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# Risk assessment of mortality for all-cause, ischemic heart disease, cardiopulmonary disease, and lung cancer due to the operation of the world's largest coal-fired power plant

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## HIGHLIGHTS

- A method to evaluate the $PM_{2.5}$-related health risks.
- The risks of all-cause mortality for the largest power plant were 0.03%–0.1%.
- Better air quality management and site chosen changes health risks significantly.

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## ABSTRACT

Based on recent understanding of $PM_{2.5}$ health-related problems from fossil-fueled power plants emission inventories collected in Taiwan, we have determined the loss of life expectancy (LLE) and the lifetime (75-year) risks for $PM_{2.5}$ health-related mortalities as attributed to the operation of the world's largest coal-fired power plant; the Taichung Power Plant (TCP), with an installed nominal electrical capacity of 5780 MW in 2013. Five plausible scenarios (combinations of emission controls, fuel switch, and relocation) and two risk factors were considered. It is estimated that the lifetime (75-y) risk for all-cause mortality was 0.3%–0.6% for males and 0.2%–0.4% for females, and LLE at 84 days in 1997 for the 23 million residents of Taiwan. The risk has been reduced to one-fourth at 0.05%–0.10% for males and 0.03%–0.06% for females, and LLE at 15 days in 2007, which was mainly attributed to the installation of desulfurization and de-$NO_x$ equipment. Moreover, additional improvements can be expected if we can relocate the power plant to a downwind site on Taiwan, and convert the fuel source from coal to natural gas. The risk can be significantly reduced further to one-fiftieth at 0.001%–0.002% for males and 0.001% for females, and LLE at 0.3 days. Nonetheless, it is still an order higher than the commonly accepted elevated-cancer risk at 0.0001% ($10^{-6}$), indicating that the $PM_{2.5}$ health-related risk for operating such a world-class power plant is not negligible. In addition, this study finds that a better-chosen site (involving moving the plant to the leeward side of Taiwan) can reduce the risk significantly as opposed to solely transitioning the fuel source to natural gas. Note that the fuel cost of using natural gas (0.11 USD/kWh in 2013) in Taiwan is about twice the price of using coal fuel (0.05 USD/kWh in 2013).



## 1. Introduction

Recently, several studies have confirmed the relationships of fine particulate air pollution (for particulate matter with a diameter of 2.5 μm or less, denoted as $PM_{2.5}$) with human health outcomes (e.g. Pope et al., 2002; Elliott and Copes, 2011; Turner et al., 2011; Vinikoor-Imler et al., 2011; Crouse et al., 2012; Hoek et al., 2013; Kloog et al., 2013) and life expectancy (e.g. Krewski, 2009; Pope et al., 2009). They found that for short-term and long-term exposures, $PM_{2.5}$ does have an important mortality burden. The health risks include all-cause mortality (excluding injury and poisoning)

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(ICD-9: 0–799), ischemic heart disease mortality (ICD-9: 410–414), cardiopulmonary mortality (ICD-9: 401–440 and 460–519), and lung cancer mortality (ICD-9: 162). Nonetheless, it is unclear how to use these findings for risk assessment. This study presents a method to evaluate the $PM_{2.5}$-related health risks for the operation of the world's largest coal-fired power plant as an example. In addition, we show an approach for reducing these risks for the power plant based on five plausible scenarios (such as emission control, changing coal for natural gas, and relocation) using 2 risk factors.

The Taichung Power Plant (TCP), located in central Taiwan (24.21 °N, 120.48 °E) (Fig. 1), is the world's largest coal-fired power plant with an installed capacity of 5780 MW (TPC, 2008, 2011). The TCP is also the world's largest $CO_2$-emitting coal-fired power plant ($36 \times 10^6$ ton $y^{-1}$ $CO_2$ emission) (CARMA; Ummel, 2012). The power plant emitted 13% of the total $CO_2$ emissions of Taiwan and is estimated to produce 0.1% of the world's $CO_2$ emission at $34.5 \times 10^6$ ton $y^{-1}$ in 2012 (Olivier et al., 2013). The power plant also emitted 14,000 ton of $SO_2$ in 2007 (CTCI, 2009; Table 1). This level of emissions may affect climate change globally, and health and environmental degradation locally.

The population density of eastern Asia is very high. In Taiwan, for example, although flat land constitutes only 20% of the nation's territory, it houses most of the country's population (Fig. 1). Air pollutants emitted from the TCP may reach to most of the flat land on Taiwan, thus affecting the daily life for the majority of the population, with 23 million residents.

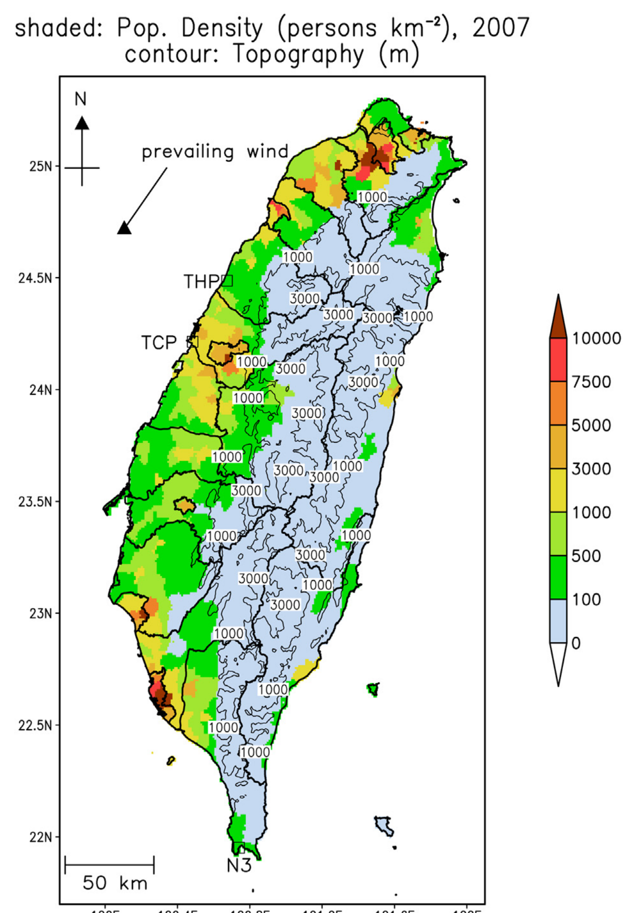


**Fig. 1.** Population density in 2007 (shaded) and topography of Taiwan (contour), where open squares denote the TCP, THP and N3 power plants.

**Table 1**
Emission inventories and power generation in two of Taiwan's fossil-fueled power plants in 1997 and 2007.

| | TCP | | THP | |
|---|---|---|---|---|
| Year | 1997 | 2007 | 1997 | 2007 |
| Fuel | Coal | Coal | Heavy Oil | Natural gas |
| Control equipments | ESP | ESP, FGD, SCR | LNB | LNB |
| Primary $PM_{2.5}$ (ton $year^{-1}$) | 864[a] | 598[b] | 1454[a] | 178[b] |
| $SO_2$ (ton $year^{-1}$) | 93,030[a] | 14,073[b] | 20,072[a] | 46[b] |
| $NO_x$ (ton $year^{-1}$) | 40,301[a] | 25,432[b] | 14,839[a] | 3899[b] |
| Installed capacity (MW)[c] | 4724 | 5780 | 1500 | 1818 |
| Power generated (TWh) | 31.2 | 43.4 | 6.5 | 6.9 |
| Primary $PM_{2.5}$ (kg/MWh) | 0.03 | 0.01 | 0.22 | 0.03 |
| $SO_2$ (kg/MWh) | 2.98 | 0.32 | 3.10 | 0.01 |
| $NO_x$ (kg/MWh) | 1.29 | 0.59 | 2.29 | 0.56 |
| Fuel cost in 2012 (USD/kWh)[d] | 0.05 | 0.05 | 0.19 | 0.11 |

[a] CTCI, 1999.
[b] CTCI, 2009.
[c] Power-technology.com (Provided from Taiwan Power Company).
[d] TPC, 2012.

All the units of the TCP had installed particle removal equipment (e.g. electrostatic precipitators, ESP) to control the emission of particulate matter since the beginning of their operations from 1991. From 1995, the Environmental Protection Agency of Taiwan (EPA/TW) began to levy emission taxes on pollution sources and implemented a number of control strategies, with the goal of improving the nation's air quality. Since 1997, the TCP has gradually installed desulfurization equipment (e.g. Flue Gas Desulfurization, FGD) for reducing $SO_2$ emission, and de-$NO_x$ (e.g. selective catalyst reduction, SCR) equipment for reducing $NO_x$ emission. In addition, the TCP has increased the efficiency of the de-PM equipment for reducing particulate matter emission further. Hence, the $SO_2$, $NO_x$, and primary $PM_{2.5}$ emissions have been shown to decline significantly since 2000. Moreover, a nearby power plant, Tunghsiao power plant (denoted as THP, Fig. 1), changed its fuel source from heavy oils to natural gas during 2000–2002. After this change, the $SO_x$ emission from THP was shown to decline significantly. THP also used low-$NO_x$ burner (LNB) to reduce the burner temperature, prohibiting the production of thermo-$NO_x$. The emission inventories of TCP and THP are shown in Table 1 (CTCI, 1999, 2009).

## 2. Methods

### 2.1. Scenarios

Before deciding the location of the power plant, not only the topography but also the geological condition, the population density, the operating cost, and so on should be considered. However, lowering the health risk from a power plant is still a target. Moreover, according to "Basic Environment Act, Article 23, 2002" (MOJ/TW, 2002), the Taiwan government is required to gradually achieve the goal of becoming a nuclear-free country. As part of this approach, the Number 3 nuclear power plant (21.96 °N, 120.75 °E) (denoted as N3 in Fig. 1) will be shut down in 2024/2025 following 40 years of operation (Forumsowhat, 2011; Atomic Energy Council, 2013). Subsequently, the site might be used to build a fossil-fuel-fired power plant. The site is located in the southern-most tip of Taiwan (Fig. 1). From September to April when northeast monsoons dominate, the site is the leeward site of Taiwan. Therefore, the fossil-fueled generated $PM_{2.5}$ could have less impact on the health if the TCP is relocated to the N3 site. In addition, natural gas is currently considered as a cleaner fuel than coal. Hence, without considering other factors, five scenarios and two risk factors have been investigated in this study to quantify $PM_{2.5}$ health risks with considering whether the pollution control equipment is installed or