Activity-determined Steps on the Growth of Atmospheric CO$_2$ Concentration Environmental Kuznets Curve (EKC) at the Country Level: Taiwan's Empirical Evidence

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Author's contribution

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

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ABSTRACT

Taiwan's atmospheric CO$_2$ concentration is half in compliance on the formation of a environmental Kuznets curve (EKC), and the major contributor of direct CO$_2$ emissions in Taiwan is from the power generation sector using coal and natural gas as fuel. Atmospheric CO$_2$ concentration has been found to have the linear increment with stepwise fluctuations every five years during the period 2001-2018. Activity-determined steps were proposed noting that there is a proportion process for the increase of CO$_2$ coming directly from the emission source of power plants and the source from the marginal sea sink to atmosphere sink due to memory delay-releasing. The alternative occurring events of *El Nino* and *La Nina* in the West-Pacific region exactly match the fluctuations every five years, and the difference between the monitored atmospheric CO$_2$ concentration with an empirical equation of calculated atmospheric CO$_2$ concentration from the electricity structure in a single country level is a new indictor for the occurrences of *El Nino* and *La Nina* phenomena in this region. Results also showed that the atmospheric CO$_2$ concentration in Taiwan for the year 2035 is predicted to be as high as 430 ppm, due to a 50% natural gas energy policy. Our study provides a

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causal explanation for why atmospheric CO_2 concentration has a linear increase shape with stepwise fluctuations for a single country. Our study has also proved that the linear increment with stepwise fluctuations also exhibits a EKC pattern.

1. INTRODUCTION

The reduction of carbon emissions is important for slowing down global warming, particularly pollution from CO_2. The Environmental Kuznets curve (EKC) was proposed for the environment from the aspect of income-driven actions [1,2], (Stern, 2004) [3,4,5]. From data spanning 1985 to 2015 in Taiwan, the primary energy consumption-to-GDP ratio (called energy intensity) exhibited an EKC pattern (an inverted U-shape of primary energy consumption along with increasing GDP). In our previous study the turning point of primary energy EKC was found to be driven by an exogenous event to endogenous policy [6] and the formation mechanism of CO_2 emission amount is a perfect inverted V-shape due to the disproportion process of electric energy course [7]. Most of the literatures compared the cross countries data and formulate a mathematic equation for a long run period. Recently the author has developed an event-induced mechanism [6] to explain the formation of EKC pattern in a single country level within the

Kuznets' period, 15-25 years. And in the paper we used the detail steps on controlling the process of atmospheric CO_2 concentration. The author tried to develop a new methodology to explain why the CO_2 concentration still keep growth even we have largely reduced the emission amount of CO_2 in Taiwan [7].

2. METHODS

The direct emissions of CO_2 in Taiwan come from the power generation sector (Fig. 1 and Fig. 2). The source of raw data in these two figures were got from Taiwan Power Co. (http://https://www.taipower.com.tw/tc/Chart.aspx?mid=194). In Taiwan, atmospheric CO_2 concentration (the unit used is ppm) shows a monopoly increasing shape with stepwise fluctuations. This shape is not a classical inverted U-shape for the environmental Kuznets curve (EKC). The proposed of this paper is to develop a modelling process and the controlled steps basing on the economic and business viewpoint
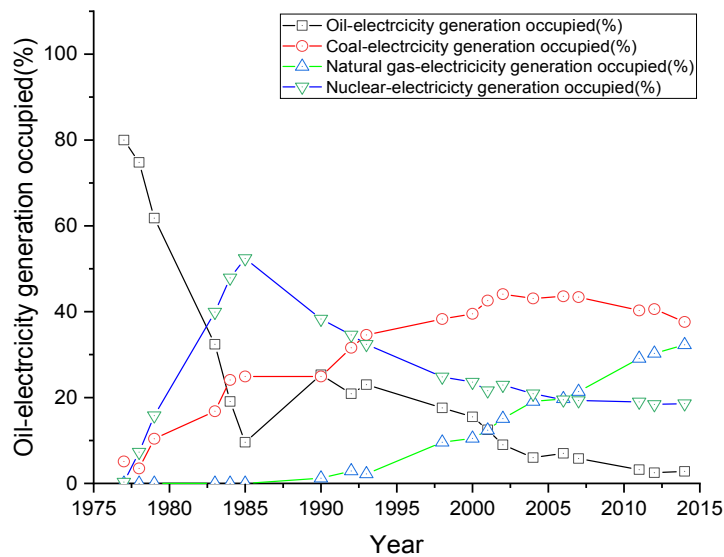

Fig. 1. Electricity generation from various primary energy sources in Taiwan from 1977 to 2014
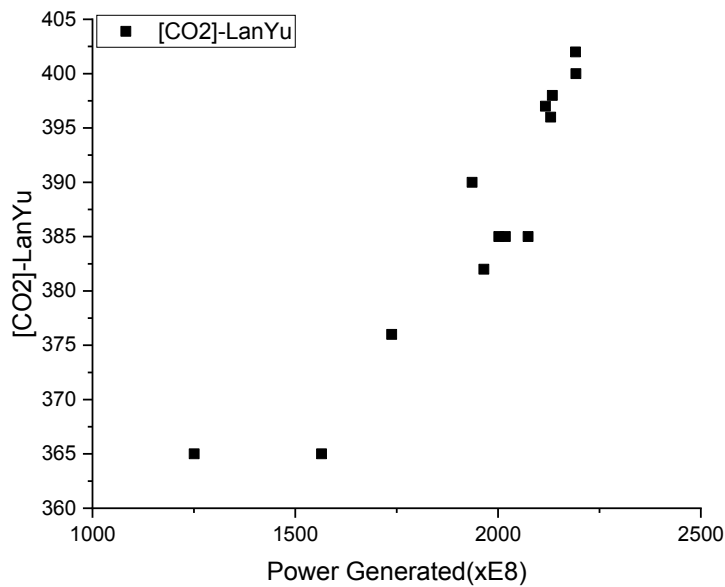
Fig. 2. Power generation and atmospheric CO_2 concentration in Taiwan from 1995 to 2015

3. RESULTS

Fig. 3 shows the EKC pattern of atmospheric CO2 concentration in Taiwan from 1990 to 2020. For one tail hypothesis testing, we use the 1% significance level, and then Z*= -2.33. Here, H0 is observed to be 15 between 2001 to 2015, with a standard derivation of "s" years. The Kuznets infrastructural investment cycle has been estimated at 15 to 25 years, and in this paper we choose 15 years (x), and the observed average value is 17 years (H0). If H0 is not rejected, then the Z value must be larger than Z*. The calculated value of s is < 3.65 years. From Fig. 3, the observed value of s is near 2.0 years, or just meeting the calculated value. Therefore, the CO_2 emission data span between 2001-2018, and the duration meets the EKC time scale. This period also matches the quick increment of natural gas' occupied percentage in Fig. 1.

This paper analyzed the energy activity of fuel used in past years and found that among total generation electricity amount (Fig. 2), the summarized percentage of coal and natural gas used is the key factor for CO_2 emissions and that natural gas is the most significant contributor of atmospheric CO_2 concentration (Fig. 4 and Fig. 5). Since 2006, the summarized percentage of coal and natural gas used has been kept at 70%, and therefore the CO_2 emission amount is the same [7], but the atmospheric CO_2 concentration has a linear increment with stepwise fluctuations (Fig. 3). This phenomenon quite fits the observation in the Asia region [8]. In their work, the CO_2 concentrations of China, India, Japan, South Asia, and East Asia were compared for 1950-2015. The CO_2 concentrations have a similar changing trend and possess a plateau area at 1995-2000, 1977-1982, and 1960-1965. In Fig. 3, due to the appearance of stepwise fluctuations, we find base-line matched points between 2001 and 2018. It means that the linear increment with stepwise fluctuations still illustrates a EKC pattern.

4. DISCUSSION

Fig. 6 shows the slopes of the natural gas used percentage as power fuel, indicated by S1, S2, and S3. The growth rate of CO_2 concentration at each corresponding step does not match with S1, S2, and S3, but shows a delayed response for 5 years later. We propose a CO_2 concentration accumulation and consumption in Scheme 1 and Scheme 2, where the direct emissions from power plants and sea sink releasing are the two major sources. 4. The descriptions of proportional process and dis-proportional process has been defined firstly for energy

sources in our previous publication as following:" We just proposed those two processes as the meaning of "proportion" and "disproportion". The "proportion process" is occurred A to (B and C), the new generation energy system totally replaces the existed energy system; while ""disproportion process" is occurred (B and C) to A, the different energy system co-exist at same time." And in here we extend the original idea to the cycling of emitted CO2 from power plants, the different two interaction models between sources and sinks of CO2. The proportional process means the same CO2 sink accept various CO2 sources. While the disproportional process means the reversible migration between CO2 sinks and sources.

If each CO_2 source has a clear cut, then the CO_2 concentration will have an inverted V-shape due to the disproportion process as shown in Scheme 1 [7], and a linear increment with stepwise fluctuations can be observed and attributed to the sea-air interaction in the marginal sea [9,10]. The panel data used here are detected at Lan-Yu Air Quality Detection Center. The site is just in the biggest marginal sea, the *South Sea*. In

addition, the atmospheric CO_2 concentration has a regular change every 5 years and also matches the alternative occurrences of *El Nino* and *La Nina* phenomena (Fig. 7). The 5-year shifted atmospheric CO_2 concentration can be calculated by the following Eq. [1]. From this empirical equation, we can make sure that the use of natural gas as power plants' fuel has a higher contribution to atmosphere CO_2 concentration than the contributions from coal power plants. 8. The empirical fitting equation tells the pre-factor of natural gas is larger than coal, therefore we can conclude this viewpoint. In addition, besides energy activity (the 2nd and 3rd terms), we obtain two other activities - they are contributed from human lives' related activity (the 1st term) and nature activity (the 4th term). 4. The "activity" means the contributions of CO2 from power plants and the natural *El Nino* and *La Nino* phenomena. The "activity-determined steps" means the CO2 concentration is determined by those two activities.

$$[CO2] = 280 + 1.85 * Natural\ Gas\% + \frac{1.2*Coal\%}{Natrual\ Gas\%} + 1.0 * Coal\% + 28 \qquad \text{Eq. [1]}$$
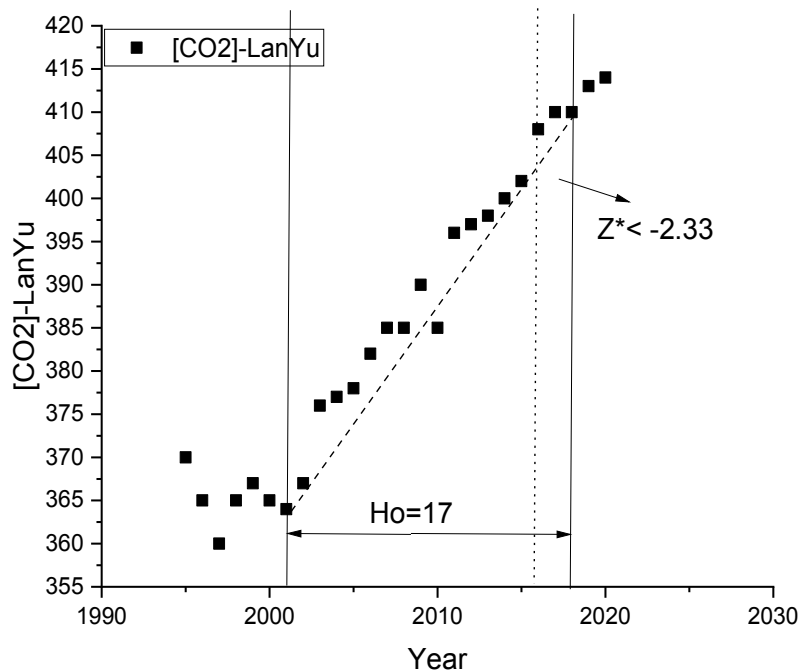

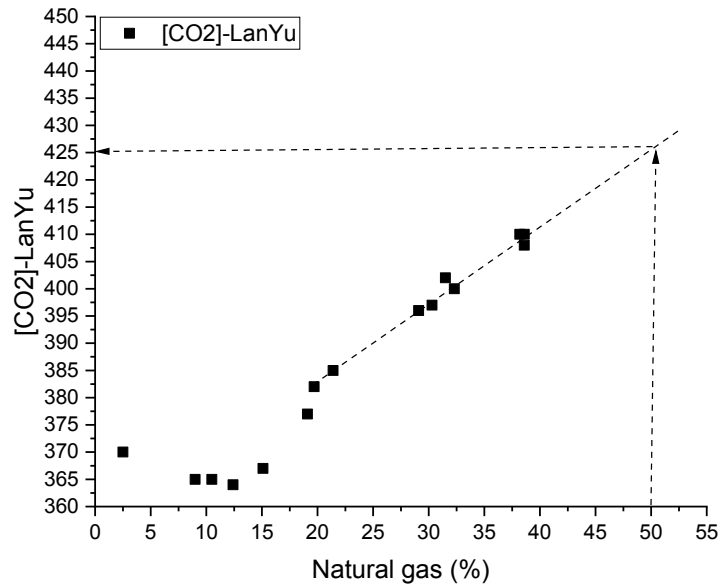**Fig. 3. Atmospheric CO₂ concentration in Taiwan from 1995 to 2020**

Fig. 4. Natural gas used percentage and atmospheric CO$_2$ concentration in Taiwan from 1995 to 2020

Fig. 5. Comparison of the growth slope between the percentage of natural gas used and atmospheric CO$_2$ concentration in Taiwan from 1995 to 2020
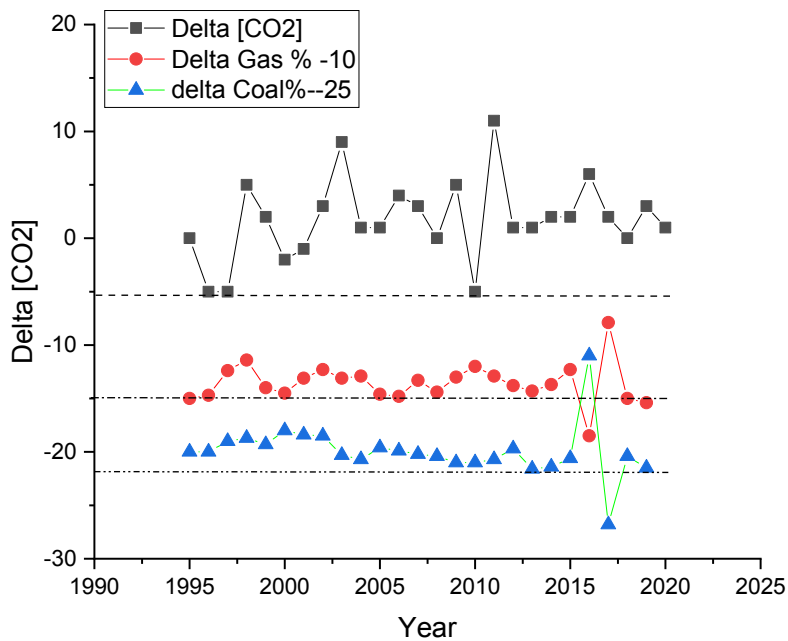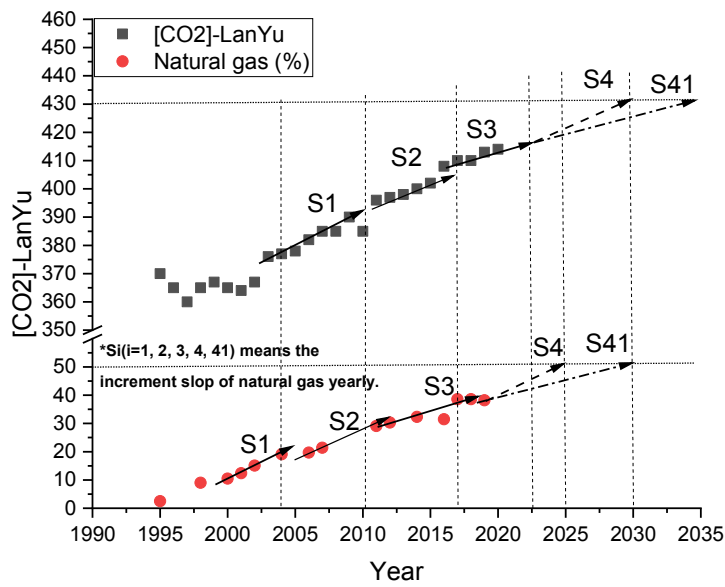
Fig. 6. Comparison of the growth slope between the percentage of natural gas used and atmospheric CO₂ concentration in Taiwan from 1995 to 2020
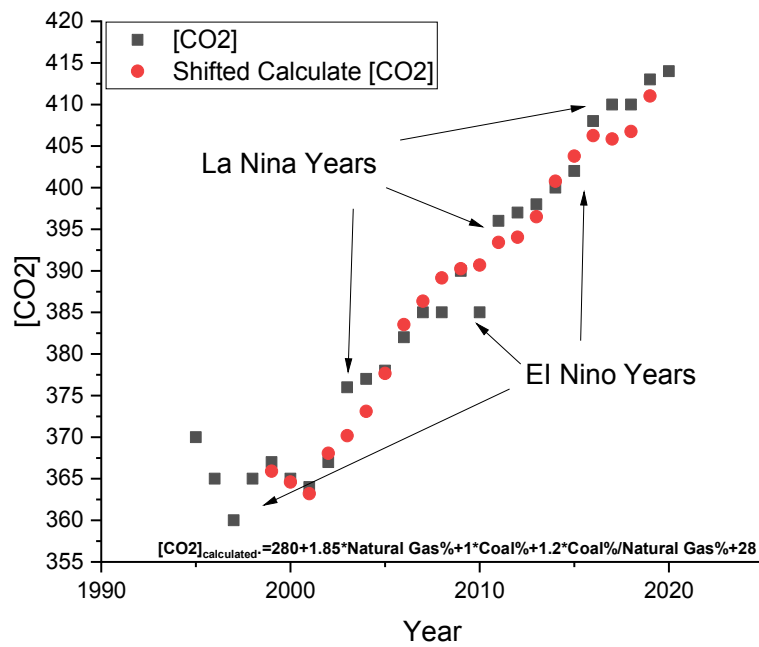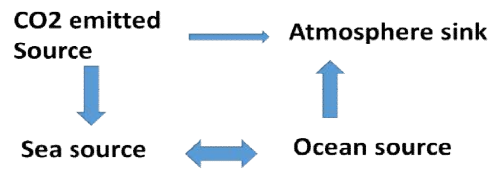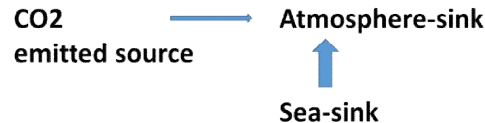

Fig. 7. Relations between stepwise plateau region and *El Nino* and *La Nina* years' atmospheric CO₂ concentration in Taiwan from 1995 to 2020

Scheme 1. The proposed disproportion process of CO_2 emissions and sinking and sourcing of the sea

Scheme 2. The proposed proportion process of direct CO_2 emissions and delay memory-releasing from sea-sink

5. CONCLUSION REMARKS AND POLICY IMPLICATIONS

Many countries have chosen the strategy for a large decrease of CO_2 emission amount by changing the fuel of fire power plants from coal to natural gas, however, the world still has higher atmospheric CO_2 concentration. Our study provides a causal explanation for why atmospheric CO_2 concentration has a linear increment with stepwise fluctuations at the single country. Our study further approves that the linear increment with stepwise fluctuations also exhibits a EKC pattern. When the natural gas percentage reaches 50%, the CO_2 concentration level in Taiwan will increase up to 425 ppm (Fig. 4), which is the proposed energy structure for the year 2025 by the Taiwan government. It indicates that a one-unit increase of natural gas used will increase atmospheric CO_2 concentration by 35ppm. For Taiwan, the maximum atmospheric CO_2 concentration will be 430 ppm after considering the effect of delay releasing from sea sink to atmosphere sink (Fig. 6). The rate of archiving the electric structure goal is independent of the final atmospheric CO_2 concentration. It means that the energy policy and natural phenomena decide the atmospheric CO_2 concentration. Because Taiwan's information and communication technologies (ICT) industry will play a key role in developing artificial intelligence (AI), internet of things (IoT), and 5th generation mobile network/wireless system (5G) applications for the world in the coming 15-25 years, the country need more electric power. Therefore, without the consideration of using renewable energy, Taiwan can keep the choice of consuming ocean and atmosphere sinks for developing its economy.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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