Low Carbon Strategic Analysis of Taiwan's industrial sector

[Fu-Kuang Ko, Institute of Nuclear Energy Research(Taoyuan City, 32546, Taiwan), +886 34711400x2700, fkko@iner.gov.tw]
[Wei-Chen Liao,Institute of Nuclear Energy Research(Taoyuan City, 32546, Taiwan),+886 34711400x2709, richer216@iner.gov.tw]

Overview

In July 2015, Taiwan promulgated the "Greenhouse Gas Emission Reduction and Management Act", stipulated a GHG reduction target to reduce GHG emissions to lower than 50% of the 2005 level by 2050. Moreover, in response to the Lima call for climate action in 2014, Taiwan has submitted its intended nationally determined contributions (NDC) to reduce GHG emissions by 20% compared to the 2005 level (227 mtCO_2e) by 2030 in August 2015. These are very ambitious carbon reduction goals for Taiwan, a developing country, to keep sustained economic growth.

Industrial companies contribute about 35% and 27% of Taiwan's GDP and employment, respectively, and make materials and goods that are integral to our daily lives, such as electronic parts, machinery and equipment. However, between 1990 and 2017, carbon emissions from fuel-combustion in the industrial sector increased by 165 percent (3.7 percent per year) in Taiwan. As emissions from industry accounted for about 50 percent of Taiwan's carbon emissions in 2017, it follows that the statutory targets cannot be reached without decarbonizing industrial activities. In Taiwan, almost 75 percent of industry's fuel-combustion CO_2 emissions result from the chemical material (29%), electrical and electronic machinery (23%), basic metal industries (15%, including steel), non-metallic mineral products (8%, including cement). About 70 percent of industry's fuel-combustion CO_2 emissions are indirect emissions from electricity use, and motor-driven systems account for 70% of that. And about 60 percent of direct emissions come from the boilers. Therefore, motor-driven systems and boilers are the two largest emitters for the industrial sector. However, less innovation and cost reduction have taken place for industrial decarbonization technologies. This makes the pathways for reducing industrial CO_2 emissions less clear and higher cost than that for for other sectors. That's why it is an important issue to analyze low carbon strategies of Taiwan's industrial sector.

In Taiwan, about 90 percent of GHG emissions are from fuel-combustion CO_2 emissions, and industrial sector is responsible for about 50 percent among them, so the reduction of industrial fuel-combustion CO_2 emissions dominates national greenhouse gas emissions reduction action. This is the reason why this research focuses on the reduction of industrial fuel-combustion CO_2 emissions. This paper describes the research methods, adopted model, assumptions and scenarios in Section 2. The model results and discussions are as shown in Section 3. Finally, the conclusions of this paper is provided in Section 4.

Methods

The TIMES (The Integrated MARKAL-EFOM System) energy model was adopted to evaluate optimal energy deployment for CO_2 emissions reduction scenarios in this paper. The TIMES model was developed as part of the IEA-ETSAP (Energy Technology Systems Analysis Program), which uses energy scenarios to conduct in-depth energy and environmental analyses. TIMES is a technology rich, bottom-up model, which uses linear-programming to produce a least-cost energy system, optimized according to a number of user constraints, over medium to long-term time horizons. In a nutshell, TIMES is used for "the exploration of possible energy futures based on different or contrasted scenarios".

Fig. 1 shows the overall scheme of TIMES model. It depicts that the simulation of TIMES model considering energy policies, technologies roadmaps and energy information statistics are more realistic for planning of low carbon strategies.

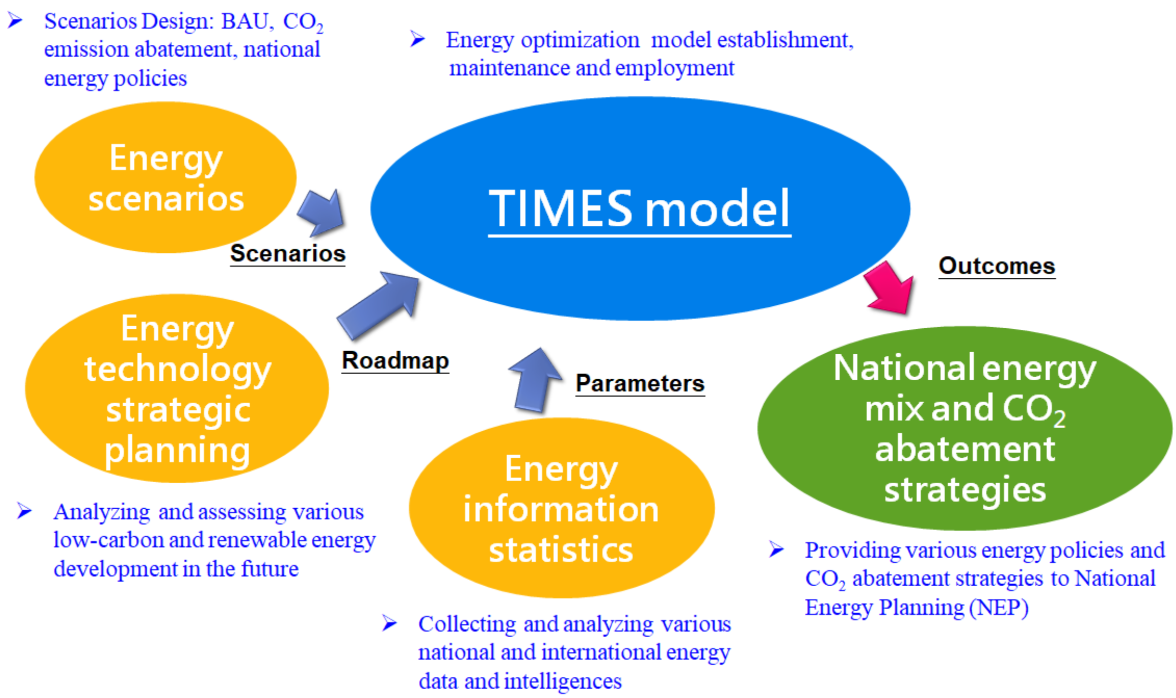

Fig. 1 The scheme diagram of TIMES model (source: own plot).

Comparing with the MARKAL model, many functions of the TIMES model are added and modified, and by which the analysis will better fit the actual situation. The new functions are briefly described below:

(1) settings of variable time period
(2) flexible time slices and storage processes
(3) flexible inputs and outputs of processes
(4) Investment and dismantling lead-times and costs
(5) Vintaged processes and age-dependent parameters
(6) Commodity related variables
(7) More accurate and realistic depiction of investment cost payments

This study first inventoried the main low-carbon technologies in Taiwan's industrial sector. It is divided into three categories: motor-driven system, boiler and process. And all these technologies are built into the TIMES model. According to current trends, the future indirect emissions from power use may be close to 70% of the overall industrial sector emissions. Therefore, the development of low-carbon power is the key to reduce carbon emissions in the industrial sector. In addition to low-carbon industrial technologies, power technology is also included in the scenario design.

The Institute of Nuclear Energy Research (INER) developed the TIMES model for Taiwan in 1or 5-year intervals extending from 2015 to 2050 with VEDA Front End 4.5.5 and TIMES modeling framework. The model provides detailed description for Taiwan’s energy system, covering energy resource mining, energy import/export, conversion, transmission and distribution to end-use as shown in Fig. 2. Demand sectors are divided into industry, commercial, residential, transportation and others (agriculture and non-energy use). For each sub-sector, the choice of technologies includes those that are commercially available today, as well as technologies that might be commercially introduced in the future. In total, more than 180 end-use technologies are presented in the model. All technologies in this model will progress with time. The energy conversion technologies consider not only the use of conventional fossil fuel power plants such as coal, oil and natural gas but also new and renewable energy technologies like integrated gasification combined cycle (IGCC), fossil-fired power plants with CCS technologies, advanced nuclear reactors, as well as hydro, on-shore wind, off-shore wind, solar, geothermal and biomass energies.

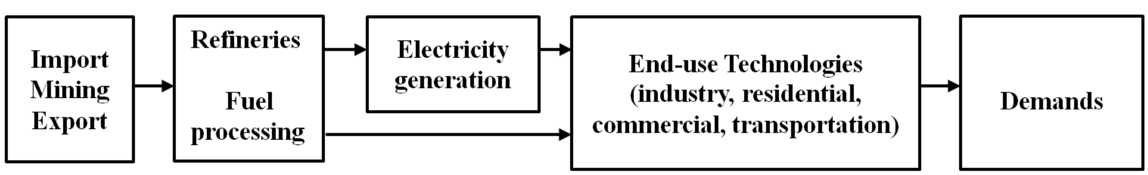

Fig. 2 The flowchart of TIMES model.

In this study, two scenarios, reference and carbon reduction, were considered to perform the analysis as shown in table 1. Basically, the reference scenario is without constrains of carbon emissions and the coal power potential is bounded according to the Taipower company planning (TPC planning published in October 2017). Therefore, even least-cost option adopted, the coal power will occupy with some reasonable electricity generation share. This is an indispensable assumption since coal power plants result in high air pollution and is not easily accepted by the public. For the carbon reduction scenario, we explore how imposing NDC and the mandated target as carbon constrains affects the optimal technology portfolio in all sectors, including the industrial one. Renewables are bounded with the potentials and the feasible penetration rates of gas and bio-charcoal boilers are also given. Since the cost-effective low-carbon process technologies and the coal-fired boilers with higher efficiency naturally arise in the reference scenario, the central focus of carbon reduction contribution, in this paper, is on the motor driven systems, gas and bio-charcoal fired boilers, and low-carbon electricity including renewables and gas-fired power. By drawing out the industrial CO_2 emissions reductions by technology (prism plot), we can explore how to use industrial low-carbon technology with low-carbon power technology to meet the challenge of dramatically reducing carbon emissions and propose strategic recommendations.

Table 1 Assumptions of scenarios.

<table>
<tr><th>Technologies</th><th>Time</th><th>Reference scenario</th><th>Carbon reduction scenario</th></tr>
<tr><td rowspan="2">Coal-fired, Gas-fired[1,2], Oil-fired power plants</td><td>2017-2028</td><td colspan="2">Upper bound set as 10610 TPC planning</td></tr>
<tr><td>2029-2050</td><td colspan="2">Upper bound of coal-, gas-, and oil-fired annual growth rate set as 1.5%/y, 5.5%/y and 0%/y, respectively</td></tr>
<tr><td rowspan="2">Renewable[1] power plants</td><td>2017-2030</td><td colspan="2">Upper bound set as the government planning</td></tr>
<tr><td>2031-2050</td><td colspan="2">Upper bound set as our own estimation</td></tr>
<tr><td>Nuclear Plants</td><td>from 2015</td><td colspan="2">Nuke 1-3 decommission as scheduled / Nuke 4 halt</td></tr>
<tr><td>Cogeneration</td><td>2020-2050</td><td colspan="2">Upper bound referred to reports of Bureau of Energy</td></tr>
<tr><td>Pump storage</td><td>2020-2050</td><td colspan="2">Existing capacity is 2.6 GW, but there is still 705MW potential in the future</td></tr>
<tr><td>Industrial boilers</td><td>from 2017</td><td colspan="2">1. Upper bound of gas replacing coal:20% in 2030, 40% in 2050
2. Upper bound of bio-charcoal replacing coal:10% in 2030, 30% in 2050</td></tr>
<tr><td>Motor driven systems[3]</td><td>from 2017</td><td>Without electricity saving</td><td>Electricity saving compared with reference scenario:10% in 2030, 20% in 2050</td></tr>
<tr><td rowspan="4">National CO_2 reduction targets</td><td>2020</td><td rowspan="4">N/A</td><td>98% of emission amounts in 2005</td></tr>
<tr><td>2025</td><td>90% of emission amounts in 2005</td></tr>
<tr><td>2030</td><td>80% of emission amounts in 2005 (NDC)</td></tr>
<tr><td>2050</td><td>50% of emission amounts in 2005 (Mandated target)</td></tr>
</table>

[1]:Electricity generation from gas-fired and renewable power plants are 50% and 20% in 2025, respectively
[2]:Importing amount of LNG is 3270 Mton in 2025, capacity of gas-fired power plant is determined by TIMES model
[3]:The electricity saving rates in carbon reduction scenario are based on New Policy Scenario in World Energy Outlook (2016)

Results

According to the results of the prism analysis for the industrial sector shown in Fig.1 and the carbon reduction contributions are mainly from low carbon industrial technologies and electricity, and demand reduction and other measures. For the category of industrial technologies, the carbon reduction contribution is mainly from low-carbon industrial technology boilers and high efficiency motor-driven systems, and the total share is about 21%. It is noted that, before 2030, coal-fired boilers are not replaced by gas and bio-charcoal ones. It means low-carbon technologies of other sectors are more cost-effective to meet the national carbon reduction target. In 2030, the abatement costs of motor-driven systems are almost one tenth of gas and bio-charcoal industrial boilers. In 2050, due to the fuel price increase, the abatement cost of gas-fired boiler is about 1-2times higher than industrial technology with CCS. Motor-driven systems are the dominant low-carbon technologies for the industrial sector. The majority of electricity savings in electric motor systems can often be found not in the motor itself but elsewhere in the system, including system-wide measures, end-use device, and variable speed drive. The benefit-cost ratios from large to small are: other system measures > end use equipment > variable speed drive > motor unit. However, industrial sites have long lifetimes; therefore, well planning for the overall system during upgrading or refurbishing these facilities is vital to lower carbon emissions. And industrial processes are also highly integrated, so any change to one part of a process must be accompanied by changes to other parts of that process. Therefore, the government should strengthen the abovementioned effectiveness and encourage operators to plan more in advance when building or renovating their plants.

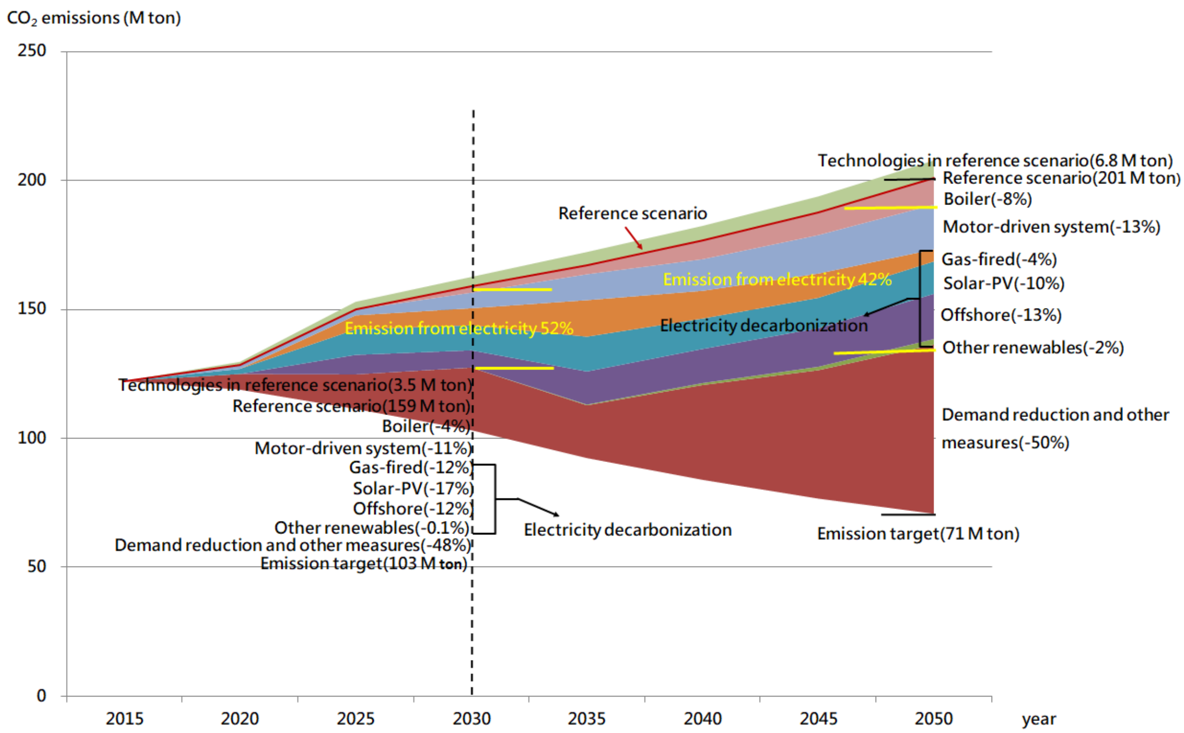

Fig. 1 The industrial CO_2 emissions reductions by technology.

From the power structure diagram of Fig. 2, the carbon reduction scenario begins to suppress electricity consumption from 2025 to meet the carbon reduction target relative to the reference scenario. The electricity consumption is reduced by 13% and 28% compared with the reference scenario in 2030 and 2050, respectively. In addition, coal-fired power generation is gradually reduced. By 2035, it has been completely replaced by renewable energy and gas-fired power generation. This power generation structure leads to higher power generation costs than the reference scenario, and the electricity emission coefficient is lower as shown in Table 2. In Taiwan, due to the increase in the amount of renewable energy and the increase in idle gas units, the electricity cost will soar up 57% and 100% in 2030 and 2050 compared wth the level in 2015, respectively. The carbon reduction contribution from electricity use, including motor-driven systems and power decarbonization, is about 52% in 2030, and 42% in 2050. This is far greater than that of fuel combustion emissions from boilers and motor drives. It is noted that energy efficiency improvements can reduce carbon emissions competitively, but cannot lead to deep decarbonization on their own.

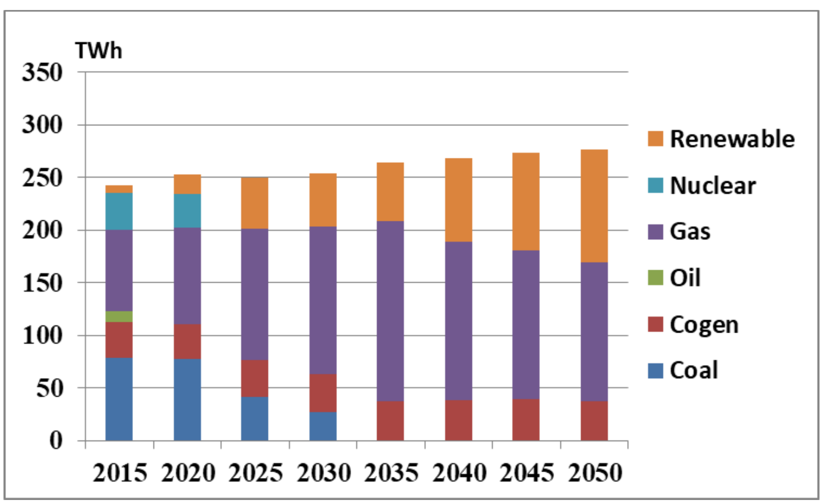

Fig. 2 Power generation structure of carbon reduction scenario.

Table 2 Generation costs and electricity emission coefficients.

Reference scenario								
	2015	2020	2025	2030	2035	2040	2045	2050
Generation cost (NTD/kWh)	2.1	2.15	2.32	2.43	2.50	2.55	2.65	2.69
Electricity emission coefficient (kg/kWh)	0.62	0.59	0.63	0.61	0.58	0.56	0.55	0.54
Carbon reduction scenario								
Generation cost (NTD/kWh)	2.1	2.27	3.04	3.30	3.64	4.02	4.03	4.20
Electricity emission coefficient (kg/kWh)	0.62	0.54	0.46	0.38	0.32	0.28	0.25	0.22

Note: The generation cost in 2015 is based on historical data from Taiwan Power Company, and those between 2020 and 2050 are calculated from TIMES model

Even so, to meet the long-term stringent carbon reduction target, the contribution from demand reduction and other measures, such as material efficiency improvement, is gradually rising to compensate the insufficient low-carbon technologies in the industrial sector. The strategies for industrial demand reduction are demand-side management and industry structure adjustment from high energy intensity industries toward high value-add ones. In addition, radical changes in consumption patterns driven by technology changes could further offset demand, such as reduced build-out of roads (and therefore cement) through autonomous driving. Moreover increasing the circularity of products, by e.g., recycling or reusing them can also cut CO_2 emissions. Producing material based on recycled products generally consumes less energy and feedstock than production of virgin materials. As an example, producing steel from steel scrap requires only about a quarter of the energy required to produce primary production of steel. Since the contribution from this part is more and more obvious from 2035, how to design more innovative and feasible strategies combined with expanded renewables will be the most important for the long-run deep decarbonization. Some examples are the direct reduction of iron with green hydrogen and the electrification of processes in certain industries, including chemicals (such as biomethane and green electrofuels) and steel.

Conclusions

With TIMES model, the low-carbon analysis for Taiwan's industrial sector has been performed in this study. Carbon emissions from electricity use account for a high proportion in Taiwan's industrial sector. Therefore, carbon reduction focuses on efficiency (especially on system-wide measures), power decarbonisation (renewable power, CCS, and nuclear power), others such as boilers and demand reduction by industry structure adjustment, consumption pattern change and price signal.

Industrial companies can reduce CO_2 emissions in various ways, with the optimum local mix depending on the availability of biomass, carbon-storage capacity and low-cost zero-carbon electricity and hydrogen, as well as production changes due to demand reduction and other measures. In the harder-to-abate industrial sectors such as steel, cement, and chemicals, bioenergy and carbon capture will also be required. If carbon-storage sites are available, CCS is the lowest-cost decarbonization option for now. However, the local availability of carbon storage capacity and public acceptance and regulatory support for carbon storage determine whether CCS is a feasible option. In the long run, the cost of zero-carbon electricity, also for producing heat and hydrogen, will be more economical than the technologies with CCS. But this depends on the availability of renewables and will differ on a country-by-country basis. And for isolated and densely populated Taiwan, how to exploit and harness more reliable renewable energy such as photovoltaics, off-shore wind power, biomass, and enhanced geothermal power is a difficult challenge to face in the future.

References

1. Wei-Chen Liao and Fu-Kuang Ko, Applying the TIMES model to propose strategic recommendations for emission targets of industrial sector, Conference of Chinese Association for Energy Economics, Taipei (2018). (in Chinese)

2. Yu-Ching Huang etc., Carbon reduction benefit assessments and strategy recommendations of Taiwan's energy supply and demand technology (II), Project Final Report of National Energy Program – Phase II (2018). (in Chinese)
3. Yu-Ching Huang etc., Carbon reduction benefit assessments and strategy recommendations of Taiwan's energy supply and demand technology (I), Project Final Report of National Energy Program – Phase II (2017). (in Chinese)
4. Arnout de Pee etc., Decarbonization of industrial sectors: the next frontier, Mckinsey&Company (2018).
5. Matthias Buck, Andreas Graf, Dr. Patrick Graichen, European Energy Transition 2030: The Big Picture, Agora Energiewende (2019).