\boldsymbol{P}_{Q,t}(\boldsymbol{i})\boldsymbol{C}_t(\boldsymbol{i})\right) + \sum_{i=1}^{39} \boldsymbol{P}_{Q,t}(\boldsymbol{i}) I_t(i) + \sum_{i=1}^{39} \boldsymbol{P}_{Q,t}(\boldsymbol{i})\boldsymbol{I}_t^{INV}(\boldsymbol{i}) + \sum_{i=1}^{39} \boldsymbol{P}_{Q,t}(\boldsymbol{i})\boldsymbol{G}_t(\boldsymbol{i}) + \sum_{j=1}^{39} \boldsymbol{P}_{Y,t}(\boldsymbol{j})\boldsymbol{EX}_t(\boldsymbol{j}) - \sum_{j=1}^{39}\left(\boldsymbol{1} + \boldsymbol{\tau}_{IM,t}(\boldsymbol{j})\right)\boldsymbol{P}_{IM,t}(\boldsymbol{j})\boldsymbol{IM}_t(\boldsymbol{j}) \tag{20}$$

That is, the composite output is distributed to intermediate goods, consumption, investment, inventory, government expenditure, and net exports.

A.2 Calibration and Estimation for AIM/CGE

We adopt two approaches for the specifications on CGE parameters. First we apply data of Taiwan for the parameter calibration. Second, we adopt the Bayesian technique for the estimation of elasticity parameters based upon the structural equations of CGE. We construct the social account matrix (SAM) using data from Directorate-General of Budget, Accounting and Statistics, Executive Yuan in Taiwan.

A.2.1 Parameter Calibration

To solve CGE model, we have to set up the initial values for endogenous variables. Let $t = 0$ correspond to the period of Taiwan's IO table in 2011. For example, $IO_0(i, j)$ is the initial value for input-output while $X_{VA,0}(j)$ is the initial value for value added. The following initial values are set according to the 2011 IO table in Taiwan: $EX_0(i)$, $C_0(i)$, $I_0(i)$, $L_0(j)$, $G_0(i)$, $K_0(j)$ and $IM_0(i)$. Because there is no data for leisure, we set the initial value of leisure equal to labor endowment, $\boldsymbol{Le_0(i)} = L_0(i)$**.** We normalize the prices to be 1.

The indirect tax rate is set to:

$$\tau_0(i) = \frac{T_0^{IND}(i)}{X_{VA,0}(i)}$$

where $T_0^{IND}(i)$ denotes the indirect tax income of Taiwan's government. The import tax rate is set to:

$$\tau_{IM,0}(i) = \frac{T_0^{IM}(i)}{IM_0(i)}$$

where $T_0^{IM}(i)$ denotes the import tax income of Taiwan's government. The direct tax rate and saving rate – such as $\boldsymbol{\tau_{k,0}}$, $\boldsymbol{\tau_{L,0}}$, $\boldsymbol{s_0^L}$, $\boldsymbol{s_0^K}$, $\boldsymbol{\tau_{IM,0}}$, $\boldsymbol{\tau_{k}}_{,0}$ and $\boldsymbol{\tau_{L,0}}$ – are calibrated according to SAM in 2011.

The initial value for gross output is:

$$\boldsymbol{Y_0}(\boldsymbol{j}) = \sum_{\boldsymbol{i}=\boldsymbol{1}}^{\boldsymbol{39}} \boldsymbol{IO_0}(\boldsymbol{i}, \boldsymbol{j}) + \left(\boldsymbol{1} + \boldsymbol{\tau_0}(\boldsymbol{j})\right)K_0(j) + \left(\boldsymbol{1} + \boldsymbol{\tau_0}(\boldsymbol{j})\right)L_0(j)$$

The initial value of domestic goods is:

$$\boldsymbol{D_0}(\boldsymbol{j}) = Y_0(j) - \boldsymbol{EX_0}(\boldsymbol{j})$$

The initial value of composite goods is:

$$\boldsymbol{Q_0(j) = D_0(j) + (1 + \tau_{IM}(j))IM_0(j)}$$

The initial value of total government spending is:

$$G_0 = \sum_{\boldsymbol{i=1}}^{\boldsymbol{39}} G_0(i)$$

The following variables are calibrated to the 2011 SAM of Taiwan: $S_{g,0}$, T^{LG} and T^{G*}.

A.2.2 Elasticity Estimation

We adopt the Bayesian technique for the estimation of elasticity of substitution. The first order conditions (FOC) of Equation (3) are:

$$\boldsymbol{IO_t(j) = a_{IO(j)} \left(\frac{P_{Q,t}(i)}{P_{Y,t}(j)}\right)^{-\eta_{y(i)}} Y_t(j)}$$

$$\boldsymbol{X_{VA,t}(j) = a_{VA(j)} \left(\frac{P_{VA,t}(j)}{P_{Y,t}(j)}\right)^{-\eta_{y(i)}} Y_t(j)}$$

where $\boldsymbol{P_{VA,t}(j)}$ is the value-added price. We can combine these two equations to:

$$\boldsymbol{\frac{IO_t(j)}{X_{VA,t}(j)} = \frac{a_{IO(j)}}{a_{VA(j)}} \left(\frac{P_{VA,t}(j)}{P_{Q,t}(j)}\right)^{\eta_{y(i)}}}$$

We take logarithm on both side of equation:

$$\begin{aligned}\boldsymbol{\log\left(P_{Q,t}(i)IO_t(i)\right)} &\boldsymbol{= \log\left(\frac{a_{IO(j)}}{a_{VA(j)}}\right) + \left(1-\eta_{y(i)}\right)\log\left(P_{Q,t}(i)\right) + \eta_{y(i)}\log\left(P_{VA,t}(i)\right)} \\ &\boldsymbol{+ \log\left(X_{VA,t}(j)\right)}\end{aligned}$$

The econometric model for estimation is:

$$\begin{aligned}\boldsymbol{\log\left(P_{Q,t}(i)IO_t(i)\right)} &\boldsymbol{= c(i) + \left(1-\eta_{y(i)}\right)\log\left(P_{Q,t}(i)\right) + \eta_{y(i)}\log\left(P_{VA,t}(i)\right) + \log\left(X_{VA,t}(j)\right)} \\ &\boldsymbol{+ \varepsilon_t(j)}\end{aligned}$$

where $\boldsymbol{\varepsilon_t(j)}$ is a forecast error of the $\boldsymbol{j}$th sector. $\boldsymbol{\varepsilon_t(j)}$ captures the effects from other unobservable information. The following times series data are adopted for estimation: nominal intermediate goods $(\boldsymbol{P_{Q,t}(i)IO_t(i)})$, the wholesale price index $(\boldsymbol{P_{Q,t}(i)})$**,** the price index for value added $(\boldsymbol{P_{VA,t}(i)})$, and real valued added $(\boldsymbol{X_{VA,t}(j)})$. This estimation for AIM/CGE is based upon a partial equilibrium assumption, but not a full information approach like the DSGE model in the literature. The CGE model has a large scale; therefore, the full information approach could be too cumbersome to estimate using the Bayesian technique. In addition, we do not have complete data for each sector and the full information estimation might not be operational. We, therefore, choose the partial equilibrium approach for the estimation.

We adopt the Bayesian technique for the estimation of $\eta_{y(i)}$. Let D the set of explained variables $\log\left(P_{Q,t}(i)IO_t(i)\right)$. The Bayesian estimation requires the specifications of prior distribution $p(\eta_{y(i)})$, and the likelihood function $p(D|\eta_{y(i)})$. The prior distributions shrink the parameters to the parameter space that is subjectively set by a researcher. The likelihood function evaluates the sample fit of model to time series. The posterior $p(\eta_{y(i)}|D)$, taken logarithm, is:

$$\log(p(\eta_{y(i)}|D)) = \log\left(p\left(D\middle|\eta_{y(i)}\right)\right) + \log(p(\eta_{y(i)})) \tag{21}$$

The prior distribution for $\eta_{y(i)}$ is:

$$\eta_{y(i)} \sim Gamma(2, 0.5)$$

where $\eta_{y(i)}$ follows a Gamma distribution with mean 2 and standard deviation 0.5. The likelihood function is

$$\log\left(p\left(D\middle|\eta_{y(i)}\right)\right) = -T log(2\pi) - 0.5\, log(|\Sigma|) - 0.5(D - \widehat{D})'\Sigma^{-1}(D - \widehat{D})$$

The fitted value $\widehat{D}_t$ is generated by:

$$\widehat{D} = \boldsymbol{\hat{c}(i)} + \left(\boldsymbol{1} - \boldsymbol{\hat{\eta}_{y(i)}}\right)\mathbf{log}\left(\boldsymbol{P_{IO}(i)}\right) + \left(\boldsymbol{\hat{\eta}_{y(i)}}\,\mathbf{log}\left(\boldsymbol{P_{VA}(i)}\right)\right) + \mathbf{log}\left(\boldsymbol{X_{VA,t}(j)}\right)$$

and the covariance matrix is:

$$\Sigma = \mathrm{E}\left(D_t - \widehat{D}_t\right)'(D_t - \widehat{D}_t)$$

We adopt Metropolis–Hastings algorithm for the MCMC draws. The number of draws is set to 100,000 times. An and Schorfheide (2007) offer a description for the Metropolis–Hastings procedure.

Directorate-general of Budget, Accounting and Statistics, Executive Yuan in Taiwan does not provide time series data for the sub-sectors such as diesel oil and fuel oil; therefore, it is impossible to estimate the elasticity values of these sub-sectors. The estimated elasticity of an aggregated sector is adopted for a sub-sector. For example, the elasticity value of crude oil sector is imposed on these of the diesel oil sector.

A.2.3 Elasticity in AIM/CGE for Taiwan

Table A 1 shows the elasticity in AIM/CGE for Taiwan. The elasticity is either estimated by the Bayesian technique or adopted from the literature. The number of each sector corresponds to the median values of MCMC draws while the numbers in parenthesis shows the 90% error bands. For the sub-sectors with one star (*), it is difficult to reconcile these sub-sectors in the respective databank of Bureau of Foreign Trade, Ministry of Economic Affairs and Directorate-General of Budget, Accounting and Statistics, Executive Yuan. We estimate the elasticity of the aggregate sectors. The estimated parameters are the same for these sub-sectors. For the sub-sectors with double stars (**), Bureau of Foreign Trade, Ministry of Economic Affairs does not offer data for their international service trade. We adopt the elasticity of Yang (2009) for these sectors.

Table A 1: The Elasticity in AIM/CGE for Taiwan

Sector	$\eta_{y(i)}$	$\boldsymbol{\eta}_{\boldsymbol{q}(\boldsymbol{j})}$
1. Agriculture and Fishing	0.5	0.8
	(0.4,0.7)	(0.7,0.9)
2. Crude Oil	0.4	1.2
	(0.0,0.9)	(1.1,1.2)
3. Natural Gas	0.4	1.2
	(0.0,0.9)	(1.1,1.2)
4. Coal	0.4	1.2
	(0.0,0.9)	(1.1,1.2)
5. Other Mineral	0.4	1.2
	(0.0,0.9)	(1.1,1.2)
6. Textile	0.9	0.4

	(0.7,1.1)	(0.1,0.8)
7. Paper	0.8	0.8*
	(0.0,1.7)	(0.0,1.7)
8. Petroleum Products	0.2	0.8*
	(0.1,0.2)	(0.0,1.7)
9. Diesel Oil	0.2	0.8*
	(0.1,0.2)	(0.0,1.7)
10. Fuel Oil	0.2	0.8*
	(0.1,0.2)	(0.0,1.7)
11. Other Petroleum	0.2	0.8*
Products	(0.1,0.2)	(0.0,1.7)
12. Coke Coal	0.2	0.8*
	(0.1,0.2)	(0.0,1.7)
13. Ethylene	0.0	0.1
	(0.0,0.0)	(0.0,0.2)
14. Other Chemicals	0.0	0.1
	(0.0,0.0)	(0.0,0.2)
15. Plastic Products	0.0	0.1
	(0.0,0.1)	(0.0,0.2)
16. Cement	0.4	0.8*
	(0.3,0.6)	(0.0,1.7)
17. Cement Products	0.4	0.8*
	(0.3,0.6)	(0.0,1.7)
18. Steel	0.1	0.1
	(0.0,0.1)	(0.0,0.1)
19. Iron	0.1	0.1
	(0.0,0.1)	(0.0,0.1)
20. Semiconductor	0.9	0.8*
	(0.8,1.1)	(0.0,1.7)
21. Other Electronics	0.9	0.8*
	(0.8,1.1)	(0.0,1.7)
22. Solar Cell	0.9	0.8*
	(0.8,1.1)	(0.0,1.7)
23. Other Manufacturing	0.3	0.8*
	(0.1,0.5)	(0.0,1.7)
24. Power Generation	0.6	0.33**
	(0.5,0.7)	
25. Combined Heat and	0.6	0.33**
Power (CHP)	(0.5,0.7)	
26. Manufactured Gas	0.7	0.33**
	(0.3,1.0)	
27. Construction	0.3	0.33**
	(0.0,0.5)	
28. Wholesale and Retails	0.7	0.9**
	(0.6,0.8)	
29. Railroad Transportation	0.5	0.9**
	(0.3,0.6)	

30. Transit Transportation	0.5 (0.3,0.6)	0.9**
31. Other Passenger Transportation	0.5 (0.3,0.6)	0.9**
32. Cargo Transportation	0.5 (0.3,0.6)	0.9**
33. Waterway Transportation	0.0 (0.0,0.0)	0.9**
34. Aviation Transportation	0.0 (0.0,0.0)	0.9**
35. Hotel and Restaurant	1.0 (1.0,1.0)	0.3**
36. Public Service	0.0 (0.0,0.0)	0.3**
37. Education	0.0 (0.0,0.0)	0.3**
38. Medical Cares	0.0 (0.0,0.0)	0.3**
39. Other Service	0.9 (0.9,1.0)	0.3**

Note: The number of each sector corresponds to the median values of MCMC draws while the numbers in parenthesis shows the 90% error bands.

* It is difficult to reconcile these sub-sectors in the respective databank of Bureau of Foreign Trade, Ministry of Economic Affairs and Directorate-General of Budget, Accounting and Statistics, Executive Yuan. We aggregate of the dataset of these sub-sectors and estimate the elasticity for the aggregate data. The elasticity of these sub-sectors are the same as that of the aggregate sector.

** Bureau of Foreign Trade, Ministry of Economic Affairs does not offer foreign trade data for these sub-industrial sectors. We adopt the elasticity of Yang (2009) for these sub-sectors.

A.2.4 Sectoral Link Between 2050 Calculator and AIM/CGE: Energy Efficiency Investment

This subsection demonstrates the sectoral link between 2050 Calculator and AIM/CGE for Taiwan. 2050 Calculator provides detail information for the energy efficiency investment. We categorize each investment corresponding to the sectors in AIM/CGE for Taiwan. The bold text indicates the sub-sectors in AIM/CGE, while the italic text implies the investment sources in 2050 Calculator.

Table A 2: The Link of Energy Efficiency Investment in 2050 Calculator and Sectors in AIM/CGE

Semiconductor, Other Electronics, and Solar Cell	**Other Chemicals**	**Other Passenger Transportation**	**Other Service**		**Wholesale and Retails**
Production Process	*Chemicals*	*Road Passenger Transport*	*Air conditioning*	*Electric fan*	*Convenient Store*
Air Compressor		*Tour Bus*	*Old building insulation*	*Electric pot*	*Supermarket*
Ice Water Maker	**Paper**	*City Bus*	*New building insulation*	*Laptop Computer*	*Discount store*
	Paper Production	*Long Distance Minibus*	*LED Tube*	*Desktop Computer*	*Department Store*
Steel and Iron		*Short Distance Minibus*	*LED lamp*	*Gas stove*	
Integrated steel mill	**Hospital**	*Motorcycle*	*LED Spotlights*	*Electric Boiler*	**Hotel and Restaurant**
electric arc furnace	*Hospital*		*Refrigerator*	*water dispenser*	*International Hotel*
steam boiler		**Cement**	*Gas water heater*	*Rapid Gas stove*	*Hotel*
Air compressor	**Cargo Transportation**	***Cement***	*Reserve type electric water heater*	*Business Building*	
	Big Truck		*Instant electric water heater*	*TV*	**Education**
Textile	*Small Truck*	**Other Manufacturing**	*Heat pump electric water heater*	*Outdoor LED*	*School*
Production Process		*Production Process*	*Management System for Residence*		

Note: The bold text indicates the sub-sectors in AIM/CGE, while the italic text implies the energy efficiency investments in 2050 Calculator.

A.3 History of Taiwan 2050 Calculator

With the supports of Bureau of Energy, Ministry of Economic Affairs in Taiwan, ITRI cooperated with DECC in the United Kingdom to build Taiwan 2050 Calculator in 2013.

During the construction of Taiwan 2050 Calculator, 70 experts joined 10 consultation meetings for the discussions of the scenario assumptions. Taking offshore wind development as an example, experts evaluated factors such as wind speed, water depth, environmental conservation areas, ship course and military areas. More than 130 low-carbon technologies and 30 major scenarios are considered in Taiwan 2050 Calculator.

To ensure the reasonability of scenarios, experts were invited to review Taiwan 2050 Calculator. Over 100 experts from electricity system operator, academia, business industries, government agencies, non-governmental organizations (NGOs), and other organizations participated the review process. In addition, participants were invited to review preliminary results. Model constructors modified the scenarios and assumptions according to the feedbacks from experts. Official responses were announced if experts' suggestions were not accepted due to lack of evidence. Regional think tanks, state-owned utility company, energy and environment authorities, industrial leaders and NGO groups in Taiwan were invited to review Taiwan 2050 Calculator.

After 7 months of intensive construction, Taiwan 2050 Calculator opened to the public and became the fifth party of DECC in the world.