Evaluation using system dynamics for renewable energy mechanism effect on electricity sector

Lee-Cheng Lin[1, a], Meng-Ning Cheng [1,b],

[1,2] Industrial Technology Research InstituteGreen Energy & Environment Research Laboratories

[a]itriA00017@itri.org.tw, [b]mandy.cheng@itri.org.tw

Abstract. In order to support electricity generation from renewable energy, most countries have instituted different mechanisms which may place impacts on the electricity sector. The purpose of this study is to establish a system dynamics model of electricity supply structure to evaluate the impacts on power cost, CO2 emission and environmental external cost. The scenarios are both fixed feed-in tariff and renewable portfolio standard mechanisms. The results show that increases in renewable energy supply will drive rises in power generation cost, and compared with the renewable portfolio standard, the fixed feed-in tariff mechanism has better effects on environment protection.

Keywords: System dynamics (SD), Renewable energy, Feed-in tariff (FIT), Renewable portfolio standard (RPS)

Introduction

Organization change has brought many discussions in the literature over the years [2] [6]. The changes in the electricity structure of the electricity sector get high attention in recent years, and since legislation to control carbon dioxide emission. In 2009, Taiwan issued “Renewable Energy Development Act” to promote installation of renewable energy equipments, which aims to raise a proportion of renewable energy electricity to total power supply.

Traditional power plants mainly utilize fossil fuels as the materials for generating electricity. In particular, coal-fired power generation emits the largest amount of CO_2, which leads to serious global warming problem. Therefore, the top concern of energy technology in the 21st century is to search for clean energy. Most countries worldwide are gradually shifting to renewable energy (RE) instead of fossil fuels to generate electricity. Compared with other energies, RE investment cost is quite high. Thus, more than 40 countries around the world, including Germany, France, Switzerland, and Canada [7] utilize both the fixed feed-in tariff (FIT) and renewable portfolio standard (RPS) mechanisms to stimulate increase in RE installed capacity.

In order to stimulate RE development, FIT and RPS mechanisms may produce impact on energy and environment in Taiwan. However, electricity generation structure change towards RE, with lower share of fossil fuels, could cause some impacts on generation cost, and then indirectly push power price to rise. Thus, the goal of this study is to evaluate impacts of different electricity generation structures on environment and power generation cost.

System dynamics model

This study utilizes system dynamics (SD) to construct a model of interconnection between electricity structure change and power generation cost as well as environment (including environmental external cost and CO_2 decrement effect). SD approach is pioneered by Forrester [3], which can help researchers to visually describe systems embodied with perplexing nonlinearity in their nature. SD has been put to good use in the studies of electricity markets [1] [4] [5]. Figure 1 shows a causal-loop relationship of increases in installed capacity of renewable energy and power generation cost as well as environment.

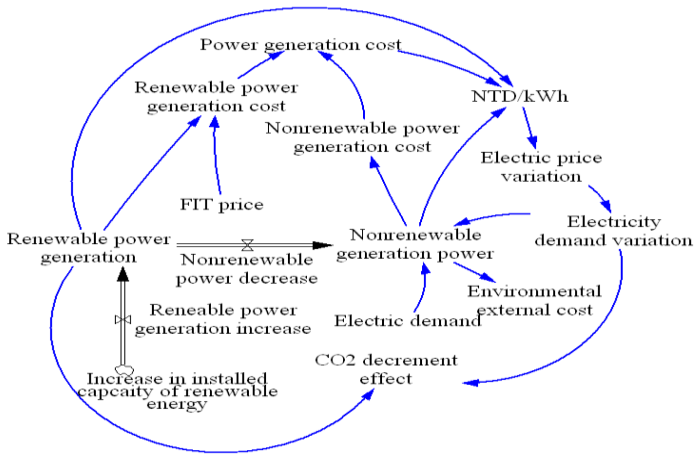

Fig.1 a causal-loop relationship of increase in installed capacity renewable energy and power generation cost as well as environment

The causal-loop relationship can be divided into two parts: one is the electricity supply structure, and the other is the impacts of electricity supply structure on power generation cost and environment external cost as well as CO2 decrement effect. In constructing the electricity supply structure, this study assumes that nonrenewable power are gradually replaced by renewable power underlie satisfied electricity demand. In the design of the tariff price, this study utilizes the calculation formula of Taiwan's tariff as following:

$$Tariff \quad price_{kt} = \frac{I_{Kt} \times (Kd + Kom_{Kt})}{Ey_{Kt}} \tag{1}$$

where k=1,…,K (as RET); t=1,…20. The variable I is the initial investment for renewable energy, and Kom is the annual constant operation and maintenance (O&M) cost, expressed as a constant proportion of initial investment (I). Kd is the capital recovery factor. Ey is the mean annual amount of renewable energy sold to the grid.

In this study, nonrenewable power generation technology contains seven different types: steam power engine (including oil, coal and gas), gas turbine, combined cycle, diesel engine, nuclear, pumped storage hydro, and cogeneration. The power generation cost per kWh contains two parts, namely fixed cost (including investment cost, operation and maintain cost, and interest paid to banks) and variable cost (i.e. fuel cost). This study regards the cost of power generation in time (t-1) as the electric price in time (t) to estimate the electricity price variation, and further obtains the electricity demand variation. The cost of renewable power-generation cost is assumed to be completely borne by all electric consumers. Figures of Taiwan's future electric supply are derived from the data announced by the Bureau of Energy of Ministry of Economic Affairs in January 2010, with a period ranging from 2010 to 2029 (as shown in Fig. 2).

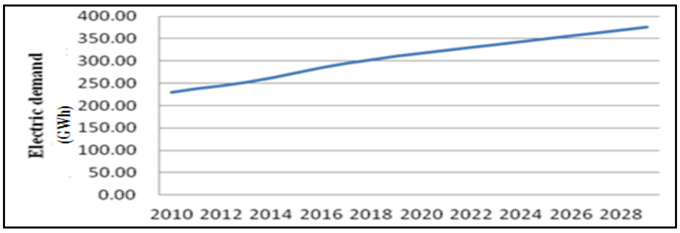

Fig. 2 Projection for Taiwan's future electric demand from 2010 to 2029

Emissions of sulphur and nitrogen oxides – as a results of the combustion of coal by power plants without or limited flue gas pollution control technologies–have also led to a higher incidence of acid rains that posed significant detrimental impacts on both human health and agricultural productivity, especially food security. In addition, large volumes of water are used in power plants- especially nuclear power plants-for cooling off boilers/reactors. This water is typically collected from either riparian or marine sources and after the water has been used, it is usually discharged to this same source; at higher temperature than phenomenon is referred to as thermal pollution and causes both thermal shock and thermal enrichment of the receiving water body, both of which reduce the amount of dissvolved oxygen. In extreme cases, thermal pollution can put stress on temperature sensitive species causing death, which in turn could have a negative effect on the food chain that may cause some adverse effects on the ecosystem in question. Thus, environmental degradation has an impact on public health (that is, loss of work days, health care costs), water and land pollution, in addition to the concerns surrounding global warming from fossil-fuel combustion. However, the power sector does not completely reflect the cost (i.e. environmental external cost) associated with this pollution of the "greater environment" on the price that consumers pay for the electricity they consume. Synthesizes above, using nonrenewable power (generation fuels from coal, oil, gas, and nuclear energy) to satisfy the electric demand, can cause the environmental degradation, and further produce the environmental external cost. This study utilizes the estimation of average European external cost for aggregated technologies of electricity production (as Table 1).

Table 1 External cost for electricity production

Technology	External cost range[1]	Average external cost adopted for this study	
	¢ per kWh	¢ per kWh	NTD per kWh
Coal steam turbine	2.0-15.0	8.5	3.4
Petroleum turbine	3.0-11.0	2.5	1
Combine cycle gas turbine	1.0-4.0	2.5	1
Nuclear electricity	0.2-0.7	0.45	0.18

Note:[1] Estimation based on EU (2003)

Thus, environmental external cost function in this study can represent as following:

$$Environmental\ \ external\ \ \cos t = CGP \times c + OGP \times o + GGP \times g + NGP \times n \quad (2)$$

Where CGP and c are separately the generation power of coal steam turbine and NTD per kWh of coal steam turbine. OGP and o are separately the generation power of petroleum turbine and NTD per kWh of petroleum turbine. GGP and g are separately the generation power of combine cycle gas turbine and NTD per kWh of combine cycle gas turbine. NGP and n are separately the generation power of nuclear and NTD per kWh of nuclear. The electricity price fluctuation has impact on change in quantity for the generation power using different the aggregated technologies.

This study divided CO2 decrement effect into direct effect and indirect effect, indicating CO2 reduction from conventional power generation replaced by renewable power (direct effect) and from the rise in electric price causing demand for electricity to fall (indirect effect).

Scenario analysis

FIT mechanism is mainly to offer guaranteed prices for fixed periods of time for electricity produced from renewable energy sources. RPS mechanism generally places an obligation on electricity supply companies to produce a specified fraction of their electricity from renewable energy sources. Different mechanisms could cause change in various renewable electricity allocated proportions, and further these various proportions have impact on power generation cost, CO_2 decrement effect, and environmental external cost. Thus, this study designs two scenarios with FIT and RPS, which aims to evaluate impact on the above mentioned shocks by different mechanisms. Required data in this study are obtained from Taiwan's related governmental organization and public utilities. Table 2 Shows hypothesis of both FIT and RPS scenarios.

Table 2 Hypothesis of both FIT and RPS scenarios

<table>
<tr><th>Mechanism</th><th>Tariff depreciation rate</th><th>Renewable energy design</th></tr>
<tr><td>FIT</td><td rowspan="2">Based on New Energy Development Committee of Executive Yuan in a meeting held in August 2010:

A. The solar photovoltaic tariff is to be reduced by 8% annually.

B. The ocean tariff is set at NTD 9/kWh initially and will be decreased at a depreciation rate of 10% from 2020.

C. Tariffs for the other renewable power are to be reduced by 1% each year.</td><td>Based on New Energy Development Committee of Executive Yuan in a meeting held in August 2010, accumulated installed capacities represents the tentative 2030 target for renewable energy development, and possible potentials of renewable energy in Taiwan: 1. Solar photovoltaic is 2500MW; 2. Biogas is 31 MW; 3. Waste is 1369MW; 4. Geothermal is 200 MW; 5. Onshore wind is 1156MW; 6. Offshore wind is 2000MW; 7. River hydro is 300MW; 8. Ocean energy is 600MW. It is assumed that all RE installed capacity are in isometric growth.</td></tr>
<tr><td>RPS</td><td>This study assumes the certified proportion for renewable electricity is gradually increased 0.005 annual. The certified proportion is up to 0.1[1] in 2029.</td></tr>
</table>

Note:[1]. The above-mentioned tentative 2030 target for accumulated installed capacities of all renewable energy is about equal to the 0.1 proportion to renewable electricity accounting for total electricity.

At present, around 72% of electricity in Taiwan is generated from coal, oil and natural gas, and around 19% of it is from nuclear; the rest is from renewable energy, pumped storage hydro, and cogeneration. Based on data from Table Ⅱ, the waste energy proportion for the FIT scenario is the largest in the first time, and the electricity amount to waste and offshore wind is over 50% total renewable electricity in 2029(as shown in Figs. 3). In the RPS scenario, renewable electricity is the main from waste and onshore wind in the first time, and major part of renewable electricity is from wind energies of onshore and offshore in 2029.

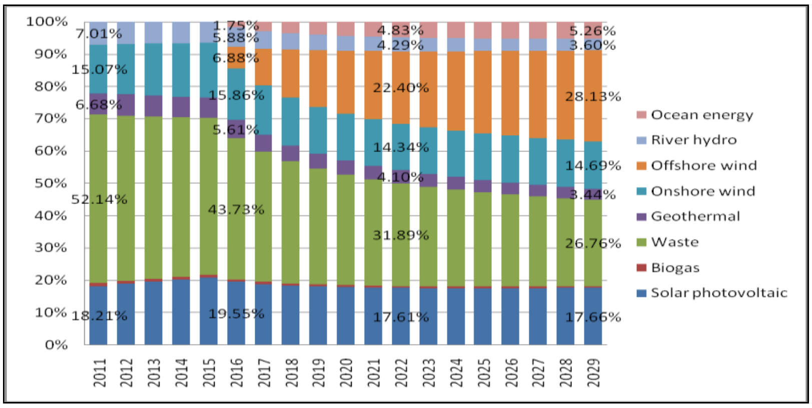

Fig. 3 Power generation structure of FIT scenario from 2011 to 2029

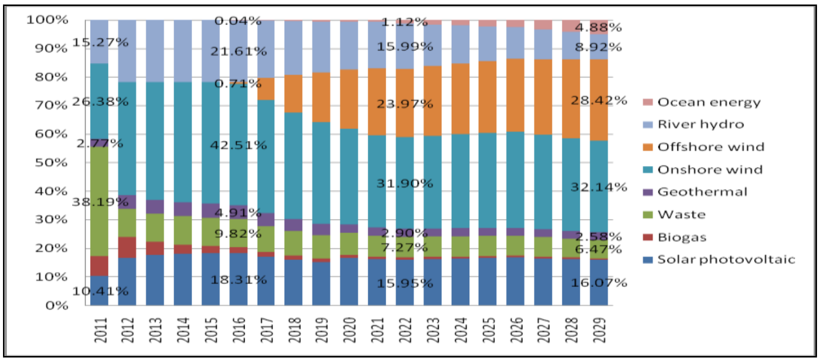

Fig. 4 Power generation structure of RPS scenario from 2011 to 2029

Table 3 shows the results of scenario simulation, average power generation cost and average CO_2 decrement effect been listed. Figure 5 shows environmental external cost of both RPS and FIT scenarios from 2011 to 2029. Results indicate that as power capacity of renewable energy is gradually raised, power generation cost and CO_2 decrement effect are increased for two scenarios. Compared with RPS, FIT would cause high average power generation and well effect on CO_2 decrement. The above-mentioned, the electricity price variation has an influence on quantity change in nonrenewable power and RE prices change would has impact on the total generation power cost (see Fig. 1). If RPS mechanism is adopted, the phenomenon which electricity operators would be toward to buy cheaper price for RE and the RE prices vary annual, would cause falling of the electricity price variation and further add nonrenewable power. Thus, produced the external cost of RPS is higher than of FIT, when RE proportions is gradually raised (after 2021 year).

Table 3 Results underlie different scenarios

Scenario	year	Average power generation cost (NTD/kWh)	CO_2 decrement effect (thousand tons)
FIT	2011-2015	2.701	9227.6
	2016-2020	3.115	10473.2
	2021-2025	3.4118	15954.2
	2026-2029	3.653	21225.25
RPS	2011-2015	2.6028	8209.2
	2016-2020	3.0158	9252.6
	2021-2025	3.2978	15613
	2026-2029	3.53	20284.25

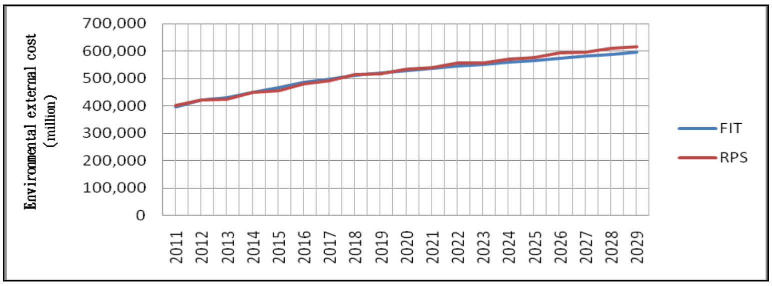

Fig. 5 Environmental external cost of RPS and FIT scenarios from 2011 to 2029

Conclusions

This study evaluates impacts coming from gradually increased RE on environment and power generation cost. Compared with RPS, FIT can cause higher power generation cost and the best CO2 decrement effect as well as less environmental external cost (following renewable energy gradually increased). In 2009, Taiwan government drafted “sustainable development policy program” to maintain sustainable development of environment, society and economy. In particular, there is much attention to sustainable development of environment, in order to reduce environment pollution and raise air quality. Thus, FIT mechanism has more positive effect on environmental protection than RPS.

Acknowledgment

The authors would like to express appreciation to the Bureau of Energy of Ministry of Economic Affairs for sponsoring this work under contract no. 100-D0110.

References

[1] A. Ford, “Boom and bust in power plant construction: lessons from the California electricity crisis,” Journal of Industry, Competition and Trade , 2 (2002), 59–74.

[2] B. Townley, “The role of competing rationalities in institutional change,” Academy of Management, 45 (2002) 163-179.

[3] J.W. Forrester, Industrial Dynamics. MIT Press, Cambridge Currently Available from Pegasus Communications, MA, 1961.

[4] J.Y. Park, N.S. Ahn, Y.B. Yoon, K.H. Koh, D.W. Bunn, “ Investment incentives in the Korean electricity marker,” Energy Police, 35(2007) 5819-5825.

[5] K.O. Vogstad, A system dynamics analysis of the Nordic electricity market. Doctoral Thesis, Norwegian University of Science and Technology, Trondheim, Norway, December 2004.

[6] M.S. Mizruchi, L.C. Fein, “The social constitution of organizational knowledge: a study of the uses of coercive, mimetic and normative isomorphism,” Administration Science Quarterly, 44(1999) 653-683.

[7] REN21, Renewables Global Status Report: 2009 Update. REN21 Secretariat, Paris, 2009.