# The inspection of $CO_2$ emission targets of industry sector in Taiwan

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**Abstract**

The aim of the study is to discuss the current $CO_2$ emission targets of industry sector in Taiwan, scenarios about the collocations of power generation and industry technologies are designed, MARKAL model are utilized to estimate $CO_2$ emissions, electricity cost, abatement cost, opportunity cost of industry sector in Taiwan. To satisfy $CO_2$ emissions targets in 2020 and 2025, the results show that the excess costs of electricity consumption in industry compared to BAU are 14% to 40% of the social welfare in 2012, and the opportunity cost are 6% to 12%, social welfare is the largest administrative expenditure in Taiwan, and the collocations can be an inspection of the current $CO_2$ reductions targets of industry sector in Taiwan. This study also suggests proper $CO_2$ reduction targets, the values are 138 (2020) and 140 (2025) million tons, which are 10.4% and 30.8% larger than the original targets, and they are 22% (2020) and 33% (2025) lower than BAU. The suggested targets have lower $CO_2$ abatement cost in industry's electricity consumption, and is designed under the consideration of annual 2% promotion at energy efficiency and announced nature gas and renewable energy policy.

## 1. Introduction

The $CO_2$ emission from industry sector is larger than other sectors in Taiwan, so it always plays an important role in national carbon reduction. Therefore the Taiwan government carried out the $CO_2$ emissions reduction target from 2011: the $CO_2$ emissions will be 125 million tons in 2020, and it will reduce to 107 million tons in 2025. If analysis is performed about the $CO_2$ emissions of industry sector, then the results showed that the electricity use emissions accounted for more than 60% in recent years, as showed in Fig 1.. For this reason, development of low carbon electricity technologies is the main method for reduction of $CO_2$ emissions of industry sector in Taiwan.

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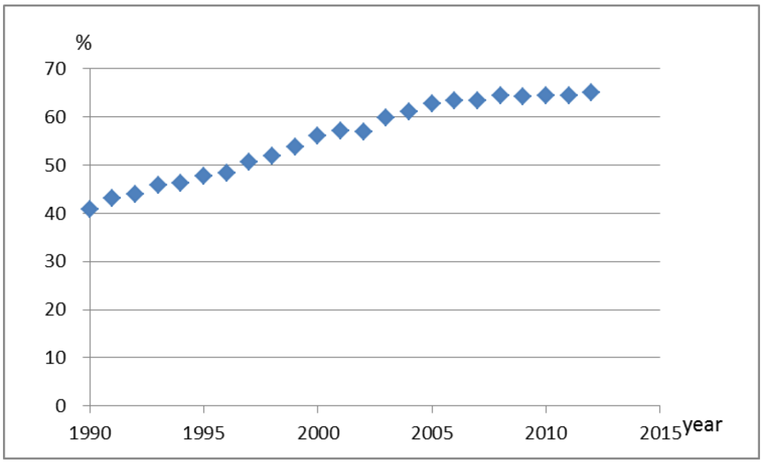


Fig.1 The proportion of electricity use emissions of industry sector in Taiwan [1]

In recent years, there are great anti-nuclear voices in Taiwan, it results in relatively expensive natural gas and renewable energy has become the only remaining low-carbon electricity options. Bureau of Energy established the policy about expanded imported liquefied nature gas (LNG) and development of renewable energies. The objectives of imported LNG are 14 million tons (2015), 15 million tons (2020), 20 million tons (2025), respectively. The main renewable energy technologies in the scheme are large hydro, solar photovoltaic, onshore wind power and onshore wind power, the development objectives are listed in Table 1.

**Table 1**

Main renewable energy capacity target in Taiwan between 2010 and 2030 (GW)

| | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| Large hydro | 1.82 | 1.88 | 1.89 | 2.1 | 2.1 |
| Solar photovoltaic | 0.02 | 0.75 | 1.62 | 3.05 | 3.1 |
| Onshore wind power | 0.48 | 0.87 | 1.2 | 1.2 | 1.5 |
| Offshore wind power | 0 | 0.02 | 0.6 | 1.8 | 3 |

In addition to the low carbon electricity technologies, the energy saving and carbon reduction of industry is also a method to reduce $CO_2$ emissions. Petrochemical raw material manufacturer, electrical and electronic manufacturer, blast furnace iron and steel, electric arc furnace iron and steel, cement are the main high energy consumption manufacturing industry in Taiwan. The manufacturers have voluntary energy saving and carbon reduction plans, the contents for each manufacturing industry are described as follows:

- Petrochemical raw material manufacturer: Manufacture procedure improvement of raw material, such as ethylene, ethylene glycol, chloroethene monomer, etc.. Catalyst reaction technology improvement, renewal of compressor. The average energy efficiency improvement rate is 0.34% per year.
- Electrical and electronic manufacturer: Manufacture procedure improvement of DRAM, liquid crystal display, wafer. The usage of high efficiency chiller and compressor. The average annual energy efficiency improvement rate is 0.67%.
- Blast furnace iron and steel: Pulverized coal injection, blast furnace control system, internal energy saving and carbon reduction, biomass replacement for steam coal, optimal utilization of self-produced furnace gas, renewal of compressors. These are the main energy saving and carbon reduction methods carried out by China Steel Corporation, and they can result 0.83% average energy efficiency improvement rate per year.
- Electric arc furnace iron and steel: The use of direct current electric arc furnace, pre-heat of waste steel. The average energy efficiency improvement rate is 0.5% per year.
- Cement: The manufacturers are taking steps to improve energy efficiency on three parts: rotary kins, clinker system, grind system. The average energy efficiency improvement rate is 0.31% per year.

In addition, Bureau of Energy declared the high efficiency motor policy in 2014, IE2 motor (efficiency is 0.89) will replace the existing motor in 2017, furthermore, IE3 motor (efficiency is 0.915) will be used exhaustively in 2020.

Energy model is a wisely used approach to identify the energy consumption, pollutants emissions, technology pathways and global scenarios. The number of the MARKAL family of models has multiplied to 77 institutions and 37 countries, which are widely used in strategies decision, policy analysis and other fields. The main research topics about MARKAL models in recent years covered biomass, electricity sector, industry sector, transportation sector [2-9].

The study applied the MARKAL model to provide collocations of electricity and industry technologies achieving the $CO_2$ emission target of industry sector in Taiwan, beside, in order to check the property of reduction target, electricity costs, abatement costs and opportunity costs were calculated.

## 2. Methods and assumption

The research applied the MARKAL model to calculate the $CO_2$ emissions, electricity costs, abatement costs, opportunity costs of industry sector in different collocations of electricity and industry technologies, MARKAL is a linear programming tool supported by IEA-ETSAP (Energy Technology Systems Analysis Program). It is a technology-rich model that maps out appropriate technologies to satisfy the endogenous energy service demands under minimizing total cost. The model is widely used not only for energy system research but strategy research of energy-related emission reduction.

In Institute of Nuclear Energy Research (INER), the ANSWER MARKAL 6.4.22 is adopted to descript Taiwan energy system, which covers resource including energy import, export and mining, process, conversion, transmission and distribution to end-use. The energy service demands are for end-use technologies in 6 sectors: industry, transportation, residual, commercial, agriculture and non-energy use sectors, there are approximately 90 end-use technologies in the model. All technologies in the model are existing and future technologies. For conversion sector, it takes into account both the traditional fossil fuel technologies such as coal-fired, gas-fired and oil-fired power plants and the new technologies e.g. Integrated Gasification Combined Cycle (IGCC), Super Critical Pulverized Coal (SCPC), Nature Gas Combined Cycle (NGCC). In addition, the renewable energy energies are hydro, solar, wind, geothermal and biomass. The technologies in industry sector are petrochemical raw material manufacturer, electrical and electronic manufacturer, blast furnace iron and steel, electric arc furnace iron and steel, cement, besides, two important industry apparatus: motor and boiler are also considered. This study provided different scenarios about the collocations of electricity and industry technologies, different categories of scenarios listed in table 2 are described as follows:

1. BAU scenario: All technologies were chosen by the MARKAL model through the least-cost combinations, and the energy efficiencies of industry technologies all maintained the 2010 levels.
2. Industry energy efficiency scenarios: These scenarios take into account different energy efficient improvement of industry technologies, the electricity generation mixes were determined by the MARKAL model through the least-cost combinations, these scenarios were designed to emphasis the impacts of industry sector $CO_2$ emissions due to improvement of industry technology energy efficiency. For INE1 scenario, the industry energy efficiency improvements were voluntary, average of improvement is about 0.5%/year, which were described in section 1. For other scenarios among number 3 to 7, the energy efficiency improvements of the main manufacturing industries were 1%, 2%, 2.5%, 4%, 5% per year.

3. Announced low carbon electricity technology scenarios: For the scenarios among number 8 to 14, they not only take into account energy efficiency improvement as described before, but also the announced low carbon electricity policies containing the development of renewable energies and the increase in LNG use, and these were described in section 1.

4. Reduced coal-fired power plant scenarios: Compared to the third category scenarios, more positive low carbon electricity method were adopted, the electricity generations of coal-fired plants were controlled to lower levels, and the lacking coal-fired electricity generations were supplemented by renewable and gas-fired electricity generations. In other words, the electricity generations from the two low carbon emissions technologies, renewable and gas-fired, were enlarged to supplement the high carbon emissions electricity generations from coal-fired power plants. These scenarios were number 15 to 19.

**Table 2**

List of scenarios

| No | Name | Description |
|---|---|---|
| 1 | BAU | The energy efficiencies of industries maintained the 2010 levels. Nuclear-Free Homeland Policy, electricity generation mixes were determined by least-cost combinations. |
| 2 | INE1 | Same as BAU, except the energy efficiencies improvements of industries were voluntary improvement rate |
| 3 | I1E1 | Same as BAU, except the energy efficiencies improvements of industries were 1% per year. |
| 4 | I2E1 | Same as BAU, except the energy efficiencies improvements of industries were 2% per year. |
| 5 | I2.5E1 | Same as BAU, except the energy efficiencies improvements of industries were 2.5% per year. |
| 6 | I4E1 | Same as BAU, except the energy efficiencies improvements of industries were 4% per year. |
| 7 | I5E1 | Same as BAU, except the energy efficiencies improvements of industries were 5% per year. |
| 8 | I0E2 | The energy efficiencies of industries maintained the 2010 levels. Nuclear-Free Homeland Policy; the gas-fired and renewable power plants obey the announced policies. |
| 9 | INE2 | Same as I0E2, except the energy efficiencies improvements of industries were voluntary improvement rate. |
| 10 | I1E2 | Same as I0E2, except the energy efficiencies improvements of industries were 1% per year. |
| 11 | I2E2 | Same as I0E2, except the energy efficiencies improvements of industries were 2% per year. |
| 12 | I2.5E2 | Same as I0E2, except the energy efficiencies improvements of industries were 2.5% per year. |
| 13 | I4E2 | Same as I0E2, except the energy efficiencies improvements of industries were 4% per year. |
| 14 | I5E2 | Same as I0E2, except the energy efficiencies improvements of industries were 5% per year. |
| 15 | I0E3 | The energy efficiencies of industries maintained the 2010 levels. Nuclear-Free Homeland Policy; lower the coal-fired electricity generation; no limitation for the electricity generation of gas-fired and renewable power plants |

**Table 2. (continued)**

List of scenarios

| No | Name | Description |
|---|---|---|
| 16 | INE3 | Same as I0E3, except the energy efficiencies improvements of industries were voluntary improvement rate. |
| 17 | I1E3 | Same as I0E3, except the energy efficiencies improvements of industries were 1% per year. |
| 18 | I2E3 | Same as I0E3, except the energy efficiencies improvements of industries were 2% per year. |
| 19 | I2.5E3 | Same as I0E3, except the energy efficiencies improvements of industries were 1% per year. |

## 3. Results and discussion

3.1 BAU scenario

The BAU of conversion sector almost excludes policies and $CO_2$ emission reduction targets. The allocation of electricity capacity and generation from 2010 to 2030 were showed in Fig.2 and Fig.3, the results showed that the total capacity and generation increase gradually over time. From the BAU results, the PC/SCPC dominated due to the lower coal price, and they extend from 2010 onward obviously, the shares of electricity generation are 38% (2010) and 70% (2030), respectively. The NGCC ranked the second, despite higher nature gas prices relative to coal, in order to the policy of increasing the nature gas usage, the BAU set the lower limit of nature gas usage in gas-fired power plants. The NGCC electricity generation almost maintains 2010 level, and the shares of generation are 25% (2010) and 18% (2030), respectively. About the nuclear power plants, the existing plants will be phased out from 2020 onwards. Generally, the cost of renewable power plant is higher than other fossil fuel power plants and the capacity factor is lower, the electricity generation from renewable power in the BAU scenario are less relative to other power plants, the share of electricity generation are close to 2% from 2010 to 2030. The renewable power plants appear in BAU scenario are hydroelectric, photovoltaics and onshore wind power plants. Under the electricity generation mixes, the electricity used $CO_2$ emission coefficients are listed in Table 3, the results show that $CO_2$ emissions per KWh increase gradually from 2010 onwards, the trend should result from the increasing of coal-fired electricity over time.

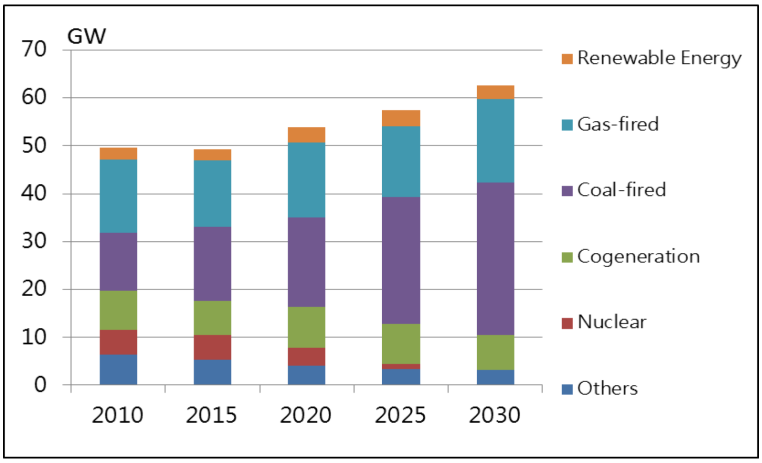


Fig.2 The allocation of electricity capacity in BAU scenario

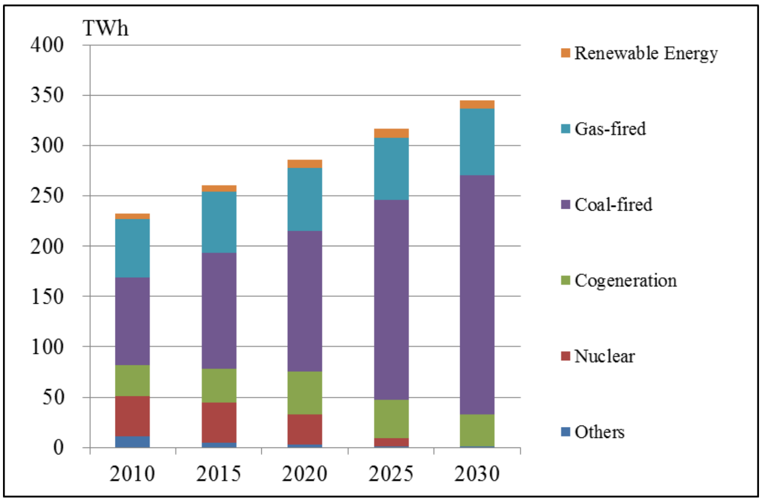


Fig.3 The allocation of electricity generation in BAU scenario

**Table 3**

$CO_2$ emission coefficient of electricity consumption in BAU scenario

| | unit | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|
| Coefficient | Kg/kWh | 0.68 | 0.69 | 0.74 | 0.82 | 0.82 |

The energy efficiencies of industry technologies in BAU scenario maintain the 2010 levels, Table 4 are amounts of $CO_2$ emission in industry sector and the total amounts in Taiwan. In addition, the shares of industry sector are also listed. The results showed that the industry sector is still the main $CO_2$ emission resource in the future. If analysis of $CO_2$ emission is performed, then it can be detected that more than 60% of $CO_2$ are released from electricity used, Table 5 is the $CO_2$ emission results from fossil fuel-fired and electricity consumption in industry sector in BAU scenario. The $CO_2$ emissions of industry sector are 178 million tons (2020) and 210 million tons (2025) in BAU scenario, and the gaps between the government reduction target are 53 million ton (2020) and 103 million tons.

**Table 4**

The results of $CO_2$ emissions in BAU scenario

| | unit | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|
| Total emission | million ton | 251 | 276 | 319 | 373 | 407 |
| Emission of industry sector | million ton | 130 | 150 | 176 | 206 | 220 |
| Percentage of emission from industry sector | % | 52 | 54 | 55 | 55 | 55 |

**Table 5**

$CO_2$ emissions of industry sector in BAU

| | unit | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|
| Emission from fuel-fired power plant | million ton | 47 | 52 | 55 | 57 | 59 |
| Emission from electricity consumption | million ton | 83 | 98 | 121 | 149 | 161 |
| Percentage of emission from electricity consumption | % | 64 | 65 | 69 | 72 | 73 |

3.2 Industry energy efficiency scenario analysis

In order to examine the influences of energy efficiency on $CO_2$ reduction, the scenarios excluding low carbon electricity technologies will be discussed. In INE1 scenario, these industry $CO_2$ reduction methods are voluntary for manufacturing industries, it includes petrochemical raw material manufacturer, electrical and electronic manufacturer, blast furnace iron and steel, electric arc furnace iron and steel as well as cement, they are the main $CO_2$ emission resources for industry in Taiwan. In addition, two important industry apparatus: motor and boiler are also included. The $CO_2$ emission reduction methods in each technology have been described in section 1. In the scenario, the industry emissions are 167 million tons (2020) and 190 million tons (2025), they reduced 6% (2020) and 9% (2025), respectively, as compared with BAU.

The results indicated that the industry $CO_2$ reduction target can't be achieved under the voluntary $CO_2$ reduction methods, it is obvious that current industry energy efficiency (the average is about 0.5% per year) is not enough. In order to achieve the $CO_2$ emission reduction target of industry, higher energy efficiencies must be considered, such as 1%, 2%, etc., therefore, the implication of different industry energy efficiency scenarios (number 3 to 7) are performed to inspect the influence on industry sector $CO_2$ emissions.

From the results, although the $CO_2$ emissions decreased with the increasing of energy efficiencies apparently, the reduction target also can't be achieved, even though under the 5% improvement per year(I5E1 scenario), there are still gaps between real $CO_2$ emissions and policy targets, 3 million tons (2020) and 25 million tons (2025), respectively.

As to electricity generation mixes, they are all determined by the least cost combinations, so all of them are similar with BAU, Fig.4 is the comparison of electricity generation mixes between BAU and I5E1 , the PC/SCPC dominated due to the lower coal price, electricity saving from industry energy efficiency promotion results in different electricity generations, of course it should be that the lowest electricity generations occur under 5% promotion per year conditions.

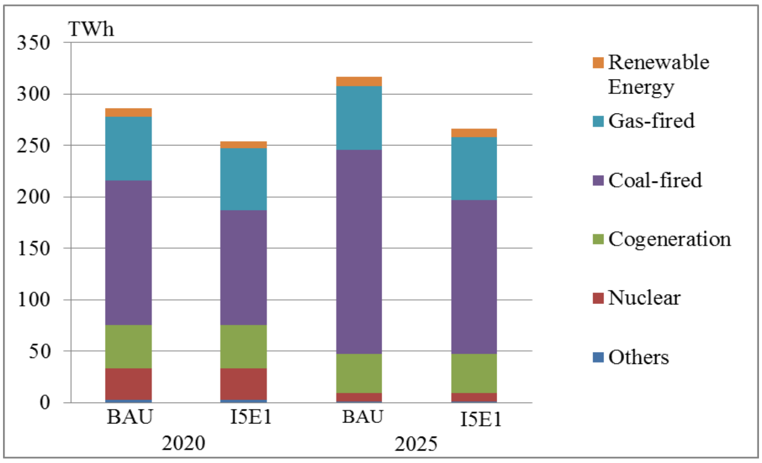


Fig.4 The allocation of electricity generation in BAU and I5E1 in 2020 and 2025

3.3 Low carbon electricity technology scenario analysis

In order to achieve low carbon target, development of low carbon electricity technology is the main policy of Taiwan government, this is because the Taiwan Power Company is a government-owned business, and government can carry out low carbon electricity policy efficiently by means of Taiwan Power Company. Due to the high pressure of anti-nuclear currently, it results in the extended use of related high cost nature gas and renewable energy is the main objective in the future, and the announced policy have been described in section 1.

The I0E2 scenario inspects the influence of announced low carbon electricity policies on industry sector $CO_2$ reductions without any energy efficiency improvement of industry. From the results, $CO_2$ released from industry sector are 162 (2020) and 178 (2025) million tons, and it can’t achieve the government target. The results showed that the announced low carbon electricity policies is not enough for industry sector, therefore, if it is expected to achieve industry sector $CO_2$ reduction target, then more positive low carbon electricity method is need. In I0E3 scenario, the energy efficiencies of industry technologies are maintained the levels in I0E2 scenario, however, different electricity mixes is introduced. In order to get more effective low carbon electricity, gas-fired and renewable energy power plants are increased to replace coal-fired plants. The results indicate even at almost no coal-fired plants electricity generation mixes, the $CO_2$ emissions from industry section are 129 (2020) and 127 (2025) million tons, it is still not low enough to meet industry $CO_2$ reduction target. Fig.5 is the comparison of electricity generation mixes in I0E2 and I0E3 scenarios, under the announced policy (I0E2 scenario), shares of coal-fired generations are about 35% in 2020 and 2025, gas-fired generations are about 35% in

2020 and 44% in 2025, and as to renewable energy, the occupation are 5% (2020) and 7% (2025). In I0E3 scenario, gas-fired and renewable energy generations almost replace those from coal-fired plants, gas-fired plants take account for near 69% (2020) and 60% (2025) electricity generations, respectively. Moreover, it's worth to mention that due to the cost of solar photovoltaic and offshore power plants will be lower than gas-fired plants in 2025, the electricity generation from renewable energy in 2025 is apparently more than 2020, it attains 25% in 2025.

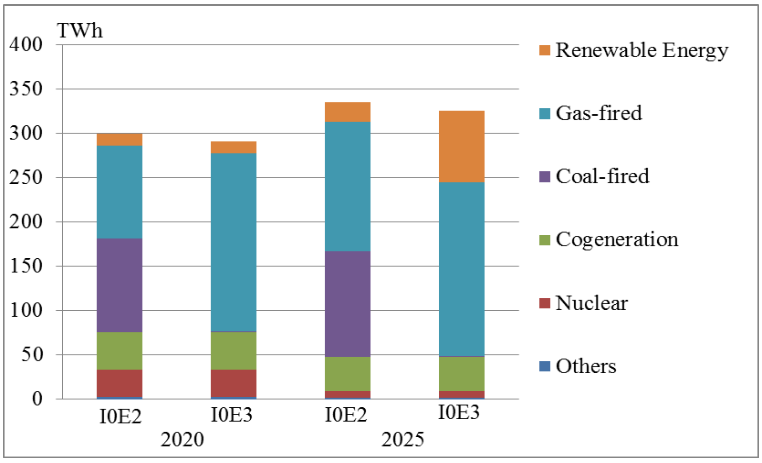


Fig.5 The allocation of electricity generation in I0E2 and I0E3 in 2020 and 2025

According to the results, if there is no industry energy saving and carbon reduction methods and take low carbon electricity development the only method, the industry sector $CO_2$ reductions are insufficient to meet the target: 125 million tons in 2020 and 107 million tons in 2025, even if under extreme electricity generations structure such like I0E3 scenarios. In addition, if industry energy saving and carbon reduction methods is the only method, the carbon reduction effect is also limited, which is discussed in section 3.2. Thus, it is necessary to develop electricity and industry technologies simultaneously.

3.4 Low carbon industry and electricity technology scenario analysis

The analysis under different collocations of low carbon industry and electricity technologies will be discussed in the section. In the INE2 scenario, the industry energy saving and carbon reduction methods follow the manufacturer voluntary plans, average of all technology energy efficiency improvement is about 0.5% per year, meanwhile, announced low carbon electricity policies are also carried out. Under the condition, $CO_2$ emissions of industry sector are reduced to 153 million tons (2020) and 161 million tons (2025), respectively, and the $CO_2$ reduction target also can't be achieved. Furthermore, in order to meet the industry $CO_2$ reduction target, more positive low carbon electricity method similar with that in I0E3 scenarios described in section 3.3 were adopted, the results showed that $CO_2$ emission in 2020 just meet the reduction target when coal-fired electricity generation reduced to only 3.4% in INE3 scenario. However, even coal-fired plants was almost replaced by gas-fired and renewable energy plants in 2025, the $CO_2$ emission was 116 million tons which was higher than target value: 107 million tons.

Therefore, higher efficient industry technologies were also adopted to collocate with low carbon electricity methods. The results indicated that under announced low carbon electricity policies, industry technology energy efficiency at 4% annual promotion (I4E2 scenario) released 124 million tons in 2020, which is lower than the 125 million tons target value, however, 120 million tons emission in 2025 can't meet 107 million tons target value. As to 5% annual energy efficiency improvement (I5E2 scenario), the emissions in 2020 and 2025 were 115 and 106 million tons, respectively, and they can achieve target values. For other annual energy efficiency improvements (1%, 2%, 2.5%), they can't achieve target values in 2020 and 2025 in I1E2, I2E2, I2.5E2 scenarios, therefore, the advanced low carbon electricity method like in INE3 scenarios must be used for the sake of target values. The results of I1E3, I2E3, I2.5E3 scenarios showed that at 1% annual energy efficiencies promotion, the target value in 2020 can be achieved when share of coal-fired generation electricity was 3%. With regard to 2% and 2.5% annual promotion, the two target values in 2020 and 2025 can be achieved as the electricity generations from coal-fired plants were reduced to about 15% (2020) and 4% (2025) occupations.

Among the cases achieving $CO_2$ reduction target mentioned above, the I5E2 scenarios can maintain related normal coal-fired plants electricity generations, as showed in Fig.6; however, the investment costs about energy efficiency improvements may be expensive. Besides, other scenarios containing enlargement use of nature gas and renewable energy should spend more cost in industry electricity investment. The cost analysis will be performed in next section.

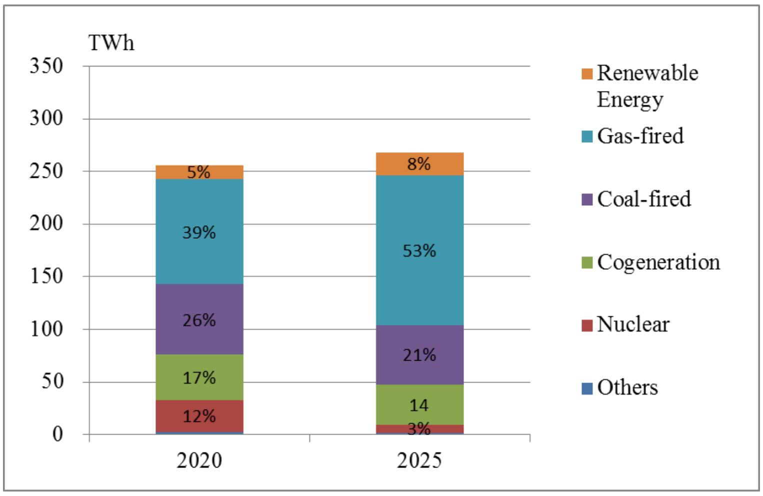


Fig.6 The allocation of electricity generation in I5E2 in 2020 and 2025

3.5 Cost analysis

In the section, some cost analysis including electricity cost of industry, abatement cost of industrial electricity compared to BAU, opportunity cost of industry technology are performed.

Fig.7 and Fig.8 are the electricity costs of industry for all scenarios in 2020 and 2025, there are three categories of power generation mixes in in Fig 7 and Fig 8, the “least cost” means the power generation mix excluding low carbon technologies; “announced policy” means the power generation mix under announced nature gas and renewable energy policy; “reduced coal-fired” means the power generation mix nature gas and renewable energy power plants replace coal-fired plants. The results showed that the costs decrease with increasing of industry energy efficiency at identical power generation type, because the electricity conservation is more effective due to higher industry energy efficiency. At a given industry energy efficiency, the reduced coal-fired power generation type was more expansive resulted from enlargement of nature gas and renewable energy. The electricity costs for the scenarios achieving the industry sector $CO_2$ reduction targets were enclosed by symbolism in Fig.7 and Fig.8, for the reduced coal-fired power generation type, the excess electricity costs of industry were compared with social welfare, which is the largest administrative expenditure in Taiwan, the compared results were in Table 6, and the results showed that they were 14% to 40% of the expenditure of social welfare in 2012. For the announced policy case, the electricity costs of industry at 4% and 5% annual industrial energy efficiency improvements were lower than BAU, and the opportunity costs of industrial energy efficiency improvements were 6% to 12% of the expenditure of social welfare in 2012, they were showed in Table 7.

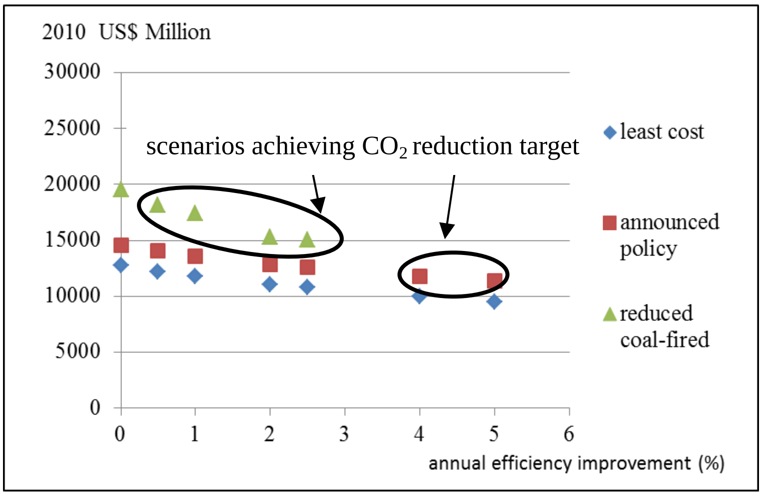


Fig.7 The electricity costs of industry in all scenarios in 2020

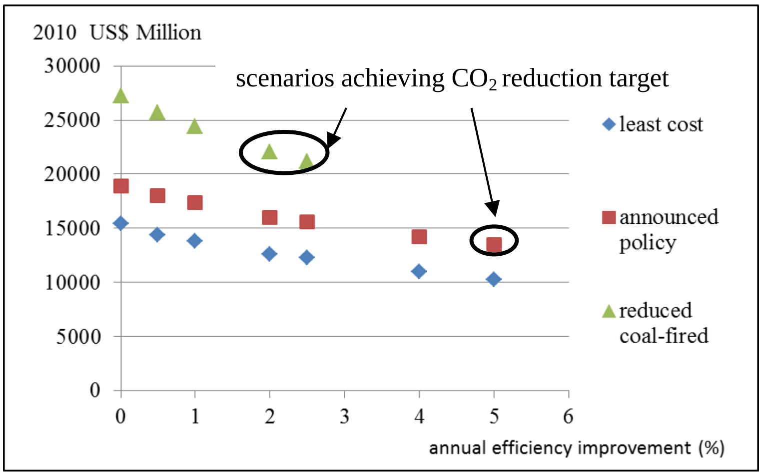


Fig.8 The electricity costs of industry in all scenarios in 2025

**Table 6** The comparison of excess electricity costs of industry with social welfare in 2012

| | The proportion related expenditure of social welfare in 2012 | |
|---|---|---|
| Annual industry energy efficiency improvement | 2020 | 2025 |
| 0.5% | 33% | -[1] |
| 1% | 28% | -[1] |
| 2% | 15% | 40% |
| 2.5% | 14% | 34% |

[1]:The scenario does not achieve $CO_2$ reduction target

**Table 7** The comparison of opportunity costs with social welfare in 2012

| | The proportion related expenditure of social welfare in 2012 | |
|---|---|---|
| Annual industry energy efficiency improvement | 2020 | 2025 |
| 4% | 6% | -[1] |
| 5% | 8% | 12% |

[1]:The scenario does not achieve $CO_2$ reduction target

The abatement cost of industrial electricity considered excess investment per one ton $CO_2$ reduction with respect to BAU scenario, the results showed in Fig. 9 and Fig. 10. For the least cost electricity generation type, the industrial energy efficiency promotion resulted in lower investment cost and $CO_2$ emission compared to BAU, therefore, the abatement costs were all negative. About other two electricity generation types, more expensive nature gas and renewable energy use for power plants lead to more excess cost in electricity compared to least cost type, the abatement costs are all positive for the reduced coal-fired, and for the announced policy type, negative values appeared at higher industry energy efficiencies, it is due to the electricity conservation effects resulted from industry energy efficiency promotions. The abatement costs of industrial electricity for the scenarios achieving the industry sector $CO_2$ reduction targets were also enclosed by black symbolism in Fig. 9 and Fig. 10, these values were higher than the $CO_2$ prices of power and industry sector in Japan at 450 scenario assumed by WEO 2014 [10]:18 and 55 2010 US$ Million in 2020 and 2025(the $CO_2$ price in 2025 is the average of values in 2020 and 2030), except for the scenarios which have annual 4% and 5% industrial energy efficiency improvements.

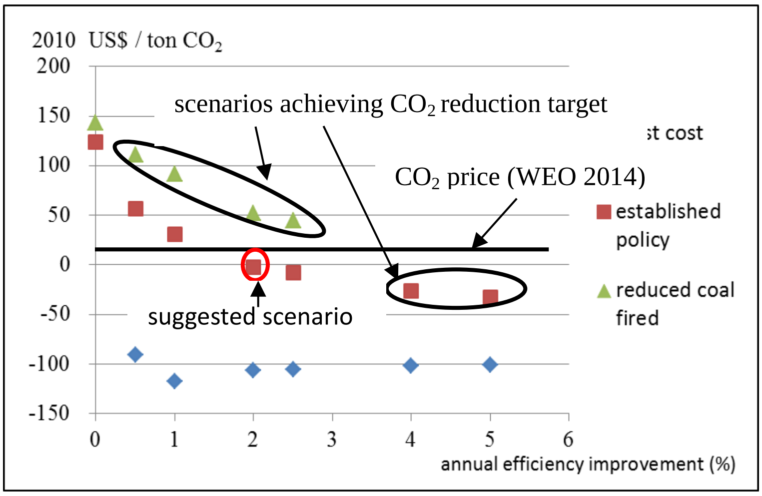


Fig.9 The abatement costs of industrial electricity base on BAU in 2020

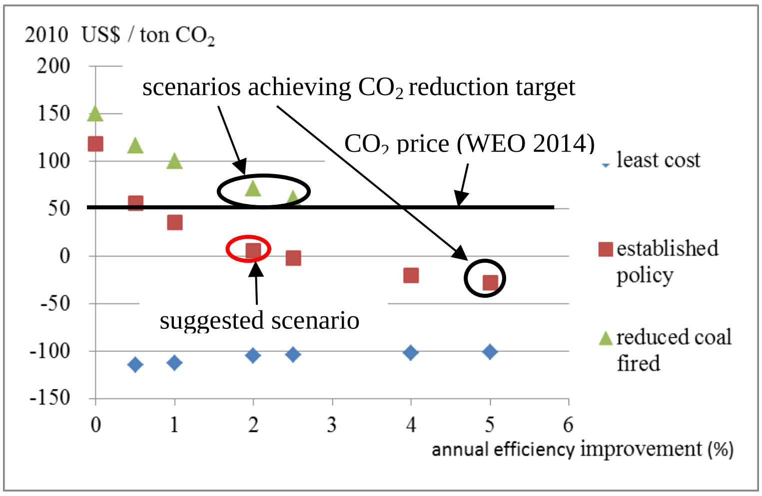


Fig.10 The abatement costs of industrial electricity base on BAU in 2025

**4. Adjustment of reduction targets**

The costs mentioned can be the review of the current $CO_2$ reduction targets of industry sector, if policy makers think the current reductions target is necessary and it is worthwhile to invest the cost, the collocations of electricity and industry technologies achieving target can be carried out.

The current $CO_2$ emissions reduction target is so ambitious that it needed expensive electricity and industry technologies to achieve the targets. If the target values are 138 million tons (2020) and 140 million tons (2025), which are 10.4% and 30.8% larger than original target, it needs the collocations of annual 2% industry energy efficiency promotion and announced nature gas and renewable energy policy (I2E2 scenario). From the view point of abatement cost of industrial electricity base on BAU, the values were low related to BAU, as showed in Fig.9 and Fig.10 (enclosed by red symbolism). Besides, 2% energy efficiency promotion of industry per year is close to the government's objective of 2% of the national annual energy efficiency improvement rate. Therefore, the collocation can be a reference of adjustment of $CO_2$ emissions reduction targets for industry sector in Taiwan. The comparison of $CO_2$ emission of industry sector between the suggested (I2E2 scenario) and BAU scenario were in Table 8.

**Table 8** The comparison of $CO_2$ emission of industry sector between the suggested scenario and BAU

| | unit | scenario | 2020 | 2025 |
|---|---|---|---|---|
| Emission from fuel-fired | million ton | BAU | 55 | 58 |
| | | Suggested scenario | 48 | 47 |
| Electricity consumption | TWh | BAU | 166 | 186 |
| | | Suggested scenario | 143 | 150 |
| Emission coefficient of electricity consumption | kg/kWh | BAU | 0.74 | 0.82 |
| | | Suggested scenario | 0.63 | 0.61 |
| Emission from electricity consumption | million ton | BAU | 123 | 152 |
| | | Suggested scenario | 90 | 93 |
| Total emission of industry sector | million ton | BAU | 178 | 210 |
| | | Suggested scenario | 138 | 140 |

## 5. Conclusions

To achieve the $CO_2$ emissions reduction targets of industry sector in Taiwan, several collocations of power generations and industry low carbon technologies were analyzed. The results showed that the $CO_2$ emissions reduction targets of industry sector can't be achieved even if the high carbon emissions coal-fired power plants are replaced by more natural gas and renewable energy power plants. The results represent that only the development of low carbon electricity technologies is not sufficient to achieve $CO_2$ emissions reduction target of industry sector. Besides, even if the annual industry energy efficiency raised by 5%, the targets are still difficult to be achieved.

From the above results, development of low-carbon electricity and industry energy technologies simultaneous may achieve the reduction targets for industrial sector in Taiwan. The results show that the following two collocations can achieve $CO_2$ emission reduction target in 2020. (1) while the annual energy efficiency promotion of industry technologies is between 0.5% and 2.5%, Taiwan needs to import more LNG (30% to 69% more than announced amounts) to fulfill the electricity demand and energy consumption; (2) under the announced development objective about renewable energy and the imported LNG storage, it needs 4% and 5% annual energy efficiency promotions of industry technologies. To reach the target in

2025, it needs industry technologies with 2% and 2.5% annual progress rate and reduction of coal-fired power, or 5% annual progress rate with the announced policy of natural gas and renewable energy. The excess costs of electricity consumption in industry compared to BAU were 14% to 40% of the social welfare in 2012, which is the largest administrative expenditure in Taiwan, and the collocations can be an inspection of the current $CO_2$ reductions targets of industry sector in Taiwan.

This study also suggests proper $CO_2$ reduction targets, the values are 138 million tons (2020) and 140 million tons (2025), which are 10.4% and 30.8% larger than the original targets. The suggested target has lower $CO_2$ abatement cost in industry's electricity consumption, and is designed under the consideration of annual 2% promotion at energy efficiency and announced nature gas and renewable energy policy.

**Acknowledgments**

Thanks for the Bureau of Energy for its support of related information. In addition, we would like to thank for Dr. Hui-Chih Chai's providing of imported energy prices.

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