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空氣品質對民眾核能偏好之影響－以臺灣兩場公投為例

The Effects of Air Quality on Citizens' Preferences for Nuclear Energy: Evidence from Two Referenda in Taiwan

劉宜瑱

Yi-Tien Liu

指導教授：石曜合 博士

Advisor: Yau-Huo Shr, Ph.D.

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摘要

核能發電因排放相對較少的空氣汙染物與溫室氣體，而被視為在能源轉型中，可用來取代火力發電的短期解方。本文探討當民眾暴露於較嚴重的空氣汙染時，是否會更傾向支持核能發電。我們使用 2018 年公民投票中的第 16 案，「您是否同意廢除電業法第 95 條第 1 項，即廢除『核能發電設備應於中華民國一百十四年以前，全部停止運轉』之條文？」及 2021 年公投中的第 17 案，「您是否同意核四啟封商轉發電？」。儘管兩提案均是與核能有關，但他們的主訴求卻大相逕庭。第 16 案的支持者以使用核能將可以降低空氣汙染為宣傳主軸，然而支 i 持第 17 案的人則著重核能將為穩定電力供給帶來助益。為處理非隨機變化之空氣品質與公投結果兩者之間的內生性問題，我們使用公投日前七天與過去同期平均空氣品質之差值為工具變數。研究結果顯示，在 2018 年公投時，若投票日前七天之細懸浮微粒濃度相較過去同期平均上升 1 $\mu g/m^3$ (1%)，第 16 案之同意率會上升 0.3% (0.06%)。然而在 2021 年公投中，我們並未發現投票日前七天與過去同期平均之空氣品質差異對第 17 案贊成比率有顯著的影響。除了空氣品質與核能相關提案贊成率之間的因果關係，我們也探討空氣品質對核能提案投票率的影響；研究結果顯示，當投票日前七天之空氣品質比過去同期平均增加 1 $\mu g/m^3$，第 16 案的投票率將上升 0.55%；但在 2021 公投中空氣品質短期變化對第 17 案並沒有顯著的效果。我們也討論空氣品質的效果對投票率在較高污染、高收入或較多國民黨支持者的村里是否有不同變化。結果顯示在 2018 公投時，居住相對有錢的村里民眾，其投票率上升幅度比在收入較低的村里低 0.09%。以上實證結果呈現出資訊、認知及選民實際行為之相互作用。

關鍵詞: 空氣汙染、能源轉型、公投、個人經驗、工具變數

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Abstract

How does personal experience of air quality influence people's demand for low-emission energy? Nuclear energy emits little greenhouse gases and brings immediate environmental benefits to citizens by reducing air pollution. In this paper, we investigate whether people exposed to elevated levels of air pollution are more likely to support the two pro-nuclear referendum proposals in Taiwan: Proposal 16, in the 2018 referendum, on repealing the law of nuclear phase-out and Proposal 17 on resuming the construction of the Fourth Nuclear Power Plant in the 2021 referendum. To overcome endogeneity between air quality and referendum outcomes, we use a recentered instrument approach to induce exogenous variations in air quality. The results show that air quality only affects citizens' support for Proposal 16, which was intensively advocated as a solution for reducing air pollution. Specifically, a 1 $\mu g/m^3$ (1%) increase in the $PM_{2.5}$ concentration grows the approval rate of Proposal 16 by 0.3% (0.06%). However, we find no effect of air quality on the approval rate of Proposal 17, which was primarily considered as a solution for meeting the energy demand. Additionally, we explore the impact of air quality on the turnouts for pro-nuclear proposals. The result shows that the turnout for Proposal 16 rises by 0.55% when the $PM_{2.5}$ concentration increases by 1 $\mu g/m^3$; however, the effect of air quality on the turnout for Proposal 17 is insignificant . We further investigate the heterogeneity, regarding village with high actual $PM_{2.5}$, higher-income level and more the KMT supporters. The result suggests that such effect on the turnout for Proposal 16 in villages with higher-income level is weaker than those without it, at -0.09%. These findings highlight the interactions between information, perception, and voters' behavioral consequences.

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Keywords: air pollution, energy transition, referendum, personal experience, recentered instrument

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1. Introduction

In order to address climate change and achieve net-zero emissions, many countries have devoted themselves to reducing greenhouse gases (GHGs) emissions. For example, in the Green Growth Strategy, the Japanese government is encouraging domestic and foreign investment in offshore wind power, and sets the goal to reach 10 gigawatts (GWs) by 2035 and up to 45 GWs by 2050 (METI, 2022). In the United States, the national climate task force of the Biden–Harris administration is aiming to achieve 100% carbon pollution-free electricity by 2035 and to increase the share of electric vehicles on road to 50% by 2030 (The White House, 2021). In Taiwan, the Tsai administration is promoting electric vehicles and energy transition, such as decreasing the share of coal-fired electricity supply.

Improving air quality is one of the co-benefits of the energy-related climate policies (e.g., Rafaj et al., 2021). Air pollution is often co-emitted with GHGs in combustion processes on a local scale. As one of GHGs, CO_2 is mainly through human activities, such as electricity. The electricity sector remains the single largest source of CO_2 emissions (IPCC, 2022). According to the fifth assessment report (IPCC, 2014), the median of lifecycle emissions of nuclear energy is only 1.4% of the emission of pulverized coal and even lower than those of hydropower and rooftop solar. In addition to renewable energy, nuclear energy is now also classed as a low-carbon form of energy (European Parliament, 2022). In a clean energy system, nuclear power and hydropower are the foundation of low CO_2 emissions in electricity supply. The share of these two types of energy accounts for three quarters when it comes to low carbon generation (IEA, 2019). People probably benefit from the clean energy types above by reducing air

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pollution-related deaths/illnesses.

Previous studies have documented how energy technologies affect health issues caused by air pollution. For instance, Lavaine and Neidell (2017) found that oil refinery shutdowns due to strikes led to lower ambient SO_2 emissions and increased newborn birth weight by more than 3% in France. Severnini (2017) revealed that replacing nuclear power plants with coal-fired generations caused the average newborn weight to decrease by 5.5% in areas close to coal-fired plants. In addition, Markandya & Wilkinson (2007) estimated that the average air pollution-related deaths from lignite, coal, gas, and nuclear are respectively 32.6, 24.5, 2.8, and 0.052 deaths/TWh[1] in Europe; while those of air pollution-related serious illness caused by lignite, coal, gas, and nuclear are 298, 225, 30, and 0.22 illnesses/TWh. Energy transition from fossil fuels to renewable and nuclear energy, in several projected scenarios, leads to lower deaths in the United States and European Union (Sovacool & Monyei, 2021). As individuals are aware of the link between environmental benefit from improving air quality and energy types, they may be more inclined to choose low-emission energy.

Poor air quality puts people's lives at risk, and so experiencing such environmental emergencies may shape individuals' attitude toward the environment. Early literature has documented a similar effect. For example, Egan and Mullin (2012) used the temperature anomalies to identify the effect of experiencing abnormal temperature on respondents' attitude toward climate change. They found that the local temperature departure, each 3.1°F, from historical mean increases the percentage of Americans believing in global warming by 1%. That is, respondents who experienced abnormally-high local temperatures were more likely to agree that the Earth is becoming warmer.

[1] Terawatt hour (TWh) is a unit for the amount of produced electricity.

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Hamilton and Stampone (2013) found that the short-term temperature effect on participants' belief regarding climate change was consistent with early mentioned study, and that people with higher educational degrees, or who identified themselves as independents, tended to believe the scientific climate change statement. Brooks et al. (2014) unveiled a U-shape relationship between personal experience and the belief regarding climate change. When respondents experienced warmer or cooler temperatures than the historical average temperature, they were more likely to be concerned about climate change. Another study by Hazlett and Mildenberger (2020) investigated how wildfire exposure affects people's environmental-vote behavior. To be more specific, people who experienced wildfire within 5 km of their homes between 2006 and 2010 were more inclined to support eco-friendly policies, compared to those without it. The findings above imply that experiencing climate-related temperature anomalies and disaster make people react to climate change when they have stronger needs for better climate or other environmental benefits. Therefore, it is plausible to hypothesize that experiencing elevated levels of air pollution would make people more likely to have a stronger need for better air quality and the associated solutions, such as low-emission energy. However, to the best of our knowledge, no study has explored how air quality influences citizens' preferences for low-emission energy.

This paper examines whether citizens exposed to a higher level of air pollution are more likely to support low-emission energy. Specifically, we study the effects of short-term air quality anomalies on the approval rates of two pro-nuclear proposals in two separate national referendums in Taiwan. Proposal 16, "Do you agree to repeal Article 95, paragraph 1 of The Electricity Act: 'The nuclear-energy-based power-generating facilities shall wholly stop running by 2025'?" (Central Election Commission, 2022), voted on November 24th 2018; Proposal 17, "Do you agree to the activation of Taiwan's

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mothballed Fourth Nuclear Power Plant?" (Central Election Commission, 2022), voted on December 18th 2021. In spite of both pro-nuclear proposals, they were advocated for different purposes. The campaign which accompanied by Proposal 16 emphasized that nuclear power could help reduce air pollution during the energy transition; however, the focal point of Proposal 17 was energy shortage, mainly due to two large-scale power outages within a week in May, 2021. With the difference in the appeals of these two pro-nuclear proposals, Proposal 16 was passed by 59% to 41%, but Proposal 17 was rejected by 53% to 47%.

A key challenge of identifying the effect of air pollution on the preferences for low-emission energy is that citizens' exposure to air pollution is likely non-random and correlated with other factors affected their preferences. To address the endogeneity, we use the recentered instrument approach proposed by Borusyak and Hull (2021) to identify the causal effect of air quality on the approval rates of pro-nuclear proposals. We use aggregated village-level dataset including voting results, socioeconomic characteristics and air quality; we measure air quality in $PM_{2.5}$ which is not only the most commonly known air pollution but notorious to individual's well-being, such as health. Our results show that a 1 $\mu g/m^3$ (1%) increase in the $PM_{2.5}$ concentration leads to the rate of voting for Proposal 16 grows by 0.3% (0.06%); however, in 2021, the effect of air quality on the rate of voting for Proposal 17 is insignificant. We further estimate the impact of air quality on the turnouts for the pro-nuclear proposals; the coefficient reports that the turnout for Proposal 16 rises 0.55% when the $PM_{2.5}$ concentration grows by $1\mu g/m^3$. The heterogeneous effect regarding income level, we find that such effect in villages with higher-income level is weaker, relative to villages without it.

The structure of this paper is as follows. Section 2 presents the background of nuclear energy in Taiwan and the differences between the two pro-nuclear proposals.

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Sections 3 and 4 describe the data and empirical strategy. Section 5 provides the results, and Section 6 is the conclusion.

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2. Background

2.1 Nuclear power in Taiwan

To meet the soaring energy demand from economic development and to enhance energy security, Taiwan initiated its nuclear energy scheme in the late 1960s. The first nuclear plant, Chin-Shan Nuclear Power Plant, began operations in 1978. The Kuosheng Nuclear Power Plant and the Maanshan Nuclear Power Plant respectively began operations in 1980 and 1984.

The Lungmen Nuclear Power Plant, also commonly known as the Fourth Nuclear Power Plant, started construction in 1999, but it was stopped in 2000 due to the safety evaluation from the Chen administration. In 2001, the construction was resumed by the government in order to avoid the long-run boycott from the opposition and the stress from a recall; however, in 2014, the construction of the Fourth Nuclear Power Plant was halted again because of the Fukushima nuclear disaster in Japan.

Even before Fukushima accident, international nuclear disasters had made the public aware of how risky this energy was. Indeed, the Three Mile Island accident in the United State in 1979 was the first nuclear disaster to draw Taiwanese attention to this high-risk technology, while the Chernobyl disaster in the Soviet Union motivated the commencement of Taiwan's anti-nuclear movements in 1980s (Ho, 2014). Later in 2013, the Fukushima nuclear disaster initiated the anti-nuclear parade, which was attended by over 220,000 people. Nevertheless, nuclear energy, one of high-risk technology, emits lower levels of GHGs, produces less air pollution, and is also less dependent on the weather conditions than other energy types, such as solar power. With the advantages above, the supporters of nuclear energy advocated it in two referenda

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with its different merits.

2.2 Different setting between two referenda

The two pro-nuclear proposals had different contexts in the referenda. In the 2018 referendum, Proposal 16 was focused on repealing the law of phasing out nuclear power; that is, by 2025, all the nuclear facilities in Taiwan shall stop operating. According to the 2018 referendum bulletin, the demand for clean air was the focal point. During the energy transition process, the Tsai administration planed that the share of electricity supply from fossil fuel and natural gas plants accounted for 80% to meet the electricity demand by 2025. To enhance the link between air quality and low-emission energy, supporters of Proposal 16 chanted the slogan "Use Nuclear to Foster Green Energy." They promoted nuclear as a method to reduce air pollution and secure electricity supply during energy transition at the same time. Proposal 17 in the 2021 referendum was resuming the construction of the Fourth Nuclear Power Plant. Although air quality was still one of the major reasons for nuclear energy, meeting energy demand attracted more attention than air quality did. There were two unexpected large-scale grid malfunction that left more than six million households to be without electricity on May 13th and 17th. The outages were partly attributed to the stay-at-home order issued due to the COVID-19 pandemic, which induced a surge in the electricity demand from the residential sector.[2] The above-mentioned events highlighted how vulnerable the electric grid was, as well as the crisis related to stable electricity supply.

To provide that air quality was likely more relevant to voters' decisions on

[2] Other reasons are the surging demand of the industry sector, and the annual inspections of power generations in May.

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Proposal 16 than to their decisions on Proposal 17, we present the Google search indexes of “referendum” and “air quality” [3]from September to December in 2018 and 2021 in Figure 2.1 and Figure 2.2. In Figure 2.1, “air quality” and “referendum” peak three and one week before November 24th 2018, respectively. However, in Figure 2.2, “air quality” in 2021 is much flatter than in 2018 in the same duration. The indexes clearly suggest that people were more concerned about air quality before the 2018 referendum and that air quality was a relatively more crucial element in shaping citizens' support of pro-nuclear proposal in 2018 than it was in 2021. Thus, we hypothesize citizens exposed to elevated levels of air pollution maybe consider nuclear energy as one solution for better air quality, and they go to vote for this energy in two referenda, in spite of air quality at different priority levels.

[3] The terms in Chinese are 公投 and 空氣品質.

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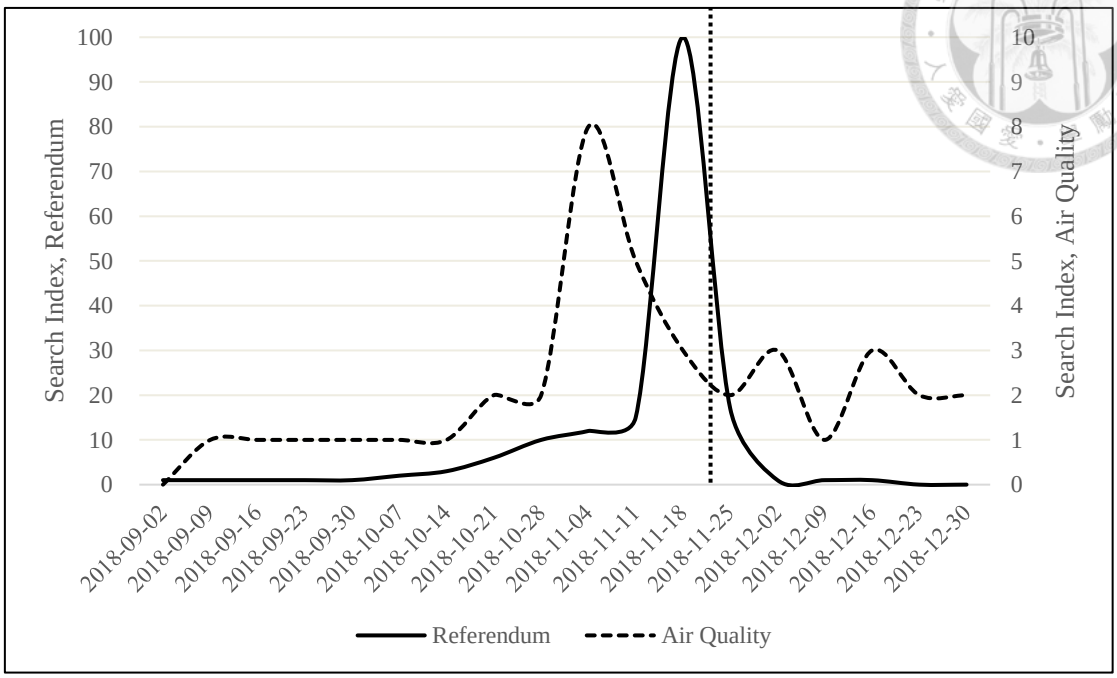
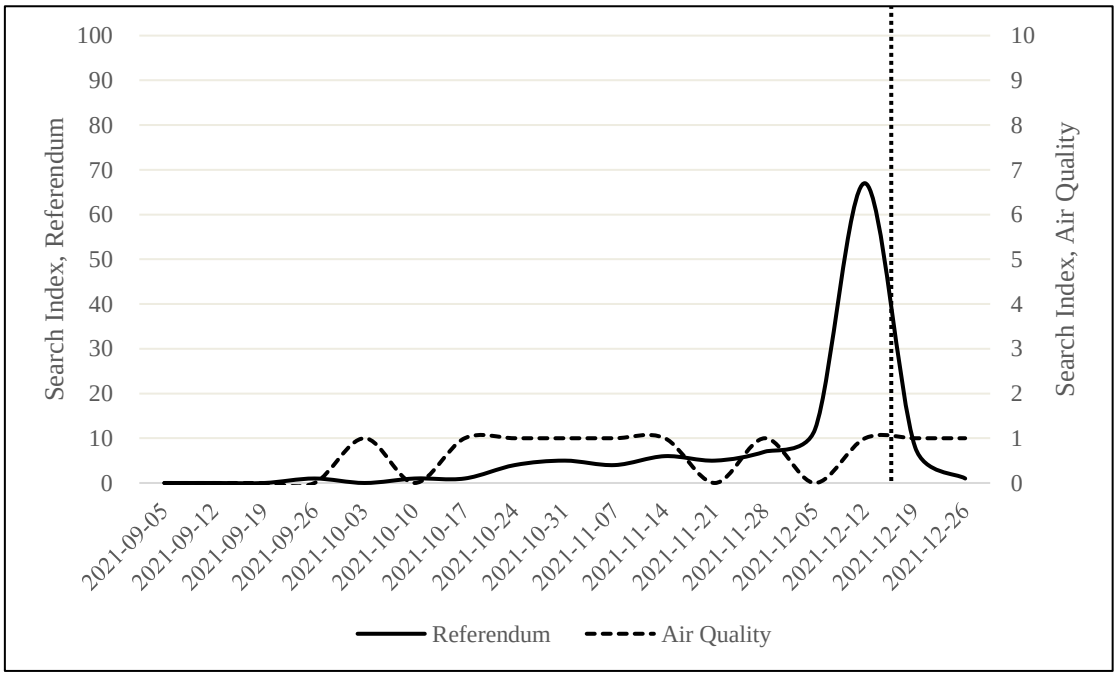
Figure 2.1 Google search indexes of “referendum” and “air quality” in 2018



Note: The figure shows the weekly Google search indexes of “referendum” and “air quality” in Taiwan between September and December in 2018. The x-axis labels indicate the start of the week. The indexes are normalized to “referendum.” The vertical dotted lines represent the referendum day in 2018.

Figure 2.2 Google search indexes of “referendum” and “air quality” in 2021



Note: The figure presents the weekly Google search indexes of “referendum” and “air quality” in Taiwan between September and December in 2021. The x-axis labels indicate the start of the week. The indexes are normalized to “referendum.” The vertical dotted lines represent the referendum day in 2021.

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3. Data

3.1 Elections and referenda

This paper collects the voting results of referendum, municipal and presidential elections provided by the Central Election Commission[4]. The referendum data includes the number voting for, voting against, valid, invalid, voted, not voted, requested, not requested, eligible, and turnout, as well as information on voting location, such as district, village, and polling station. Mayoral and presidential elections contain candidates' names, their party affiliations, and the numbers of votes casted in favor, against, etc. For the study, due to redistricting[5], the data above was converted to the 2021 census block group before aggregated. To merge with air quality data, the data above were aggregated from polling station level[6] to village level; we have 7,747 observations at village level.

3.2 Air quality and atmospheric conditions

The hourly ground level air quality monitoring data and the weather conditions data comes from the Environmental Protection Agency (EPA) in Taiwan.[7] In this study, we aggregate this data from hourly to daily level, and use the $PM_{2.5}$ concentration as the

[4] Mayoral elections in 2018 is available at: https://db.cec.gov.tw/ElecTable/Election?type=Mayor; https://db.cec.gov.tw/ElecTable/Election?type=CountyMayor
Presidential election in 2020 is available: https://db.cec.gov.tw/ElecTable/Election?type=President
The 2018 referendum is downloaded at: https://web.cec.gov.tw/referendum/cms/p_result/29618
The 2021 referendum is downloaded at: https://web.cec.gov.tw/referendum/cms/p_result/36189

[5] For instance, Qiaozi Village shared the same polling station with Houwo Village and Tangqi Village, but, in current status, it was redistricted to the polling station with Qinbi Village, Banli Village, and Baisha Village. The population was as the weight to change the format.

[6] The numbers of polling stations in the 2018 and 2021 referendum are 15,887 and 17,479, respectively. There were 15,887 polling stations for the 2018 mayoral election; in the 2020 presidential election, 17,726 polling stations were set for the election.

[7] The hourly ground level monitoring data can be download at: https://data.epa.gov.tw/dataset/detail/AQX_P_13

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measure for the air quality. As the most commonly known air pollution, $PM_{2.5}$ affects individuals in many ways, such as health. The atmospheric conditions data includes daily average temperature, hours of rain, precipitation per hour, relative humidity, wind speed, and the number of hours the wind blows from the four cardinal directions. To process the air quality and weather data from hourly to daily data, we first winsorize the numbers that are lower than 0.05% or higher than the 99.95% percentile in the raw data. We consider a daily observation to be missing, if less than eight hours of data are registered. After aggerating the hourly data to daily data, we drop the missing observations.

We then estimate township-level air quality and atmospheric conditions by the inverse distance weighting based on the measures of a township's three nearest monitors. To find the three nearest monitors, we use the administrative-district boundaries data[8] to calculate the centroids of each town. After determining the centroids, we employ the inverse distance weighting to calculate the average of air quality collected from the three nearest monitoring sites. The following equations are used to find the inverse distance weights and the estimated air quality in a district/town

$$\lambda_{ia} = \frac{\frac{1}{d_{ia}^2}}{\sum_{i=1}^{3} \frac{1}{d_{ia}^2}} \tag{3.1}$$

$$Z_{ea} = \sum_{i=1}^{3} \lambda_{ia} Z_{ia} \tag{3.2}$$

where subscript *i* indicates the monitoring station closest to the centroid of the township, *a* refers to a district/town, and λ_{ia} is the weight for the monitoring station *i* in

[8] The data can be downloaded at: https://data.gov.tw/dataset/7441.

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district/town a. Moreover, d_{ia} is the distance of the monitoring station i from the centroid for district/town a, in Equation (3.1). In Equation (3.2), Z_{ia} is a realized value of air quality in district/town a from the monitoring station i; Z_{ea} is an estimate of air quality for district/town a determined by the realized air quality and the inverse distance weighting.

3.3 Socioeconomic characteristics

The sociodemographic data are downloaded from the National Development Council.[9] We collect village-level data of population, educational attainment, and income . Using the population data, we generate variables including the share of female population, people with a college degree of above, and age groups, i.e. 20 to 39, 40 to 59 and 60 and above. The income data include the first quartile, median, and third quartile. We also calculate the income gap as the difference between the third and first quartiles. Due to precinct boundaries and names changing over time, all data is converted to the 2021 census block group.

3.4 Data description

Table 3 reports the summary statistics, along with variable descriptions, which are weighted by the aggregated eligible voters in each referendum.[10] In panel A of Table 3, the average of $PM_{2.5}$ over the seven days before the 2018 referendum day is 17 μg/m^3. The approval rate of and the turnout for Proposal 16 are 59.4% and 54.8%, respectively. The vote share of the KMT in the municipal election is 48.6%. Panel B presents the

[9] The sociodemographic data is available at: https://data.gov.tw/
[10] The number of eligible voters in the 2018 referendum is 19,757,067, and in the 2021 referendum, it is 19,825,468.

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statistics of the data associated with the 2021 referendum. On average, the mean $PM_{2.5}$ over a week prior to the referendum day is 20.08 $\mu g/m^3$. The percentages of voting for and turnout for Proposal 17 are 47.2% and 41%. Both of these two numbers are lower than the statistics in 2018. The portion supporting the KMT in the presidential election in 2020 is 38.7%.

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Table 3 Summary statistics with variable descriptions

Variables	Description	Mean	S. D.
Panel A: 2018			
$PM_{2.5}$	Average of $PM_{2.5}$ in seven days before voting ($\mu g/m^3$)	17.006	9.180
Proposal 16	Approval rate of Proposal 16	0.594	0.031
Turnout	Turnout for Proposal 16	0.548	0.058
Vote share of KMT	Share of voting for the KMT in the 2018 mayoral election	0.486	0.123
Median income	Median of income tax	655.480	127.290
Income gap	The difference between the third and first quartiles	744.873	254.803
Share of people with a college degree or above	Portion of people with a college degree and above	0.399	0.098
Share of female population	Portion of female population	0.503	0.022
Age: 20 to 39	Share of age group between 20 and 39	0.288	0.031
Age: 40 to 59	Share of age group between 40 and 59	0.311	0.023
Age: 60 and above	Share of age group greater than and equal to 60	0.216	0.054
Temperature	Average temperature (°C)	21.817	1.159
Rainfall	Precipitation (mm)	0.364	1.263
Rain_hr	Hours of rain	0.718	2.168
Rh	Relative humidity (%)	74.364	5.075
Wind speed	Wind speed (meter/second)	1.994	0.806

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Table 3 Continued

Variables	Description	Mean	S. D.
Panel B: 2021			
$PM_{2.5}$	Average of $PM_{2.5}$ in seven days before voting ($\mu g/m^3$)	20.086	8.271
Proposal 17	Approval rate of Proposal 17	0.472	0.112
Turnout	Turnout for Proposal 17	0.410	0.055
Vote share of KMT	Share of voting for the KMT in the 2020 presidential election	0.387	0.096
Median income	Median of income tax	657.467	130.957
Income gap	The difference between the third and first quartiles	747.183	257.294
Share of people with a college degree or above	Portion of people with a college degree and above	0.416	0.098
Share of female population	Portion of female population	0.504	0.022
Age: 20 to 39	Share of age group between 20 and 39	0.278	0.030
Age: 40 to 59	Share of age group between 40 and 59	0.314	0.023
Age: 60 and above	Share of age group greater than and equal to 60	0.233	0.056
Temperature	Average temperature (°C)	16.197	1.955
Rainfall	Precipitation (mm)	0.107	0.444
Rain_hr	Hours of rain	0.195	0.774
Rh	Relative humidity (%)	64.279	5.198
Wind speed	Wind speed (meter/second)	2.914	1.511

Note: All data is provided at village level and weighted by the aggregated eligible voters in each election.

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4. Empirical Strategy

Among the literature on how personal experience would influence people's attitude toward the environment, many studies have leveraged the short-term average deviation from historical records as an exogenous shock to the associated personal experience. For instance, Egan and Mullin (2012) employed the variations between the current and historical average temperature over seven days before respondents were surveyed to identify the effect of short-run weather conditions on their attitude toward climate change. With the seven-day temperature departure from the historical average, the above authors put forth the belief that respondents probably recalled how they felt in the seven days prior to the interview when asked about climate change. In the current study, we explore how air quality influences referendum outcomes. Without controlling for other environmental variables, our results would suffer from endogeneity. To be more specific, air pollution would be affected by atmospheric variables such as precipitation, humidity, wind speed, and wind directions. As Borusyak and Hull (2021) mentioned, an environmental variable is often jointly determined by other conditions; therefore, they design the recentered instrument to avoid the biased estimation due to non-random exposure.

To alleviate endogeneity from non-random exposure, this paper employs the recentered instrument proposed by Borusyak and Hull (2021). In our setting, building on previous literature, we leverage the seven-day average of $PM_{2.5}$ departure to identify the causal effect of air quality on the pro-nuclear referendum results. Specifically, we write the referendum outcome y in village v at time t to be a function of socioeconomic controls (X) and air pollution ($PM_{2.5}$) which villages located in the same district/town

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employs the same estimation by Equation (3.2).[11] That is:

$$y_{vt} = \beta PM_{2.5at} + \gamma X_{vt} + \varepsilon_{vt} \quad (4.1)$$

If the air quality is randomly assigned, which means that $\mathrm{E}(PM_{2.5at}\ \varepsilon_{at}) = 0$, we use Equation (4.1) to estimate the effect of air quality on the referendum outcomes, and interpret the parameter, β, as the casual effect. Nevertheless, air quality is more likely influenced by other exogenous shocks (e) and predetermined (non-random) factors (p); thus, we write $PM_{2.5at}$ as a function $PM_{2.5at} = f_{at}\ (p,e)$, whereby e is independent to ε conditional on p. For example, estimating $PM_{2.5at}$ by hours of wind blowing from four cardinal direction (e) could be exogenous, regarding location and time (p).

We then write the expected instrument as $\overline{PM_{2.5at}} = \mathrm{E}[f_{at}\ (p,e)|p]$. To have an exogenous recentered instrument, the departure from normal, we subtract the expected instrument from the realized instrument and take the expectation as follows:

$$\widetilde{\mathrm{PM}_{2.5\mathrm{at}}} = \mathrm{PM}_{2.5\mathrm{at}} - \overline{PM_{2.5at}} \quad (4.2)$$
$$\mathrm{E}\left(\widetilde{\mathrm{PM}_{2.5\mathrm{at}}}\varepsilon_{\mathrm{at}}\right) = \mathrm{E}(\mathrm{PM}_{2.5\mathrm{at}}\varepsilon_{\mathrm{at}}) - \mathrm{E}\left(\overline{PM_{2.5at}}\varepsilon_{\mathrm{at}}\right) = 0$$

with $\widetilde{\mathrm{PM}_{2.5\mathrm{at}}}$, the exogenous recentered instrument, we could identify the causal effect of air quality on the outcomes of the pro-nuclear proposals.

In this research, to better address the non-random exposure, we construct the expected instrument, $\overline{PM_{2.5at}}$, controlling for the available atmospheric variables associated with $PM_{2.5}$ as well as the temporal and spatial fixed effects. To construct the

[11] Due to data availability, measuring exactly village-level air quality is limited.

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expected instrument, we estimate via the following equation:

$$PM_{2.5at} = f_{at}(w_{at};\delta) + e_a(t) + v_{at} \quad (4.3)$$

where $f_{at}(w_{at};\delta)$ is a function for the flexible relationship between $PM_{2.5}$ concentration and the atmospheric variables, w_{at}, and $e_a(t)$ refers to the time-specific spatial fixed effects. In w_{at}, we include the linear and quadratic terms of daily average ambient temperature, precipitation, hours of rain, wind speed, and number of hours in a day that the wind blows from the south, west, or north. $e_a(t)$ is the district/town-specific year-month and day-week fixed effects; v_{at} is an error term. For each of the referendum dates, we respectively run Equation (4.3), and use the predicted value ($\widehat{PM_{2.5at}}$) as the expected instrument to construct the recentered instrument ($\widetilde{PM_{2.5at}}$) in Equation (4.4):

$$\widetilde{PM_{2.5at}} = PM_{2.5at} - \widehat{PM_{2.5at}} = PM_{2.5at} - f_{at}(w_{at};\hat{\delta}) + \widehat{e_a}(t) \quad (4.4)$$

with the recentered instrument, Equation (4.1) is rewritten as Equation (4.5) in order to estimate how air quality affects the referendum outcomes.

$$y_{vt} = \beta\widetilde{PM_{2.5at}} + \gamma X_{vt} + f_{at}(w_{at};\tau) + \varphi_c + \varepsilon_{vt} \quad (4.5)$$

The dependent variable, y_{vt}, is the approval rate of the pro-nuclear proposal in each referendum. $\widetilde{PM_{2.5at}}$ is either the absolute value or the percentage change. The percentage change of $PM_{2.5}$ concentration is the residual divided by the predicted/ expected value. In this paper, village-level $\widetilde{PM_{2.5at}}$ in the same district/town employs

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the identical estimation from Equation (4.4). Subscript *v* indexes that variables are at village level, and *t* refers to the referendum dates, namely November 24th 2018 and December 18th 2021. The vector, X_{vt}, controls for turnout, median income, income gap, share of the female, share of people hold a college degree or above, and share of two age groups: 20 to 39 and 60 and above. The benchmark of age group is age range from 40 to 59. Early literature has demonstrated that party identity would affect the voters' choices of the environmental proposals (Bornstein & Lanz, 2008; Burkhardt & Chan, 2017; Leduc, 2002; Hazlett & Mildenberger, 2020). To capture this effect, we use the KMT vote share in the elections in 2018 or 2020 as the proxy of party identity and put it in the vector X_{vt} when running Equation (4.5). That is, in the 2018 referendum model, the 2018 mayoral election is included. When running the regression for the 2021 referendum, we control for the presidential election in 2020. w_{at} is the vector of weather controls, and φ_c are county level fixed effects controlling for time-invariant unobserved variables, such as the local government's regulations on the emissions of coal-fired power plants.

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5. Results

5.1 Air quality and the approval rates

In this section, we illustrate the main results based on Equation (4.5). In column (1) of Table 5.1, the result suggests that when the $PM_{2.5}$ concentration increases by 1 $\mu g/m^3$, the percentage of voting for Proposal 16 repealing the law of nuclear phase-out grows by 0.3%. However, in 2021, the impact of the $PM_{2.5}$ departure on the approval rate of Proposal 17 resuming the construction of the Fourth Nuclear Power Plant is insignificant and close to null in column (2). In addition to estimating the absolute variation of the $PM_{2.5}$ concentration, we also use the percentage change of the $PM_{2.5}$ concentration to investigate the impact of air quality on the approval rates of pro-nuclear proposals. In column (3) of Table 5.1, the coefficient suggests that a 1% increase in $PM_{2.5}$ concentration leads to a 0.06% increase in the approval rate of Proposal 16. In column (4), the estimated results again show that air quality has little effect on the approval rate of Proposal 17. These results imply that, when citizens experienced higher level of air pollution and were aware of the link between low-emission energy and air pollution, they were more supportive of nuclear energy.

We further conduct robustness checks to ensure that the recentered instrument is plausibly exogenous. First, we probe the exogeneity of the recentered air quality variation by omitting other dependent variables. In Table 5.2, Model (1) simple regresses the approval rate of Proposal 16 on the $PM_{2.5}$ departure and omits all other independent variables. Models (2) to (4) include socioeconomic characteristics, weather controls, or both. All of the results show that elevated level of air pollution has a positive and significant effect on the approval rate of Proposal 16. The coefficients of interest are all quantitatively similar to that in Model (1) in Table 5.1, providing strong

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evidence of the exogeneity of the recentered $PM_{2.5}$ concentration. Next, we further control for the long-run average of $PM_{2.5}$ concentration (e.g., 90 days, 365 days, 1,095 days, etc.) in Equation (4.5). If the results of controlling for longer period average of $PM_{2.5}$ are different from those without such control, this means that the $PM_{2.5}$ departure is correlated with the historical average of $PM_{2.5}$ concentration. The results in Table 5.3 demonstrate that the seven-day average of $PM_{2.5}$ departure still has a significantly positive impact on the rate of voting for repealing the law of nuclear phase-out. We also conduct falsification tests using "placebo" treatments. Specifically, we use the $PM_{2.5}$ departure in the week prior to November 24th in 2017 and 2016 as the treatment variable. The results in column (1) and column (2) of Table 5.4 report the effects of the placebo treatments. The coefficients of the $PM_{2.5}$ departure in 2017 and 2016 are both close to zero and highly insignificant.

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Table 5.1 Effects of air quality on approval rates of Proposal 16 and Proposal 17

	(1)	(2)	(3)	(4)
Variables	Proposal 16	Proposal 17	Proposal 16	Proposal 17
$PM_{2.5}$ departure ($\mu g/m^3$)	0.0030***	-0.0003		
	(0.0006)	(0.0008)		
% change of $PM_{2.5}$ ($\mu g/m^3$)			0.0597***	-0.0099
			(0.0114)	(0.0120)
Expected $PM_{2.5}$ ($\mu g/m^3$)	-0.0000	0.0003	-0.0001	0.0003
	(0.0004)	(0.0004)	(0.0003)	(0.0004)
Vote share of KMT	0.1126***	1.0117***	0.1131***	1.0114***
	(0.0205)	(0.0096)	(0.0094)	(0.0082)
Turnout	-0.0314**	0.0022	-0.0312***	0.0022
	(0.0126)	(0.0265)	(0.0105)	(0.0185)
Median income	0.0000*	0.0000	0.0000*	0.0000*
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Income gap	-0.0000	-0.0000*	-0.0000	-0.0000**
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Share of people with a college degree or above	0.0175	0.1614***	0.0170	0.1612***
	(0.0231)	(0.0198)	(0.0157)	(0.0162)
Share of female population	0.0278	-0.0834**	0.0252	-0.0834**
	(0.0417)	(0.0398)	(0.0344)	(0.0343)
Age: 20 to 39	-0.0960***	0.0920***	-0.0929***	0.0918***
	(0.0306)	(0.0253)	(0.0260)	(0.0262)
Age: 60 and above	-0.0528**	-0.1155***	-0.0544***	-0.1161***
	(0.0236)	(0.0195)	(0.0167)	(0.0152)
Weather Controls	Y	Y	Y	Y
Observations	7,732	7,573	7,732	7,573
Adjusted R-squared	0.186	0.947	0.189	0.947

Notes: the outcome variables are the percentages of votes for the two pro-nuclear proposals. $PM_{2.5}$ departure and Expected $PM_{2.5}$ are the seven-day average prior to the referenda. % change of $PM_{2.5}$ is the residual divided by the predicted/expected value. All models control for county fixed effects. Weather controls include the linear and quadratic terms of average temperature, relative humidity, precipitation, hours of rain, and wind speed on the date of each referendum. Standard errors are in parentheses and clustered at township level (number of clusters = 365 in 2018; 352 in 2021).

*, **, ***: significant at 10%, 5%, and 1%.

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Table 5.2 Effects of air quality on approval rate of Proposal 16 by omitting other covariates

Variables/Models	(1)	(2)	(3)	(4)
$PM_{2.5}$ departure ($\mu g/m^3$)	0.0028***	0.0026***	0.0028***	0.0027***
	(0.0010)	(0.0009)	(0.0010)	(0.0009)
Vote share of the KMT	N	N	N	N
Socioeconomic characteristics	N	Y	N	Y
Weather controls	N	N	Y	Y
Observations	7,732	7,732	7,732	7,732
Adjusted R-squared	0.106	0.123	0.110	0.127

Notes: the outcome variable is the approval rate of the proposal on repealing the law of ending the use of nuclear facilities by 2025. $PM_{2.5}$ departure is the seven-day average before the referendum. All models control for county fixed effects. Socioeconomic characteristics are median income, income gap, share of citizens with a college degree or above, and share of female population, as well as share of age group from 20 to 39 and the age group of 60 and above. Weather controls include linear and quadratic terms of average temperature, relative humidity, precipitation, hours of rain, and wind speed on the referendum day. Standard errors are in parentheses and clustered at township level (number of clusters = 365 in 2018; 352 in 2021).

*, **, ***: significant at 10%, 5%, and 1%.

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Table 5.3 Effects of air quality on approval rate of Proposal 16 controlling for long-term average $PM_{2.5}$

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$PM_{2.5}$ departure ($\mu g/m^3$)	0.0026***	0.0029***	0.0030***	0.0031***	0.0030***	0.0030***	0.0030***	0.0030***
	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0006)
Long-run average $PM_{2.5}$ in days	90	180	365	730	1095	1460	1825	3650
Weather Controls	Y	Y	Y	Y	Y	Y	Y	Y
Observations	7,732	7,732	7,732	7,732	7,732	7,732	7,732	7,732
Adjusted R-squared	0.187	0.188	0.186	0.185	0.185	0.185	0.185	0.186

Notes: the outcome variable is the approval rate of the proposal on repealing the law of ending the use of nuclear facilities by 2025. $PM_{2.5}$ departure is the seven-day average before the referendum. Models (1) to (8) control for the average $PM_{2.5}$ concentration in the previous 90, 180, 365, 730, 1,095, 1,460, 1,825, and 3,650 days, respectively. All models control for county fixed effects. Weather controls include linear and quadratic terms of average temperature, relative humidity, precipitation, hours of rain, and wind speed on the referendum day. Standard errors are in parentheses and clustered at township level (number of clusters = 365 in 2018; 352 in 2021).

*, **, ***: significant at 10%, 5%, and 1%.

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Table 5.4 Effects of air quality in one or two years before referendum on approval rate of Proposal 16

	(1)	(2)
Variables	Proposal 16	Proposal 16
$PM_{2.5}$ departure in 2017	0.0003	
	(0.0007)	
$PM_{2.5}$ departure in 2016		-0.0004
		(0.0006)
Weather Controls	Y	Y
Socioeconomic characteristics	Y	Y
Observations	7,732	7,732
Adjusted R-squared	0.181	0.182

Notes: the outcome variable is the approval rate of the proposal on repealing the law of ending the use of nuclear facilities by 2025. All models control for county fixed effects. Weather controls include linear and quadratic terms of average temperature, relative humidity, precipitation, hours of rain, and wind speed on the referendum day. Socioeconomic characteristics are median income, income gap, share of citizens with a college degree or above, and share of female population, as well as share of the age group from 20 to 39 and the age group of 60 and above. Standard errors are in parentheses and clustered at township level (number of clusters = 365 in 2018; 352 in 2021).

*, **, ***: significant at 10%, 5%, and 1%

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5.2 Socioeconomic characteristics and the approval rates

In Table 5.1, the estimates of vote share of the KMT, income, education, share of female population, and share of two age groups are correlated with the approval rates of pro-nuclear proposals, regardless of the measure of air quality in the absolute value or percentage change. In Taiwan, the KMT are more pro-nuclear than other parties (Ho, 2014); therefore, their supporters are expected to be more likely to vote for the pro-nuclear proposals. The coefficients of the KMT vote share in columns (1) to (4) suggest that the share of the KMT supporters is positively and strongly correlated with the support for repealing the law of nuclear phase-out and for resuming the construction of the Fourth Nuclear Power Plant. Party identity affects voters' decisions (e.g., Bornstein & Lanz, 2008; Leduc, 2002; Thalmann, 2004), and our results are in line with this notion. We also find that the R-squared in the 2021 referendum is extremely high; therefore, we simply regress the rate of voting for resuming the construction of the Fourth Nuclear Power Plant and the vote share of the KMT, and find that the R-squared is also over 0.9. This suggests that party identity in 2021 referendum is a much more important determinant for voters' support of pro-nuclear proposal.

Bornstein and Lanz (2008) reported that individuals in the median income group prefer eco-friendly proposals. Moreover, air quality is in theory a normal good, so the need for air quality is expected to increase with income (Burkhardt & Chan, 2017). In our case, and consistent with the early literature outlined above, voters in the median-income-level group are positively associated with the rate of voting for Proposal 16 in columns (1) and (3).

In addition to income, gender has been documented as another factor affecting the decision of voting for or against the environmental issues. The female are inclined to show more environmental concerns and behavioral intentions, considering the

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frequency of car use and recycling (Li et al., 2019; López-Mosquera et al., 2015). If the pro-nuclear proposal is promoted as a pro-environmental proposal, we expect that the female tend to support it. Despite insignificance, the results in columns (1) and (3) suggest that the correlation between the share of female population and the support of repealing the law of nuclear phase-out is positive. However, in the 2021 referendum, the focal point of Proposal 17 resuming the construction of the Fourth Nuclear Power Plant is energy shortage, which priority was not directly linked to the environmental benefit, relative to Proposal 16 repealing the law of nuclear phase-out. In addition, as one of the high-risk energy technologies, nuclear power may have lower support from the female (Goebel et al., 2015; Kim et al., 2021). The signs of estimation results in columns (2) and (4) report the negative associations between the share of female population and the proposal which priority is meeting energy demand.

Compared to the age group between 40 and 59, the young (range from 20 to 39) and the elderly (60 and above) are negatively correlated with the rate of voting for Proposal 16. Fort and Bunn (1998) found that the young generation are more likely to be pro-environmental; nevertheless, extreme pro-environmental voters[12] tend to reject nuclear power. The estimations in columns (1) and (2) or in columns (3) and (4) report that the young supporting for resuming the construction of the Fourth Nuclear Power Plant in 2021 is higher than for repealing the law of nuclear phase-out in 2018. That is, the young generation perhaps consider Proposal 16 as extreme eco-friendly issue due to its associated campaign.

5.3 Asymmetric/heterogeneous effects of air quality on the approval rates

[12] Fort and Bunn (1998) indicated extreme pro-environmental voters by their score being positive deviation from the center of the score, at 50 points.

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The main results show that the $PM_{2.5}$ departure prior to seven days before the referendum has a positive impact on the approval rate of Proposal 16, but little effect on the rate of voting for Proposal 17; we further examine the asymmetric and heterogeneous effect of the $PM_{2.5}$ departure on the approval rates of pro-nuclear proposals.

We first investigate whether the impact of air quality on the rates of voting for Proposal 16 and Proposal 17 changes across villages where actual air quality is better than predicted/expected value. The variations of air quality before referendum day could be positive or negative; thus, we expect that there may be asymmetric effects of air quality on the approval rate of Proposal 16. Column (1) of Table 5.5 shows such effects on the approval rates of two pro-nuclear proposals in panel A and B. In 2018, the interaction term between the seven-day average of $PM_{2.5}$ departure and the negative $PM_{2.5}$ departure suggests that the impact of air quality on villages with negative variations of the $PM_{2.5}$ concentration is smaller. That is, in villages where the actual air quality is better than the predicted/expected air quality, the effect of air quality on the support for repealing the law of nuclear phase-out is weaker than villages where its actual air quality is worse than the predicted/expected value, at -0.88%. The asymmetric effect of air quality has no significant impact on the approval rate of Proposal 17 which focal point is energy shortage in the 2021 referendum.

We then examine if the effects of air quality on the support for repealing the law of nuclear phase-out and for resuming the construction of the Fourth Nuclear Power Plant vary across villages with high level of actual $PM_{2.5}$ concentration, high-income level, or more the KMT supporters. Since air is normal good, the expectation of such effect in high-income village may be stronger than those without it. As previously mentioned, the KMT supporters are more likely to support the pro-nuclear proposals, or they are more

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inclined to choose nuclear energy as a solution for elevated level of air pollution in the 2018 referendum. However, due to the priority of Proposal 17 is meeting energy demand, our expectation is that air quality minorly affects the support for resuming the construction of the Fourth Nuclear Power Plant. In columns (2) to (4) of Table 5.5, these heterogeneous effects are all insignificant in both referenda.

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Table 5.5 Asymmetry/heterogeneity in effects of air quality on approval rates

Variables/Models	(1)	(2)	(3)	(4)
Panel A: The 2018 referendum				
$PM_{2.5}$ departure ($\mu g/m^3$)	0.0113**	0.0036***	0.0028***	0.0027***
	(0.0044)	(0.0008)	(0.0007)	(0.0007)
$PM_{2.5}$ departure x (-$PM_{2.5}$ departure)	-0.0088*			
	(0.0045)			
$PM_{2.5}$ departure x $PM_{2.5}$_high		-0.0014		
		(0.0008)		
$PM_{2.5}$ departure x Income_high			0.0004	
			(0.0002)	
$PM_{2.5}$ departure x KMT_dominant				0.0007
				(0.0006)
Weather Controls	Y	Y	Y	Y
Observations	7,732	7,732	7,732	7,732
Adjusted R-squared	0.187	0.186	0.186	0.186
Panel B: The 2021 referendum				
$PM_{2.5}$ departure ($\mu g/m^3$)	-0.0009	-0.0006	-0.0004	-0.0003
	(0.0010)	(0.0006)	(0.0009)	(0.0008)
PM2.5 departure x PM2.5 departure_neg	0.0026			
	(0.0019)			
$PM_{2.5}$ departure x $PM_{2.5}$_high		0.0007		
		(0.0009)		
$PM_{2.5}$ departure x Income_high			0.0002	
			(0.0004)	
$PM_{2.5}$ departure x KMT_dominant				0.0003
				(0.0011)
Weather Controls	Y	Y	Y	Y
Observations	7,573	7,573	7,573	7,573
Adjusted R-squared	0.948	0.947	0.947	0.947

Note: the outcome variable in panel A is the approval rate of Proposal 16; in panel B, the dependent variable is the rate of voting for Proposal 17. $PM_{2.5}$ departure is the seven-day average of $PM_{2.5}$ concentration prior to the referendum day. All models control for the KMT vote share, turnout, village-level sociodemographic characteristics, and county fixed effects. Weather controls are the linear and quadratic terms of average temperature, relative humidity, precipitation, hours of rain, and wind speed on each referendum day. The standard errors are in parentheses and clustered at the township level (number of clusters = 365 in 2018; 352 in 2021). *, **, ***: significant at 10%, 5%, and 1%.

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5.4 Air quality and the turnouts

Elevated levels of air pollution may influence the turnouts, but the effect is unclear. On the one hand, the voters may avoid going out to vote since leaving abodes will increase their exposure to a higher level of air pollution (e.g., Graff Zivin & Neidell, 2013); on the other hand, they choose to cast their ballots when believing that the benefits of going out to vote for pro-nuclear proposals associated with better air quality are not smaller than the cost of suffering the elevated levels of air pollution. In our case, better air quality was promoted at different priority levels in the pro-nuclear referendum proposals. The estimations regarding the effect of air quality on the turnouts for Proposal 16 and Proposal 17 are in Table 5.6. In 2018, we find that air quality has a strong and positive effect on the turnout for Proposal 16, which is 0.55% in column (1). However, in the 2021 referendum, this impact is insignificant. As mentioned previously, the focal point of Proposal 17 was meeting energy demand. It is plausible to see that air quality had little impact on the turnout for Proposal 17.

The estimates in columns (2) to (4) of Table 5.6 show the heterogeneous effects of air quality on the turnouts for the pro-nuclear proposals. Overall, the effects are insignificant, except for villages with higher-income level in the 2018 referendum. In column (3), the effect of air quality on the turnout for repealing the law of nuclear phase-out in higher-income villages is smaller than villages with lower income, despite significance merely at 10% level. As richer people probably view their lives more and they could afford more alternatives to mitigate their exposure to elevated levels of air pollution than going out to vote (Bornstein & Lanz, 2008). For example, higher-income citizens could afford the price of installing more air purifiers to maintain the good air quality than those with lower income; thus, they had not to go out to vote for better air quality.

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Table 5.6 Effects of air quality on turnouts

Variables/Models	(1)	(2)	(3)	(4)
Panel A: The 2018 referendum				
$PM_{2.5}$ departure ($\mu g/m^3$)	0.0055**	0.0057**	0.0060**	0.0058*
	(0.0026)	(0.0023)	(0.0026)	(0.0029)
$PM_{2.5}$ departure x $PM_{2.5}$_high		-0.0005		
		(0.0019)		
$PM_{2.5}$ departure x Income_high			-0.0009*	
			(0.0005)	
$PM_{2.5}$ departure x KMT_dominant				-0.0007
				(0.0013)
Weather Controls	Y	Y	Y	Y
Observations	7,732	7,732	7,732	7,732
Adjusted R-squared	0.448	0.448	0.448	0.448
Panel B: The 2021 referendum				
$PM_{2.5}$ departure ($\mu g/m^3$)	0.0001	0.0006	0.0003	-0.0002
	(0.0019)	(0.0029)	(0.0020)	(0.0019)
$PM_{2.5}$ departure x $PM_{2.5}$_high		-0.0011		
		(0.0031)		
$PM_{2.5}$ departure x Income_high			-0.0003	
			(0.0008)	
$PM_{2.5}$ departure x KMT_dominant				0.0018
				(0.0014)
Weather Controls	Y	Y	Y	Y
Observations	7,573	7,573	7,573	7,573
Adjusted R-squared	0.716	0.716	0.716	0.716

Notes: the outcome variable in panel A is the percentage of votes for the proposal on repealing the law of ending the use of nuclear facilities by 2025; in panel B, the dependent variable is the portion of votes for resuming the construction of the Fourth Nuclear Power Plant. Models (2) to (4) control for the interaction of $PM_{2.5}$ departure with the seven-day average of actual $PM_{2.5}$ concentration before the referendum day, the median income of villages, or the vote share of the KMT municipal/presidential candidate over 50%. All models control for village level sociodemographic characteristics, the KMT vote share and county fixed effects. Weather controls are the linear and quadratic terms of average temperature, relative humidity, precipitation, hours of rain, and wind speed on each referendum day. Standard errors are in parentheses and clustered at township level (number of clusters = 365 in 2018; =352 in 2021).
*, **, ***: significant at 10%, 5%, and 1%.

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6. Conclusion

Previous papers have found that personal experience affects people's attitude toward climate-related issues. Although better air quality is a co-benefit of energy-related climate change policy, there is no study to investigate how the variations of air quality influence citizens realized political behavior, to our best knowledge. In this paper, we use two referenda in Taiwan to ascertain whether citizens exposed to elevated levels of air pollution tend to support the pro-nuclear proposals. In terms of the two pro-nuclear proposals, Proposal 16 and Proposal 17 were campaigned for different appeals. In 2018, better air quality was the focal point, but energy shortage attracted more attention in 2021. To alleviate endogeneity from non-random exposure of air quality, we use the recentered instrument proposed by Borusyak and Hull (2021).

The results show that air quality has a stronger impact on the approval rate of the pro-nuclear proposal in 2018 than it does in 2021. In 2018, nuclear energy was campaigned for an eco-friendly method which improved air quality during energy transition process. Our result reports that a 1 $\mu g/m^3$ increase in the $PM_{2.5}$ concentration over seven days before the referendum day leads to a 0.3% increase in the rate of voting for Proposal 16 repealing the law of nuclear phase-out; or, when the $PM_{2.5}$ concentration over a week before the referendum day increases by 1%, the approval rate of Proposal 16 grows by 0.06%. To ensure that our results are reliable, we conduct robustness and falsification tests. All the tests show that the effects of air quality on the support of repealing the law of nuclear phase-out are significant and positive. In the 2021 referendum, Proposal 17 was close to meet energy demand with nuclear energy; we find the impact of air quality on the support for resuming the construction of the Fourth

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Nuclear Power Plant is insignificant.

In addition to the approval rate of pro-nuclear proposals, we also examine whether air quality affects the turnouts for pro-nuclear proposals. The result shows that the turnout for Proposal 16 increases by 0.55% when the $PM_{2.5}$ departure over seven days before referendum rises by 1 $\mu g/m^3$. However, such effect is weaker in villages with higher-income level, relative to lower-income village, at -0.09%. Overall, the findings present new empirical evidence regarding how personal experience of environmental emergency affects citizens' realized voting behaviors.

There are some limitations in the current study, one of which is that voters are not representative of all citizens; thus, using aggregated electoral outcomes and socioeconomic characteristics to understand all citizens' preferences may cause biased results (Lang & Pearson-Merkowitz, 2022). Other limitation is the issue saliences in these two referendums were different. In 2018, there were other proposals related to air quality in addition to Proposal 16 repealing the law of nuclear phase-out; however, proposals related to import pork products containing ractopamine and relocate the construction site of liquified natural gas terminal were more noticeable than Proposal 17 resuming the construction of the Fourth Nuclear Power Plant. As omitted variables associated with above-mentioned issues might not be captured in this study, this might lead to biased estimations. However, we consider that the concerns above would not threaten our main results because voters could not determine the variations of air quality.

Aside from the caveats above, future work could disentangle the turnouts for proposals in referenda because the turnouts are influenced by many other factors. Early literature found that turnouts would become higher when the referendum was in conjunction with an election (Bowler & Donovan, 2013; Tolbert et al., 2009), or

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analyzed how the weather conditions affect turnouts in elections (Fraga & Hersh 2011, Hansford & Gomez 2010, Stadelmann-Steffen & Gerber, 2019). In addition to the turnouts, future work may further investigate the relationship between voting behavior and income level, considering environmental justice; or explore how energy security changes people's attitude toward low-emission energy.

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Appendix

Table A.1 Proposals in the 2018 referendum

Title	Description	Approval rate	Disapproval rate	Turnout
Proposal No. 7	Do you agree "to reduce at least 1% on average per year" gradually of the power generation outputs of thermal power plants?	79.04	20.96	54.56
Proposal No. 8	Do you agree to establish an energy policy to "Stop the construction and expansion of any fossil fuel power station or generator units (including the Shen Ao Power Plant currently under expansion construction)"?	76.41	23.59	54.51
Proposal No. 9	Do you agree that the government should continue to prohibit the import of agricultural products and food from areas affected by the Fukushima March 11th Disaster, specifically those from Fukushima district and the four surrounding cities of Ibaraki, Tochigi, Gunma, and Chiba?	77.74	22.26	54.56
Proposal No. 10	Do you agree that marriage defined in the Civil Code should be restricted to the union between a man and a woman?	72.48	27.52	55.80
Proposal No. 11	Do you agree that the Ministry of Education and schools (elementary and junior high schools) should not implement the gender equality education defined by the Enforcement Rules for Gender Equity Education Act with students under primary and junior high school education level?	67.44	32.56	55.73
Proposal No. 12	Do you agree to implement the protection of same-sex couples' rights to permanent cohabitation by ways other than amending the marriage definition in the Civil Code?	61.12	38.88	55.75

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Table A.1 Continued

Title	Description	Approval rate	Disapproval rate	Turnout
Proposal No. 13	Do you agree to use the name “Taiwan” when applying to attend all international sport competitions, including the upcoming 2020 Tokyo Olympics?	45.20	54.80	55.89
Proposal No. 15	Do you agree that the “Gender Equality Education Act” should stipulate the implementation of gender equality education in every stage of primary and junior high school education, including relationship education, sex education and Sexual Orientation & Gender Identity education?	34.01	65.99	55.33
Proposal No. 16	Do you agree to repeal Article 95, paragraph 1 of The Electricity Act: “The nuclear-energy-based power-generating facilities shall wholly stop running by 2025”?	59.49	40.51	54.83

Source: Central Election Commission

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Table A.2 Proposals in the 2021 referendum

Title	Description	Approval rate	Disapproval rate	Turnout
Proposal No. 17	Do you agree to the activation of Taiwan's mothballed Fourth Nuclear Power Plant?	47.16	52.84	41.09
Proposal No. 18	Do you agree that the government should put a ban on the importation of pork, internal organs and pork products containing ractopamine (β-adrenergic receptor agonists)?	48.79	51.21	41.09
Proposal No. 19	Do you agree that, within six months from the date the referendum is announced, if there is a national election to take place during the period, and in accordance with the provisions of the Referendum Act, the referendum shall be held in conjunction with the national election?	48.96	51.04	41.08
Proposal No. 20	Do you agree to relocate the construction site of CPC Third LNG Receiving Terminal away from the coastal and sea areas of Taoyuan's Datan Algae Reef? (The coastal area from the estuary of Guanyin River in the north to the estuary of Xinwu River in the south, and the sea area stretching out 5 km parallelly alongside the lowest tide line of the aforementioned coast.)	48.37	51.63	41.09

Source: Central Election Commission

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