



Activity-determined Steps on the Attenuation of Atmospheric PM_{2.5} Concentration Environmental Kuznets Curve (EKC) at the Country Level: Empirical Evidence in Taiwan

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Finding ways to minimize the atmospheric concentration of PM_{2.5} is an emergency issue throughout the world. This research has found a method to calculate historical PM_{2.5} data and to define the PM_{2.5} environmental Kuznets curve (EKC) pattern in Taiwan. From the analysis of the Taiwan Environmental Protection Agency's public emission data, results showed that the continuous decay of PM_{2.5} is mostly contributed by the energy policy, while several short-term regular stepwise fluctuations in PM_{2.5} concentrations are caused by natural activity. Our study also proved that the linear decay with stepwise fluctuations also exhibits an EKC pattern.

The results herein mean that the continuous decay of PM_{2.5} is caused by the energy policy, while the regular fluctuation of PM_{2.5} concentrations is caused by natural activity, like the La Nino phenomena. Based on the viewpoint of this paper, the oil consumption percentage for electricity generation should be first reduced to zero. However, oil-based power plants are an important emergency source of electricity supply. If Taiwan wants to continue the reduction of PM_{2.5} in the future, then a big capacity electric storage facility should be built as an emergency source of electricity supply. The energy policy in Taiwan at 2025 will be 50% natural gas, 30% coal, and 20% green energy. As oil fuel will reach 0%, PM_{2.5} will be affected by the energy intensity contributed from coal and natural gas, meaning that PM_{2.5} will maintain a long-term attenuation trend until 2035.

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1. INTRODUCTION

The Environmental Kuznets curve (EKC) was proposed from the aspect of the income-driven willingness-to-pay for the environment [1-7]. From 1985 to 2015, the primary energy consumption-to-GDP ratio (called energy intensity) in Taiwan exhibited an EKC pattern (an inverted U-shape path of primary energy consumption along with increasing GDP). Only a few recent works have focused on a single country [8-11]. This present study found that an inverted V-shape trend is usually observed for EKC in a single country level, and linear growth also exhibits a EKC pattern [12]. The driving force of EKC formation is caused by international events inducing national policy response [10].

How to minimize the atmospheric concentration of $PM_{2.5}$ is an emergency issue around the world. In Taiwan, the regulated annual atmospheric concentration of $PM_{2.5}$ has been defined as 15 $\mu\text{g}/\text{M}^3$ at 2012 and a protection level of 10 $\mu\text{g}/\text{M}^3$ for human health by the World Health Organization (WHO). However, Taiwan has still not reached this goal. One of the big issues is that $PM_{2.5}$ data started being collected since 2005, and they show a simple attenuation trend. The $PM_{2.5}$ data of the U.S. started since 1980, and they also show a similar simple attenuation trend. In this paper we have found the correlation between Taiwan's $PM_{2.5}$ and its energy policy. It means that we can calculate historical $PM_{2.5}$ data from historical energy fuel consumption data.

Taiwan has passed the turning point of primary energy EKC. Therefore, the most important result is that this study has confirmed that the simple attenuation on $PM_{2.5}$ is an EKC pattern. In recent years, the $PM_{2.5}$ real-time monitoring system has been built and is open for everyone to view on a website. Since 2016, the red-damage of air pollution has been defined as when the Air Quality Index (AQI) is > 160 or $PM_{2.5}$ is $> 150 \mu\text{g}/\text{M}^3$. The Taiwan Power Company has been forced by local governments to adopt proper actions - for example, to slow down the output of coal fire plants' electricity generation. However, the electric supply is very strict due to a need-response operation model. A suddenly slow-down in the electricity generation loading of a coal fire plant is not a very good choice. From our results, we can perform the $PM_{2.5}$ reduction acts in more precision for the long term environmental policy.

2. METHODS

This paper targets to find the EKC pattern of $PM_{2.5}$ in Taiwan in the past 15 years. The panel data of $PM_{2.5}$ (shown in Fig. 1) and energy structure are obtained from the open-source websites of Taiwan EPA and Taiwan Energy Agency.

3. RESULTS AND DISCUSSION

Fig. 1 illustrates $PM_{2.5}$ from a simple attenuation model since 2005. In Fig. 2, the results show that the concentration of $PM_{2.5}$ is related to the primary energy intensity and fuel used in fire power plants, especially for oil as a consumption percentage for electricity generation. After oil was burned and the $PM_{2.5}$ was emitted to the atmospheric environment, it is not reflected on the $PM_{2.5}$ monitoring data daily the data occurred timing is late for 10 years. From the results of Fig. 3, the measured $PM_{2.5}$ data have good matching with the calculated $PM_{2.5}$ based on fitting the empirical equation, Eq. (1).

$$PM_{2.5} = 0.4 * \text{Energy Intensity} + 1.5 * \text{Oil}\% + 2 \quad (1)$$

Fig. 4 shows the attenuation EKC model of calculated $PM_{2.5}$ in Taiwan from 1990 to 2020. For one tail hypothesis testing, we used the 1% significance level, and then $Z^* = -2.33$. Here, H_0 is observed to be 18 between 2002 to 2020, with a standard derivation of "s" years. The Kuznets infrastructural investment cycle has been estimated at 15 to 25 years. In this paper we choose 18 years (H_0), and the observed averaged value is only 15 years (x) for 2005-2020. If H_0 is not rejected, then the Z value must be larger than Z^* . The calculated s value is < 3.4 years. From Fig. 4, the observed s value is 3.0 years, or just meeting the calculated value. Therefore, the duration data of the measured data for $PM_{2.5}$ between 2005-2020 is included in the EKC time scale from 2005-2023. This period also matches the quickly decrement period in oil consumption percentage in Fig. 2 for 1995-2010.

In our last publication [12] the delay emission of the CO_2 on its monitored atmospheric concentration can get the good correlation with the natural gas consumption percentage after shifting the axial data. Fig. 5 shows the relation between shifted oil% and shifted calculated $PM_{2.5}$, from where we can observe four increment

stepwise growth onset points at years 1999, 2003, 2011, and 2019, which were *La Nina* years. This is similar with our previous study [12], in which atmospheric CO₂ concentration has a significantly stepwise fluctuation during *El Nino* and *La Nina* years in West Asia. In Plate 1, we also proposed the proportional process for PM_{2.5}

by a simple decay model with a regular stepwise fluctuation, releasing from the atmosphere sink to land and ocean sinks. It means that the continuous decay of PM_{2.5} is caused by the energy policy, while the regular fluctuation in PM_{2.5} concentrations is caused by natural activity, like the *La Nina* phenomena.

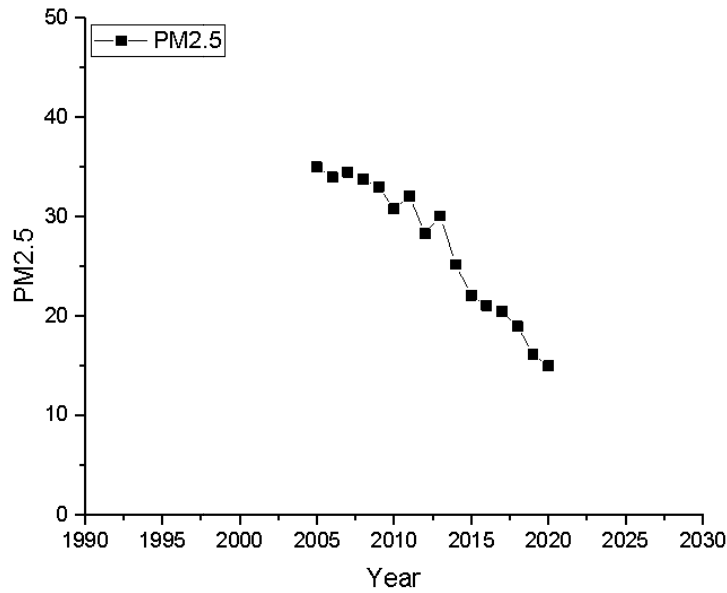


Fig. 1. The measured PM_{2.5} concentrations in Taiwan from 2005 to 2020

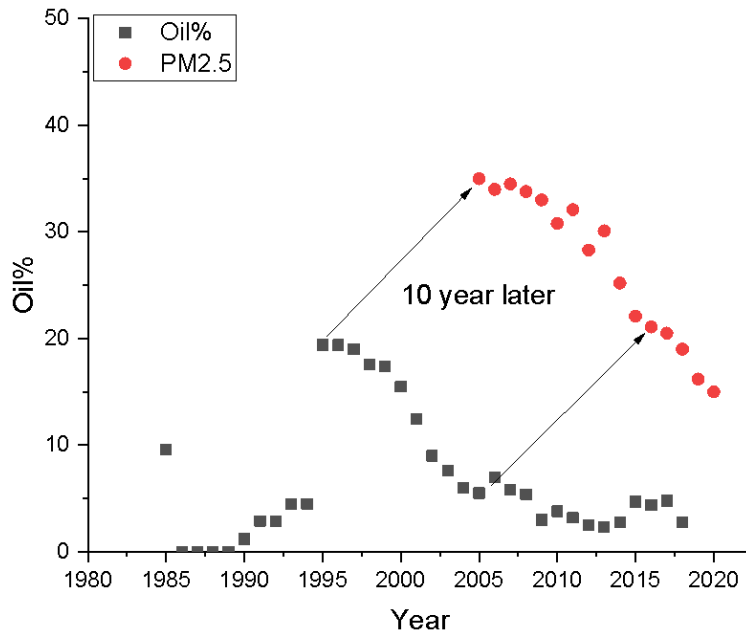


Fig. 2. The measured PM_{2.5} concentrations and oil consumption used percentage in Taiwan from 1985 to 2020

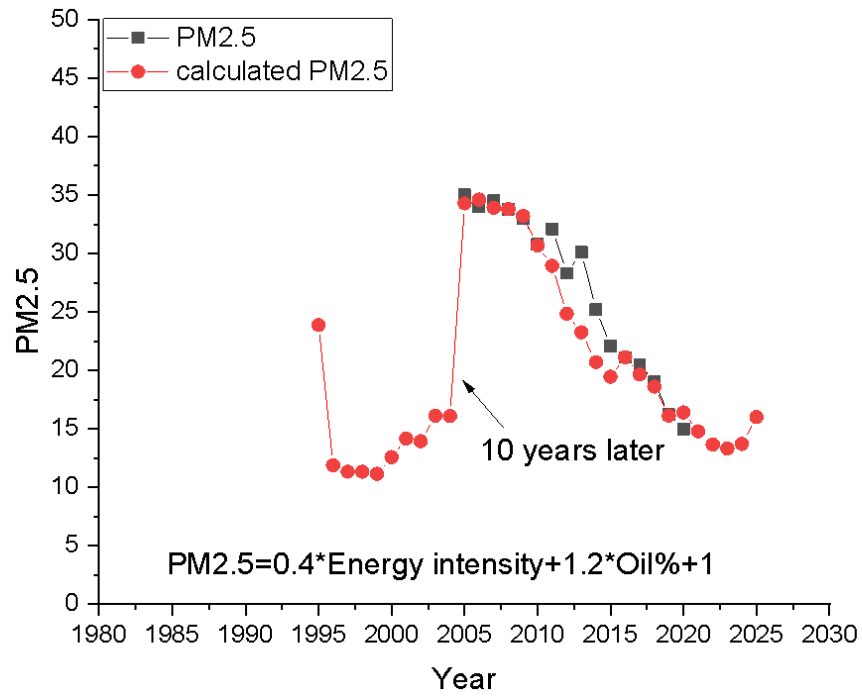


Fig. 3. The measured and calculated PM_{2.5} in Taiwan from 1995 to 2025

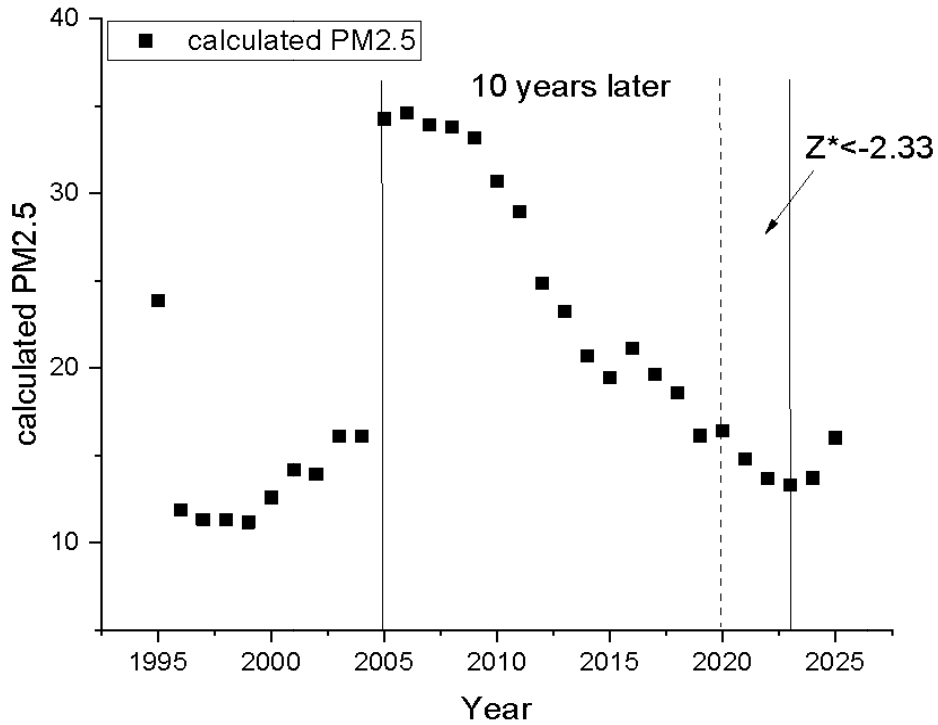


Fig. 4. EKC attenuation modes of calculated PM_{2.5} in Taiwan from 2005 to 2023

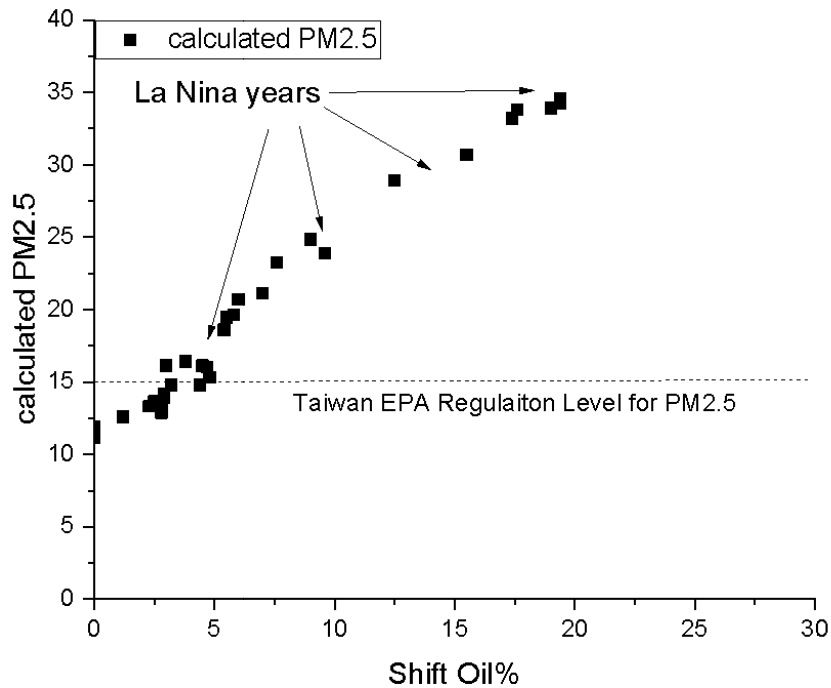


Fig. 5. Relation between calculated PM_{2.5} and Oil% in Taiwan

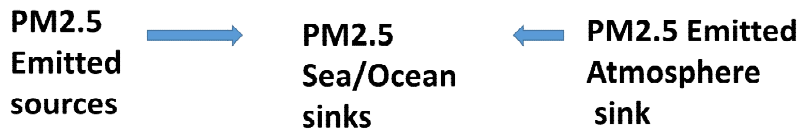


Plate 1. The proposed proportion process for PM_{2.5}

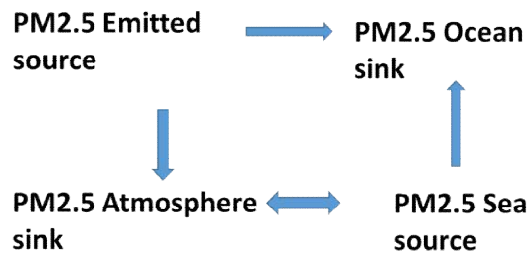


Plate 2. The proposed disproportion process for PM_{2.5}

4. CONCLUSION REMARKS AND POLICY IMPLICATIONS

In this paper we have found that historical PM_{2.5} data can be calculated through primary energy intensity and oil% for electricity generation consumption. This fact indicates that to reduce the coal power percentage might not be a precise solution for Taiwan's long-term PM_{2.5} reduction policy. This study also proposes a proportional process for the PM_{2.5} EKC curve that is a simple decay model with a regular

stepwise fluctuation. It means that the continuous decay of PM_{2.5} is caused by the energy policy, while the regular fluctuation of PM_{2.5} concentrations is caused by natural activity, like the *La Nino* phenomena. Based on the viewpoint of this paper, the oil consumption percentage for electricity generation should be reduced to zero first. However, oil-based power plants are an important emergency source of electricity supply. If Taiwan wants to continue the reduction of PM_{2.5} in the future, then a big capacity electric storage facility should be built as an emergency

source of electricity supply. The energy policy in Taiwan at 2025 will be 50% natural gas, 30% coal, and 20% green energy. As oil fuel will reach 0%, PM_{2.5} will be affected by the energy intensity contributed from coal and natural gas, meaning that PM_{2.5} will maintain a long-term attenuation trend until 2035.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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