Load pattern and the deployment of renewables in Taiwan within the TIMES framework

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Abstract

A sustainable national energy system plays a key role in economic growth. Since the climate change is a global hot issue, renewable energy development (namely, energy exploitation) has been viewed as an effective solution to support energy service demand, as well as to mitigate fossil fuel depletion, environmental degradation, and the uncertainty of oil prices. Considering the independency of Taiwan's power grid, the renewable intermittence should be a serious consideration in planning energy supply and demand while renewable power provides an increasing share of the energy mix.

The Taiwan TIMES model has been developed and implemented to assess the energy supply and demand planning of national energy policy. This study applied this model to build the temporal fluctuation pattern of power supply in Taiwan. Our results show that the power intermittency does affect the commercialization process of renewable energy. This implies that the intermittent nature is essential to deploy the renewable energy and to plan a solid national energy supply and demand scheme.

Keywords：Load pattern; Taiwan TIMES model; intermittent; renewable; residential and service sector; cooling demand.

1. Introduction

It is the key driver of economic growth to establish a sustainable national energy system. The use of imported energy including coal, oil, and natural gas accounts for 97.5% of total energy use in 2012 (BOE, 2014a). Currently, renewable energy development (one approach of energy exploitation) has been viewed as an effective alternative to mitigate fossil fuel depletion, environmental degradation, and the uncertainty of oil prices. However, there is an independent electricity grid in Taiwan. The intermittence of most renewable resources can create problems to electricity grids when renewable energy provides an increasing share of the energy mix. Is

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there a suitable modelling framework that can explore the consequence of application of renewable energy? This study employed the high-resolution Taiwan TIMES Model, which optimizes the investment and operation of photovoltaic (PV) and wind power systems until 2030.

The energy conservation is also critical for sustainable energy policy, which might affect the development of renewable sources. Previous literature has not explicitly considered the interaction between energy conservation and exploitation. In Taiwan, air conditioners in buildings account for over 40% of the total electricity consumed in the residential and service sectors (Ku, 2003; TGPF, 2012). Inefficient air conditioners waste considerable amounts of money and energy. The Bureau of Energy (BOE), Ministry of Economic Affairs has been gradually setting up the efficiency criteria, like minimum energy performance standards, to accelerate the replacement to more efficient air conditioners and cooling technology improvement. This study investigated the effect of implement of efficiency criteria for air conditioning in the residential and service sectors on renewable energy development.

The paper is organized in five sections. Section 2 describes the renewable energy development status. Section 3 provides the methodological advances proposed in this paper and scenario description. Section 4 exhibits the simulated results and discussions. Finally, Section 5 draws some conclusions and discusses further developments.

2. Renewable energy development status

The issues of climate change and energy security have led to the renewable energy development. Nuclear power was regarded as a useful solution to CO_2 emission reduction in the world's most countries. The Japan 311 Nuclear Disaster fuelled intense debates over the safety of nuclear power, which has brought its development to a standstill. Table 1 illustrates the deployment and investment of renewable sources in world.

Table 2 summarizes of Taiwan's development strategies for renewable power technologies. The government approved the "Renewable Energy Development Act (REDA)" to set a renewable energy target of 6,500-10,000 MW of domestic installed capacity, and began implementing the Feed-in Tariffs (FIT) mechanism in 2009. At same time, the "Dawning Green Energy Industry Program" was mapped out the blueprint for Taiwan's low carbon energy development in the future. Thus, 10% of the 500 billion NTD for the 4-year "Economic Revitalization Policy Project to Expand Investment in Public" would be allocated to the development of green energy. These measures set the foundation for Taiwan's renewable energy development.

Table 1 Global renewable energy deployment and investment

Selected global indicators	2008	2009	2010	2011	2012	2013
Investment in new renewable capacity (billion USD/year)	130	160	211	257	244	214
Existing renewables power capacity, including large-scale hydro (GWe)	1,140	1,230	1,320	1,360	1,470	1,560
Existing renewables power capacity, excluding large hydro (GWe)	200	250	312	390	480	560
Hydropower capacity (existing) (GWe)		915	945	970	990	1,000
Wind power capacity (existing) (GWe)	121	159	198	238	283	318
Solar PV capacity (grid-connected) (GWe)	16	23	40	70	100	139
Solar hot water capacity (existing) (GWe)	130	160	185	232	255	326
Ethanol production (annual) (billion liters)	67	76	86	86	83	87
Biodiesel production (annual) (billion liters)	12	17	19	21	22	26
Countries with policy targets for renewable energy use	79	89	98	118	138	144

Source: REN21 (2012, 2014)

Table 2 Taiwanese policy deployment target of renewable energy

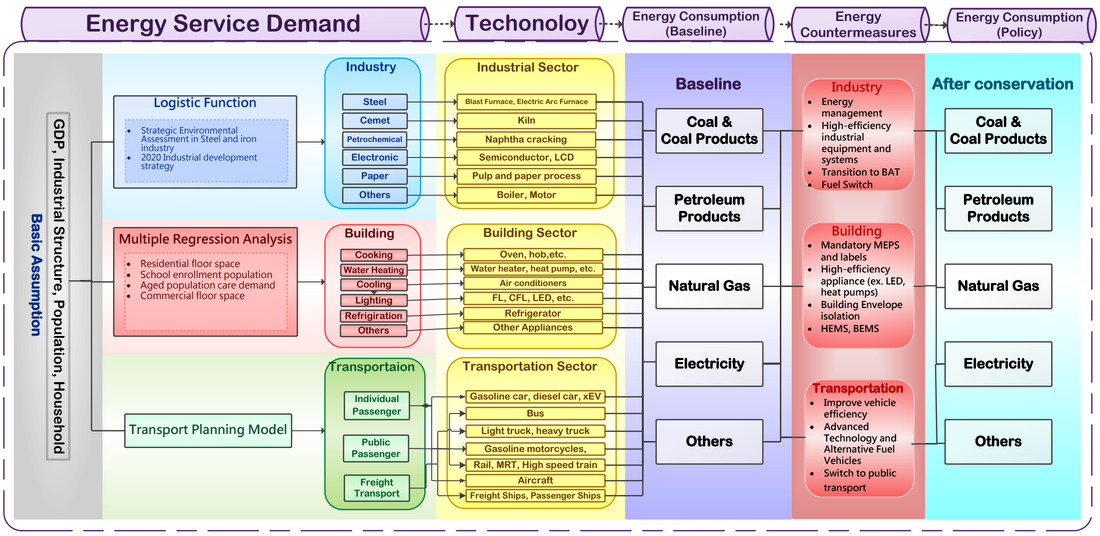
		Installed capacity (MW)								
Energy source		2009	2010	2011	2012	2013	2015	2020	2025	2030
Wind	Onshore	374	476	523	571	614	814	1,200	1,200	1,200
	Offshore	0	0	0	0	0	15	320	1,520	3,000
Hydro		1937	1977	2041	2081	2,081	2,089	2,100	2,150	2,200
PV		10	22	118	223	392	842	2,120	4,100	6,200
Geothermal		0	0	0	0	0	4	66	150	200
Biomass		739	739	736	740	740	745	768	813	950
Total		3,060	3,215	3,417	3,615	3,828	4,509	6,574	9,933	13,750

Source: BOE (2014a, 2014b)

3. Methodology

(1) Taiwan TIMES model and policy scenarios

This study adopted Taiwan TIMES model to explore the effect of load pattern on the deployment of renewable energy from 2010 to 2030. TIMES (The Integrated MARKAL-EFOM System) is a combination of both the MARKAL and EFOM (Energy Flow Optimization Model) models, developed by IEA-ETSAP. The Industrial Technology Research Institute (ITRI) has established the Taiwan TIMES model since 2007 with funding support by the Bureau of Energy (BOE), Ministry of Economic Affairs. It has played an important role in making energy policy decisions. Currently, our model database is categorized by three major technologies: conversion technology (63 items), processing technology (75 items), and demand technology (256 items). The Taiwan TIMES model relies on a wide range of materials and information sources including national statistics, reports, websites, as well as achievements gained from the voluntary “Energy Label” program initiated by the BOE.

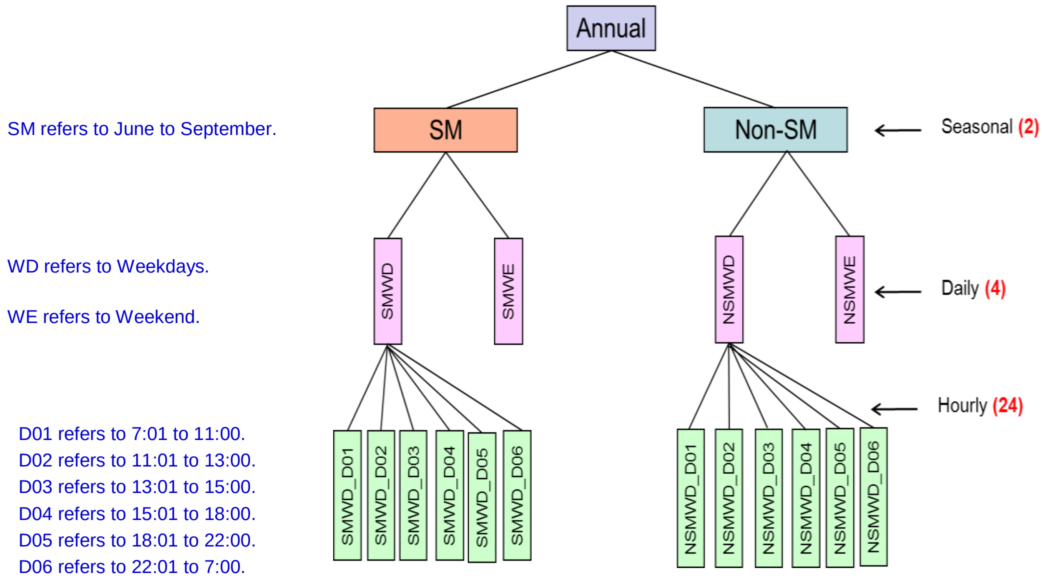


Source：Taiwan TIMES Model, ITRI.

Figure 1　Analyzed procedures in Taiwan TIMES Model

The TIMES model is a technology explicit, dynamic partial equilibrium models of energy markets.　It balances the energy supply and demand by minimizing total energy system cost, as well as satisfying the energy service demand.　Therefore, the estimation of energy service demand is the most important exogenous parameter of the TIMES model and is the essential driving force behind a long-term projection for a sustainable energy use.　Figure1 illustrates the procedure of the Taiwan TIMES model. Incorporated with updated energy service demand (based on the latest social and economic information), the technology database and the conditions and assumptions of scenarios, this model could conduct various scenarios to simulate future energy demand.

A major feature of TIMES consists on its flexibility of time resolution setting, which can be defined by the user with as much or as detail as desired. The innovation of the model developed in this study is that each year is divided into summer/non-summer, weekdays/weekend and six divisions per day (totaling 24 periods per year, shown in Figure 2). This increase in time resolution needs electricity consumption profiles for each sector and profiles for the availability of renewable energy to be assumed for the different days and seasons.



Source: Taiwan TIMES Model, ITRI.

Figure 2 Mode of time slice in Taiwan TIMES Model

Table 3 Scenario description

Scenario	Description
Without time slices	
CASE1	■ Without energy efficiency policies of air conditioning for residential and service sectors ■ Introducing the renewable energy technological database
CASE2	■ With energy efficiency policies of air conditioning for residential and service sectors ■ Introducing the renewable energy technological database
With time slices (totally 24 time divisions)	
CASE3	■ Without energy efficiency policies of air conditioning for residential and service sectors ■ Introducing the renewable energy technological database
CASE4	■ With energy efficiency policies of air conditioning for residential and service sectors ■ Introducing the renewable energy technological database

With the mode of time divisions within a year, Pina et al. (2011) suggested that the TIMES model can optimize the investment decision of renewable energy taking into account the existence of peak and off-peak hours, hourly variations in renewable electricity production and time specific consumptions. Therefore, this study applied the Taiwan TIMES Model to assess the effect of electrical load pattern on the renewable energy development. Previous literature has not explicitly considered the cooperative and competitive interaction between two types of energy policies, energy conservation and exploitation (namely, reducing energy consumption and increasing energy supply). Actually, Taiwan government have devoted to greenhouse gas emissions through energy efficiency policies and increasing use of renewable energy. It is important to explore the effect of energy conservation policy on the development of renewable energy. The simulated scenarios are presented in

Table 3.

(2) Cooling energy service demand for residential and service sectors

In assessing the impact of load patter, the basic assumptions of social and economic scenario must be established. These include actual economic growth rate, population and household growth rate, industrial transition, world energy price, etc. The detailed settings for these assumptions are shown in Table 1.

Table 4 Basic assumptions

Driver	Assumption
GDP	Annual average GDP growth of 2.80% (2010-2030).
Industrial Structure	Share of primary sector of GDP is about 1.01%, secondary increases little and tertiary sector decreases to a share of 59.71% in 2030.
Population	Annual growth rate is 0.04%.
Household	Mean size of household decreases; annual growth rate of household is 1.23% from 2010 to 2030.
Energy Carrier Prices	Based on Word Energy Outlook 2013 (IEA) and American Energy Outlook 2013 (EIA).

Source：TaiSEND (2014), Council for Economic Planning and Development (2013), IEA (2013), WEO (2013).

Prior to scenario simulation, this study applied the multiple regression model to project the energy service demands of residential and service sectors, considering economic growth rate, historical electricity consumption, gross domestic product, number of households, building floor space and population, cooling capability, operating hours, etc. (see Fig. 3). Even though Taiwan’s population is heading toward a negative growth track, the cooling energy service demand is still increasing.

The driving forces are the increasing electricity demand for cooling due to global warming and the declining cost of cooling equipment with mature technology. The estimation of cooling energy service demand for residential and service sectors is displayed in Table 2.

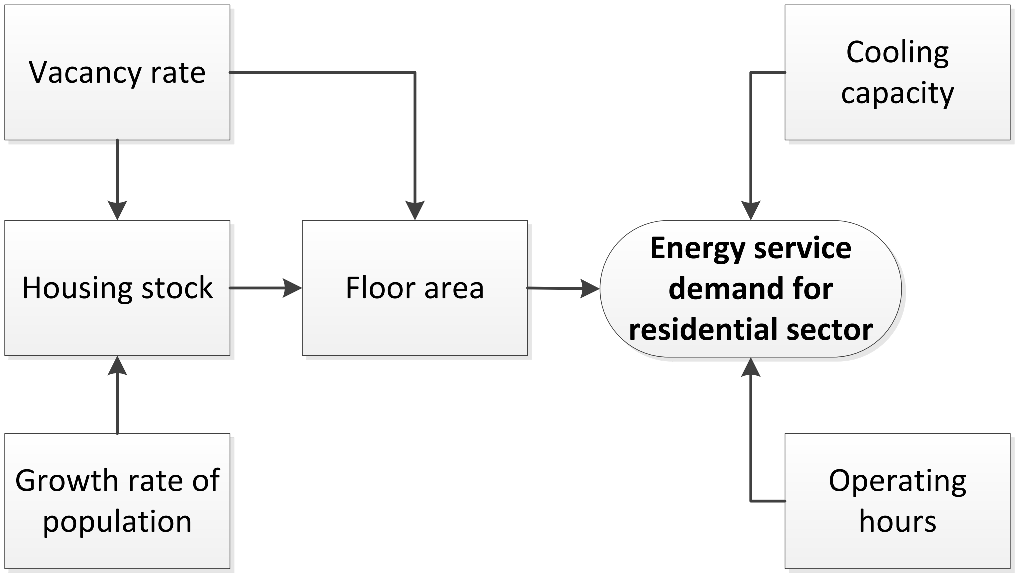


Figure 3 Scheme for cooling energy service demand for residential sector

Table 5 Estimation of cooling energy service demand for residential and service sectors

	Real data (GWh/yr)	Estimation of growth rate (%/yr)			
Year	2010	2011-2015	2016-2020	2021-2025	2026-2030
Residential sector	31,003	2.29%	1.73%	1.54%	1.32%
Service sector	71,700	2.10%	2.82%	2.45%	2.42%

(3) Database of air conditioning and renewable energy technology

The climate change has stimulated the cooling demand for residential and service sectors. During the summer, the electricity consumption of air conditioning accounts for 67% or more of total peak load in Taiwan (TGPF, 2012). This direction has accelerated the development of numerous measures of energy efficiency managements that can drive higher energy efficiencies. Taiwan's government, as well as most countries' in the world, has been aggressively pursuing energy efficiencies by means of Energy Label (EL), Energy Efficiency Rating (ER), Minimum Energy

Performance Standards (MEPS) and the draft of Cooling Seasonal Performance Factor (CSPF) in order to reduce the energy use for meeting cooling demand. This paper adopted the air conditioning technology data based on Taiwan's current and ongoing energy efficiency programs (see Table 3 and 4), as for the market penetration of air conditioning was sourced from Taiwan 2050 Calculator (ITRI, 2014).

To cope with the intermittent nature of renewable energy, this paper applied the time-slice functionality of TIMES framework to configure the varying power production of renewable energy based on the TaiPower's (2014) (Taiwan's state-own power enterprise) power curve (shown in Figure 4). The information is important to make reasonable decisions of renewable energy deployment planning. Considering that the natural geographical features will limit the development of renewable energy, we referred to the database of Taiwan 2050 Calculator (ITRI, 2014) and Taiwan's governmental policy target (see Table 2) to set the upper limits of installation of onshore wind power and PV, at 9 and 1.2 GW respectively. The investment and O&M (operating and maintenance) costs of renewable energy were updated from the Taiwan 2050 Calculator (see Figure 5).

Table 6 Key parameters of current and new air conditioners for residential sector

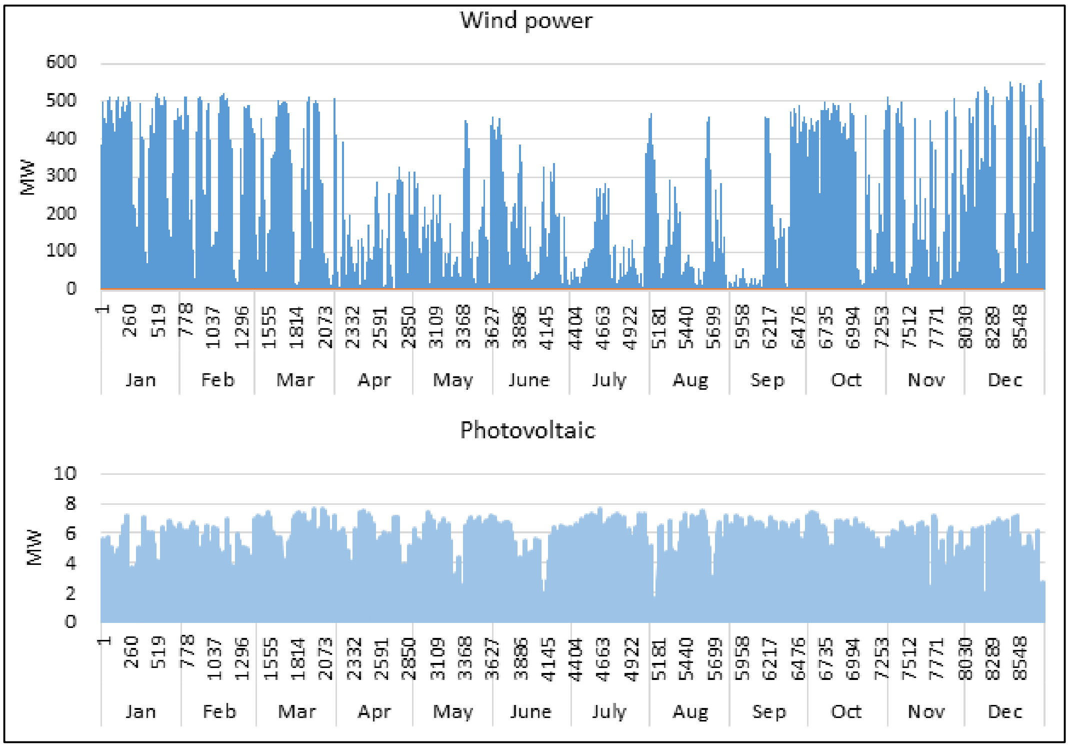
Parameter	Unit	Window-type air conditioner			Split-type air conditioner			Central air conditioner	Box -type air conditioner	
		R20 (2002MEPS)	R21 (2011MEPS)	R25 (2016MEPS)	R26 (MEPS)	R26-ER (ER)	R26-CSPF (CSPF)	R27 (MEPS)	R28 (MEPS)	R28-ER (ER)
Stock capacity of equipment (base year)	PJ	395.58			460.873			29.49	15.42	
Energy use for cooling (base year)	PJ	17.99			16.83			0.71	0.59	
Availability	%	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%	12.6%
Efficiency	W/W	2.77	3.2	3.45	3.45	3.85	4.17	5.25	3.27	3.7
Investment cost	MUS$/PJ	5.8300	6.8794	8.1177	8.1400	9.6052	10.3448	11.5000	9.3700	10.3070
O&M	MUS$/PJ	0.1749	0.2064	0.2435	0.2442	0.2882	0.3103	0.3450	0.2811	0.3092
Lifespan	Year	10	10	10	10	10	10	20	15	15

1. PJ: petajoule; W: watt; MUS$: million US dollar.
2. Stock capacity of equipment = Energy use of a particular type air conditioner × equipment efficiency / equipment availability. Higher equipment efficiency leads to less equipment capacity for need.
3. Energy use of a particular type air conditioner is estimated by the energy service demand model.
4. Availability of air conditioner for residential sector is 0.126 (=1100/8760), because the yearly average operating hours for cooling demand is1100 hours (TaiPower, 2007).
5. Equipment efficiencies are based on current and ongoing energy efficiency criteria, including MEPS, ER, CSPF and IPLV (BOE, 2014c).
6. Investment and O&M (operating and maintenance) costs are revised according to Taiwan 2050 Calculator (ITRI, 2014).
7. Lifespan is pursuant to ASHRAE (1977).

Table 7 Key parameters of current and new air conditioners for service sector

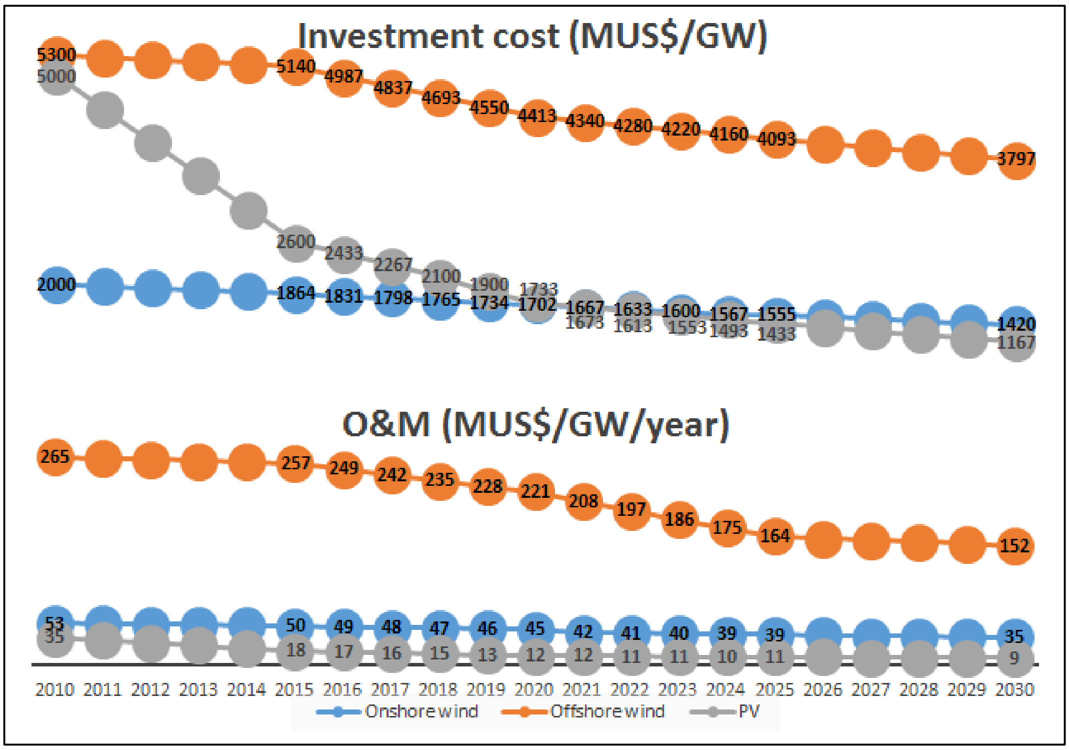
Parameter	Unit	Window-type / Split-type air conditioner			Box -type air conditioner		Central air conditioner		Ice-storage air conditioning
		R73 (2002MEPS)	R75 (2011MEPS)	R75-CSPF (CSPF)	R76 (MEPS)	R76-ER (ER)	R7H (MEPS)	R7H-IPLV (IPLV)	R7S (MEPS)
Stock capacity of equipment (base year)	PJ	199.57			69.69		699.875		29.38
Energy use for cooling (base year)	PJ	22.25			6.80		42.66		5.14
Availability	%	32%	32%	32%	32%	32%	32%	32%	32%
Efficiency	W/W	2.87	3.45	4.395	3.28	3.7	5.25	5.52	1.83
Investment cost	MUS$/PJ	5.8300	6.8794	7.4091	9.3700	10.3070	11.5000	14.3750	11.0000
O&M	MUS$/PJ	0.1749	0.2064	0.2223	0.2811	0.3092	0.3450	0.4313	0.3300
Lifespan	Year	10	10	10	15	15	20	20	20

1. See footnotes in Table 3.
2. Availability of air conditioner for service sector is 0.32 (=2800/8760), because the yearly average operating hours for cooling demand is 2800 hours (TaiPower, 2007)



Source: TaiPower (2014)

Figure 4 Power curve of renewable energy



Source: Taiwan 2050 Calculator (ITRI, 2014).

Figure 5 Investment and O&M costs of renewable energy

4. Results and discussions

Heide et al. (2011) have identified that using weather-driven energy sources is feasible to balance temporal fluctuations of power generation and load. Our findings provide evidences that a sound national energy system planning should take account of renewable intermittency (see Figure 6). PV power systems, compared with gas-fired ones, have no fuel cost and higher power availability factor during periods of peak demand of electricity. Considering the intermittency, the utilities would accelerate the commercialization process of PV facilities in order to match the peak power demand, as well as to minimize the total cost of national energy system. In contrast, the utilities would choose to postpone the investment of off-shore wind power systems. A reason is that wind power generation is slightly higher during night time/non-summer seasons and the load is higher during day time/summer seasons (see Figure 4). Furthermore, the off-shore wind projects suffer from high capital and O&M costs (see Figure 5).

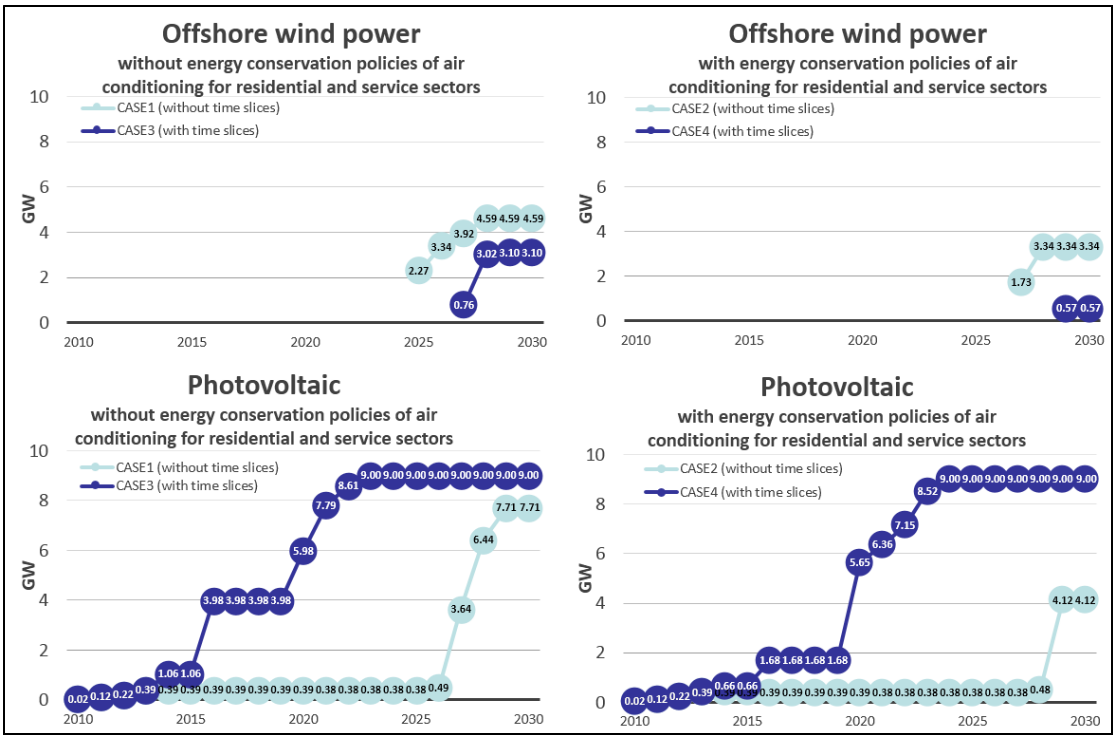


Figure 6 Impact of time-slice consideration on renewable energy deployment

It is worth noted that this study has the duplicate consequences of the deployment of on-shore wind power systems (shown in Figure 7). These results show the installed capacity of on-shore wind energy can reach at Taiwan's government target of 1.2 GW by 2014. While the estimation of levelized cost is around 2.5

NTD/kWh, the on-shore wind technology can compete with conventional power which average electricity price is 2.7 NTD/kWh. This suggests that the energy system invest the deployment of on-shore wind power system in national energy mix.

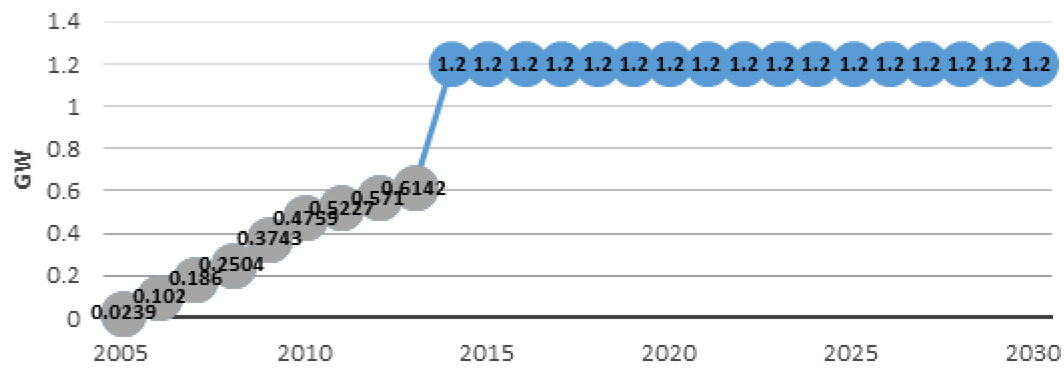


Figure 7 Simulated installation of onshore wind power

5. Conclusions

This study demonstrates an effort to simulate the temporal fluctuation pattern of balancing power in Taiwan by means of the Taiwan TIMES model. Our results show that the power intermittency does affect the commercialization process of renewable energies. This implies that the intermittent nature is an essential consideration to propose a solid energy supply and demand planning.

In addition, the reliability of Taiwan TIMES model relies on the accuracy of technological databases and load pattern. In this study, the power pattern of off-shore wind power was simulated according the history of on-shore power due to lack of real information. Future research should seek to establish a statistical analysis of off-shore wind power. An important direction for future research will be in the refinement of approaches to the analysis of the relationship between energy use and consumer behaviour.

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