***Low Carbon Strategic Analysis of Taiwan's industrial sector***

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## Overview

In 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 (INDC) to reduce GHG emissions by 20% compared to the 2005 level (227 mtCO2e) by 2030 in August 2015. These are very ambitious carbon reduction goals for Taiwan 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 equipments. 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 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. Almost 75 percent of industry’s fuel-combustion CO2 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 CO2 emissions are indirect emossions from electricity use, and motor-driven systems account for 70%. About 60 percent of direct emissions come from the boiler. Less innovation and cost reduction have taken place for industrial decarbonization technologies. This makes the pathways for reducing industrial CO2 emissions less clear and higher cost than they are 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 CO2 emissions, and industrial sector is responsible for about 50 percent among them, so the reduction of industry’s fuel-combustion CO2 emissions dominates national green house gas emissions reduction action. This is the reason this research focuses on the reduction of industry’s fuel-combustion CO2 emissions .

## Methods

The TIMES (The Integrated MARKAL-EFOM System) energy model was adopted to evaluate optimal energy deployment for CO2 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".

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.

In this study, two scenarios, reference and carbon reduction, were considered to perform the analysis. Basically, the reference scenario is without constrains of carbon emissions and the coal power potential is bounded according to the Taipower company planning. 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 INDC 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 penetration rates of gas and bio-charcoal boilers are also given feasible rates. Since the cost-effective low-carbon process technology and the efficiency improvement of coal-fired boilers 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 CO2 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.

## Results

According to the results of the prism analysis shown in Fig.1, if the existing power structure is maintained, the carbon reduction contribution is mainly from low-carbon industrial technology boilers and high efficiency motor-driven systems, and the total share is almost less than 20%. It must be decarbonized with low-carbon power, energy service demand reduction and other means, such as material efficiency improvement and fuel alternatives. 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. 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. Even so, to meet the long-term stringent carbon reduction target, the contribution from demand reduction is gradually rising to compensate the insufficient low-carbon technologies in industrial sector.

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. However, industrial sites have long lifetimes; therefore, upgrading or replacing these facilities to lower carbon emissions requires that planning and investments start well in advance. And industrial processes are 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 when building or renovating their plants. Energy efficiency improvements can reduce carbon emissions competitively, but cannot lead to deep decarbonization on their own. In Taiwan, due to the power decarbonization, the electricity cost will soar up 57% and 100% of the level in 2015, in 2030 and 2050, respectively. 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 CCS technology.



Fig. 1 The industrial CO2 emissions reductions by technology.

## 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.

By 2050, the carbon reduction target will be strigent, and the proportion of demand reduction will increase to 50%.Industry structure adjustment means some energy-intensive industries need to be phased out and transform into the higher-valued ones. Besides, 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 CO2 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 virgin steel.

Industrial companies can reduce CO2 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 projected production changes due to demand reduction. In the harder-to-abate industrial sectors such as steel, cement, and chemicals, bioenergy sources and carbon capture will also be required.Where carbon-storage sites are available, CCS is the lowest-cost decarbonization option for now. However, the local availability of carbon storage capacity and public and regulatory support for carbon storage determine whether CCS is a feasible option. In the long run, the cost of other zero-carbon electricity, also for producing heat and hydrogen, will be more economical than CCS. However, this depends on the availability of renewables and will differ on a country-by-country basis.