FACULTAD ECONOMÍA Y NEGOCIOS UNIVERSIDAD DE CHILE

Coal-fired power generation and student achievement: The case of *Gran Concepción*

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Abstract

This paper shows the impact that air pollution from coal-fired power plants has on school achievement and attendance in Southern Chile. To identify causality, we leverage monthly variation in power generation and temporary plant openings and closures in combination with rich individual student data from standardized tests and monthly school attendance. We found plant openings led to lower mathematics and lecture test scores among fourth-grade students of schools within 25 kilometers of distance from these plants. Our results also show strong evidence of the negative effects of coal-based plant generation on school attendance. Our findings document the impact of proximity to coal-fired power generation beyond the health dimension.

1 Introduction

Coal power plants are a way of producing energy extensively in different types of contamination. One of these is air pollution, releasing emissions of sulfur, arsenic, mercury, fluoride, polycyclic Aromatic Hydrocarbons and other forms of particular matter (Wang et al., 2016; Liu et al., 2008), all harmful to human health. Current evidence suggests this exposure to pollution could be more dangerous for children, not only in terms of health but also in their intelligence quotient (Sanders, 2012; Zhang et al., 2018). Therefore, children who study closer to coal power plants could have lower levels of human capital and, consequently, lower future salaries. On the other hand, reducing pollution from coal improves student performance even in the short term (Duque and Gilraine, 2022).

Most of this evidence, however, focuses on the case of developing countries, particularly the United States, where pollution levels are relatively lower and environmental law is stricter than in emerging economies. The goal of this study is to identify a causal relationship between fossil fuel air pollution and educational achievement in the context of a developing country. To that end, we take advantage of the opening of three new coal-fired generators in the "*Gran Concepción*" area in Southern Chile between 2011 and 2012. Chile is an interesting case to analyze because of the opening of several coal-fired power plants between 2000 and 2015, followed by its recent turn to greener policies and restrictions on plant pollution. This situation let us analyze the effects of the introduction and closure of coal power plants in a cohort of 4 generations of students in their late childhood.

We approximate student achievement using school attendance and fourth and tenth-grade Education Quality Measurement System (SIMCE) test scores during 2008 and 2013 and 2008 and

2018, respectively. SIMCE is a standardized test applied to all compulsory schools in Chile for different student ages and courses. Different versions of this test assess mathematics, Spanish language, science, and English language courses. We will use those that refer to the first two (mathematics and Spanish language), since these are the ones that are carried out more frequently and comprehensively in the different grades.[1]. The fourth-grade SIMCE has been held every year since 2005. Questionnaires for the students, their tutors, and teachers are handed out along with the tests which together with educational facilities data provide a rich set of controls. School monthly attendance is public on the Chilean Government Education Ministry website since 2011 for every student with an individual identifier number (mrun) in all education campuses of the preschooler, primary, and secondary education.

The introduction of two new coal power plants on Coronel, one in 2011 (Santa María) and the other in 2012 (Bocamina II), the high variation of coal-based generation between 2008 and 2018, and different wind patterns allow us to sort endogeneity problems and found a causal relationship between the massive ignite of coal on power plants and educational relevant outcomes such as school attendance and achievement in standardized test. For this our empirical approach is a two-way fixed effect difference in difference strategy at three levels of quasi-experiment, which allows us to identify a causal relationship between coal power generation and student outcomes by comparing a control group and a treatment group within a close radius with the plants. The first level of quasi-experiment is the opening (and re-opening) and closure of plants. The second level is the generation level variation caused by the demand in the entire grid (not only the *Gran Concepción*) and the closure of plants. The third level of quasi-experiment is the interaction of the treatment and wind direction.

In our results, we find evidence that the opening of coal-fired plants worsened school performance on math ability by around 0.345 standard deviations in fourth-grade students within 10 kilometers of distance from these installations. We also observe negative impacts on the mathematics test of around 0.335 standard deviations on tenth-grade students. In terms of school attendance, our results suggest that the opening of plants causes 2.42 percent points (pp) less attendance at schools within 10 kilometers of distance, while plant closure improves attendance by 1.29 pp.

This study adds to the existing literature in two fronts. First, we provide evidence of the learning impairment and worsening of school attendance caused by air pollution from fossil fuel plants in a developing-country context. Previous evidence has shown the adverse effects on the

[1]The Spanish language test measures only reading abilities for fourth-grade students, whereas for tenth-grade students, it measures both reading and writing abilities.

educational achievement of early childhood exposure to mineral air pollution (Bharadwaj et al., 2017), yet, to the best of our knowledge, this is the first attempt to quantify these impacts for Chile. Second, it applies new differences in difference econometric analysis at the frontier of actual knowledge, which is new in this environmental economics topic at the authors' knowledge.

The remainder of this paper is organized as follows. Section 2 contains background details, followed by Section 3 describing data information and details. Section 4 includes our empirical strategy and approach, Section 5 shows and discusses our results, and Section 6 concludes.

2 Background Details

2.1 Coal Combustion, Air Pollution, and Educational Achievement

Coal-based energy production is a highly polluting way of producing electricity. The reason is in the emissions of several gases and particulate matter. The principal emissions of these plants are carbon dioxide, nitrogen oxides, sulfur dioxide, particulate matter, and mercury (Oberschelp et al., 2019).

Pollution from coal-fired power generation can affect different aspects of human development. There is ample evidence that shows the effects of coal-based energy production on health outcomes such as respiratory diseases (Gupta and Spears, 2017), fetal health (Yang and Chou, 2018), and infant mortality (Cesur et al., 2017). The effects mentioned before are greater in magnitude in childhood because of the lower defense, an increased vulnerability in their lungs, more time spent outdoors, and time spent in activities that raise ventilation (breathing) rates that have at early ages (Gauderman et al., 2004) (Schwartz, 2004; Austin et al., 2019).

Recent literature finds that different types of pollution have effects on human capital accumulation, including hazardous water, traffic, and air pollution (Currie et al., 2013; Heissel et al., 2022; Balakrishnan and Tsaneva, 2021) in childhood ages. Pollution from coal is no exception causing gaps between those students affected by it and who are not. For instance, Duque and Gilraine (2022) find that North Carolina students who attend at a ratio of 10 kilometers near to coal-power plants and are "downwind" have 0.03 fewer standards deviations in math scores for each million MWh produced, and the closure of a plant implies an increase of 0.132 and 0.18 standard deviations on math and english test scores.[2] To the best of our knowledge, there are no works that evidence coal power plants affecting scholarly performance in Chile, although exists evidence of air pollution and hazardous waste doing it (Rau et al., 2015; Miller and Vela,

[2]The authors also find these effects are heterogeneous in time increasing the longer the plant is closed.

2013).

The main mechanisms that explain this effect are a lower scholarly assistance product of respiratory diseases and decreased brain oxygenation capacity. While the first of these mechanisms can be offset with extra classes and extracurricular education, the second is harder to counteract because is a more accumulative effect that gets worse with aging (Zhang et al., 2018).

The scholar's absence is the primary mechanism in which coal pollution affects school performance. Gauderman et al. (2004) found a strong relationship between the health of the child and his school assistance, which was a significant cause of school performance in terms of grades and dropout possibility. Komisarow and Pakhtigian (2022) provides evidence of an average decrease of 0.369 percent points in scholar absence after the closure of coal-powered plants which translates into 363 fewer student absence days per year for the typical elementary school. The other mechanism found is the damage that air pollution causes to the brain, mainly not allowing the correct oxygenation of it (Zhang et al., 2018). Because this is an accumulative damage and most of its effects are seen at advanced ages is that the main driver of pollution effects on school achievement is seen in school absence.

2.2 Coal-Fired Generation in Chile

The Chilean electric generation grid has suffered many changes in the 21 century. In the last 2000 and early 2010 decades Chile's leak of energy power, this makes the national government look to new energy sources passing from hydro to coal-based thermal plants as primal energy source.[3] This meant an increase of 45% in 2004 and 277.4% between the years 2006 to 2013 coal-based energy, displacing hydroelectric sources as the main method of energy generation.

In the mid-2010s, green energy (mainly wind and solar) takes place for the market as the one to invest in because of the low marginal cost of solar generation in the north and wind in the south displacing coal-based generation (Rivera et al., 2021). In combination with a new national policy of decarbonization and stricter environmental rules on scrubbers meant an increase in the total participation of the non-conventional renewable energy (NCRE) in the electric grid.[4] The economic decarbonization is led by the "*Plan de Retiro del Carbón*", a program for coal-powered plants' retirement or reconversion.

[3] See A1 in the appendix.
[4] See table A3 in the appendix.

The *Gran Concepción* conurbation is a reflection of this history. Their electricity demand was mostly supplied by hydroelectric sources at the beginning of the century until after a constant increase of thermal generation driven by the installation of two new coal-fired power generating units in late 2011 and early 2012 -Santa María and Bocamina II- in the district of Coronel, which already have one coal-powered generation plant since 1970. The proportion of thermal energy in the total equalizes the amount of hydroelectric during the year 2013 driven by the installation of Bocamina II, and surpasses it after two years of cease operations of Bocamina I & II -caused by the cessation of operations due to non-compliance with environmental (scrubbers) regulations- in the year 2016, when this two new plants operated using much of their potential.[5]

Recently, due to the speeding up of the coal-fired power plant closure program, Bocamina I closed its operations in 2020, followed one year after by Bocamina II do the same just one year after only ten years behind his inauguration.

2.3 Local Regulations on Emissions from Thermal Plants

Chile has a history of environmental and social problems, especially in the so-called "*sacrifice zones*", the name for an area with deplorable living conditions usually caused by their deplorable environmental status provoked by industrial or agricultural activity. This has meant large mobilizations and demonstrations in the zones affected, the most symbolic case is the citizen organization "Chao Carbon" which has organized manifestations, marked a document, and made lobby in the national congress to stop coal-based power before 2030.

Environmental policy has taken major relevance in the last part of 2010's decade in Chile creating new institutions for a cap on emissions from thermal plants, an "Long Term Strategy for Climate Change", a climate change framework bill, co-organizing the COP25, and making a withdrawal and reconversion program for coal-fired power plants, which has seen his goals ahead of time thanks to a massive introduction of NCRE.

The plan for retirement and/or reconversion of coal generation does have compensation programs for workers of the plants but does not include a compensation program for the human capital not acquired from those impacted by those effects that we expect to find in this study (Ministerio de Energia, 2020, 2021). This analysis will contribute with evidence for the improvement of the environmental programs of coal plants retirement by estimating the average effects on student performance and school attendance, inputs that could be considered in these programs.

[5] See table A4.

3 Data

3.1 Educational Achievement

We use two main datasets connected by a unique identifier. First, we use students' SIMCE math and Spanish language scores, a standardized test for primary and secondary students, as a proxy for student performance. This dataset contains detailed information about the student, her parents, her professor specialization and professional career, and the school.

This base is obtained from "*Agencia de Calidad de la Educacion*" after requesting it and completing an application form. From it we obtain data for 117,891 students from 547 schools for fourth-grade students and 146,180 students in 195 schools for tenth-grade students. For fourth-grade students this test is realized each year since 2005 and evaluates both mathematic and spanish levels. On the other side, tenth-grade students have been taking the SIMCE test every two years, with annual tests beginning in 2012. However, the math SIMCE test was not administered to tenth graders in 2013 and 2015, and the Spanish language test was not evaluated in 2016.

The second database is the monthly attendance database at the level of students from the years 2012 to 2018. This base has information about the monthly story of school attendance of every student on the Chilean education system in preschool, primary, or secondary education and is obtained from the public website[6] of the Chilean Government Education Ministery. In this database there are 328,365 students in 580 different schools.

Tables 1 and 2 show descriptive statistics of SIMCE test and school attendance on treatment and control groups. The treatment area considered in this study is 10 kilometers as in Duque and Gilraine (2022). Control students are located between 50 and 75 kilometers from the coal powered-plants. This distance has been chosen as it is beyond the range where any effects have been observed according to related literature[7]. The upper limit distance on the control group has been selected so that the nearest biggest cities (Chillan, Los Angeles, and Angol) along with Yungay (the nearest coal-based power plant) are outside the control area and the students were more similar to the treated group. It is seen that the treated students have lower scores on both tests in fourth-grade and lower school attendance. While in tenth grade there is not much difference, the average scores in the treatment area being even higher by 2 points in the mathematics tests.

[6] https://centroestudios.mineduc.cl/datos-abiertos/.

[7] Duque and Gilraine (2022) found coal power plant effects on school achievement on 15 miles (24 kilometers) while Currie et al. (2009) does find effects on school attendance on a distance of 10 miles (16 kilometers).

Table 1: Descriptive statistic of school achievement by group

	4th-grade			10th-grade		
Group	Control	10 km area	Downwind	Control	10 km area	Downwind
Lecture:						
Max	382.5	382.5	382.5	468.10	449.44	449.44
Min	104.16	113.16	113.41	86.37	86.22	93.31
Mean	265.62	262.51	263.70	240.76	240.66	249.65
SD	49.52	50.23	50.94	58.47	58.94	64.21
Obs.	17,517	12,142	5,177	25,260	16,752	6,260
Nº Schools	157	51	19	31	23	10
Mathematics:						
Max	387.17	387.17	387.17	397.49	397.49	397.00
Min	84.56	101.71	111.27	115.72	114.02	118.00
Mean	256.50	249.03	249.69	238.14	240.11	245.46
SD	51.70	50.48	49.92	49.06	50.13	50.71
Obs.	17,527	12,149	5,150	25,270	167,98	6,254
Nº Schools	157	51	19	31	23	10

Notes: This table shows the average, standard deviation, minimum, and maximum of the SIMCE scores according to whether the group received is in the area of treatment and is downwind. Data was obtained from SIMCE databases from "Agencia de Calidad de la Educación" from the Chilean Education Ministry. The data for 4th-grade students is from the period between 2008 and 2013, while the data for 10th-grade students is from 2008 to 2018. The left side of the table displays statistics for 4th-grade students, while the right side displays statistics for 10th-grade students.

Table 2: Descriptive statistic of school attendance by group

Group	Control	10 km area	Downwind
Attendance:			
Max	1.00	1.00	1.00
Min	0.00	0.00	0.00
Mean	0.91	0.88	0.89
SD	0.18	0.21	0.20
Obs.	2,816,264	2,175,818	910,384
Nº Schools	166	65	26

Notes: This table shows the average, standard deviation, minimum, and maximum of attendance according to whether the group received is in the area of treatment and is downwind. Data was obtained from SIMCE and attendance databases from "Datos Abiertos" from the Chilean Education Ministry. Attendance data is available for the years 2013 and 2018. The sample includes students from all grades between first and 12th grade.

Summary statistics of students are reported in Appendix Table A1. The first column names the variable, the second column shows the average punctuation of children who studied at a range of more than 50 and less than 75 kilometers from a coal power plant, the third column shows the score of those who studied nearest to these plants, and the fourth column shows those who study nearest this plant and downwind (in the three columns the standard deviation is in parenthesis below the score).

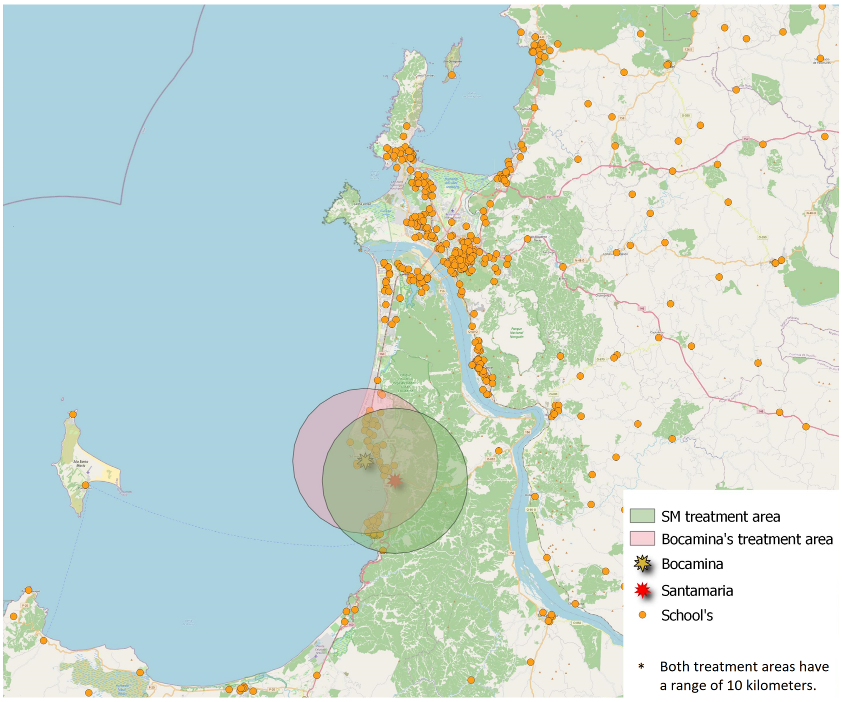


Figure 1: Gran Concepción map. *Note*[1]: Areas around coal power plants had 10 kilometers radius distance calculated based on Euclidean distance. The label shows the symbols for plants (stars) and schools (pink dots). Data was obtained from *"Datos Abiertos Mineduc"* and *"Coordinador Eléctrico Nacional"*.

We merge this information with the geographical location of each of these schools. With this, we are able to see whose schools are in the radium of interest. In Figure 1 we can see the map of Gran Concepción with a euclidean radius of 10 kilometers around coal-powered plants.[8].

3.2 Electricity Generation

We have data on hourly generation from coal power plants in Lota (Bocamina I, Bocamina II, and Santa María) from the *Coordinador Eléctrico Nacional.* The data report the generation from an hourly level, letting us make an hourly average and total amount of power generation every month between 2008 and 2018. There are currently three coal power plants located in

[8]In the map, the buffers zone is made in euclidean distance while we calculate it in geographical distance for our results. This difference means a large change in the number of schools within one treatment area and not in the other, being just one in geographic distance and ten in the euclidean one.

this area. These include Bocamina I, which was established in 1970, Bocamina II, which was commissioned in 2012, and Santa María, which began operating in 2011. Together, they have a total generation capacity of 851 MW, with Bocamina I producing 128 MW, Bocamina II producing 350 MW, and Santa María producing 373 MW. The dataset also has the generation from other sources -two biomass, one propane, one natural gas, and one petcoke thermal power plant- which should have less impact on the student's performance.[9]

Appendix Figure A2 shows variation in the participation of the coal-based electric grid and the accumulated coal-powered energy. There we can see how Bocamina I has roughly the totality of participation on the electric grid based on coal at first, tracked by a change principally around the year 2012 with the incorporation of Bocamina II. Santa María incorporated in the year 2011 and generated on a constant base with some variations monthly.

Figure 2 indicates that when the coal-powered plants were in operation, they were typically active during school hours, ruling out that the operation of the plants does not coincide with school hours. This suggests that pollutant gases from the plant were likely to reach students during those times. This figure also shows the plant's average generation levels when they were functioning, revealing the difference between the new plants and the old (Bocamina I). This difference proceeds from the cost of generation and their maximum capacity.

Wind and meteorology

Our wind direction and speed data come from two different sources. First, we gather information from the National Air Quality Information System (SINCA) with hourly information between the years 2012 and 2019, starting the day 21 of march, twenty-two days after the beginning of the scholar year. These data show us seasonal wind direction and speed patterns generally and specifically for school hours. Appendix Figures A3, A4, A5, A6 show average monthly wind direction in the treated area during summer, all seasons, and winter, respectively, and during school hours (8am to 4pm). These graphs reveal that in summer and spring there is a strong and constant pattern of winds coming from the southwest. The pattern weakens in mid of fall (May) until mid-winter season (August), this period stands out for having both winds from the southwest and from the northeast.

Rainfall data comes from the "Climate Explorer CR(2)", which has daily precipitation data.[10]

[9]Petcoke is a carbonization product of high-boiling hydrocarbon fractions obtained in petroleum processing (Nič et al., 2009).

[10]CR(2) is a data exploration website sponsored by the Chilean National Climate Directorate, the Chilean National Water Directorate, the Faculty of Physics of the University of Chile, and the NOAA (National Centers

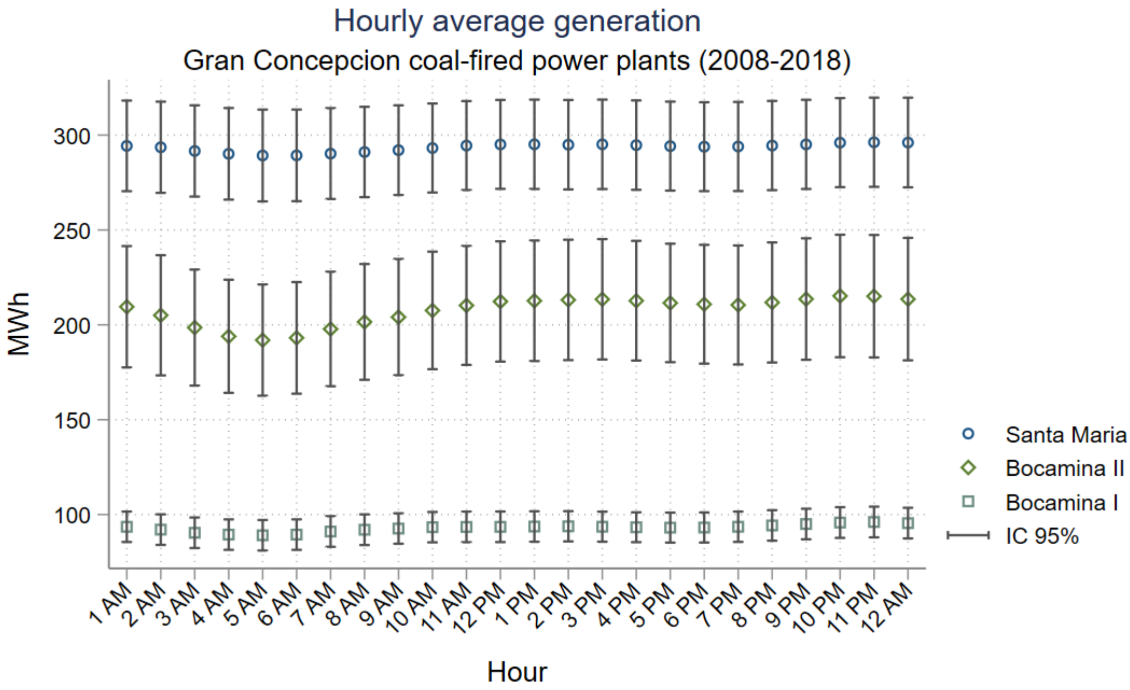


Figure 2: Hourly average generation: Gran Concepción coal-fired power plants (2008-2018). Note: This graph shows the average generation of each plant at an hourly level. Data from Coordinador Eléctrico Nacional. Only included months were students were in class and plants were operating.

We chose twelve data source locations and in cases where data was missing on a particular date, we replaced it with the closest available source. Table A2 shows descriptive statistics of rain between the years 2008 and 2018.

4 Empirical Strategy

We explore two ways fixed-effects differences in difference (TWFE) as the approach to finding evidence. This is a traditional method in the literature related to educational outcomes and air pollution and studies that use the difference in difference approach in general (De Chaisemartin and d'Haultfoeuille, 2020).

4.1 Quasi-experiments

For this analysis, we will rely on two quasi-experiments following the methodology of Duque and Gilraine (2022). We rely on the parallel trends assumption on our dependent variables which we will discuss in the results section.

for Environmental Information).

First Quasi-experiment: Opening and closure of coal-powered plants

We leverage variation that comes from the opening and closure of these plants. First, two of the coal-powered energy plants under analysis started operations in the years 2011 and 2012, these are plants *Santa María* and *Bocamina II* respectively. *Bocamina II* reopened at the beginning of 2011 after shutting down its operations due to the 2010 earthquake.[11] Later on, *Bocamina I* and *Bocamina II* were closed after failing to comply with environmental regulations.[12], and then the following year they returned to generate.

Another source of closure (and the following reopening) is due to changes in the grid's electric demand (caused for economic growth and the interconnection with the Northern transmission system). Over the course of 2013-2018, there were 27 instances of plant shutdowns and eight plant openings (including two initial operations), but only 3 of the previously mentioned shutdowns lasted more than six months.

Second Quasi-experiment: Wind Direction

The second quasi-experiment consists in the use of wind direction, a key factor in the displacement of air pollution (Heissel et al., 2022). One consideration is that parents could select schools based on the surrounding pollution levels, which could create self-selection-based endogeneity problems. Yet, it is highly unlikely that parents consider wind direction when deciding which school to enroll their children in, which allows a clear design to identify causal impacts. We observe wind patterns by creating average monthly wind roses between 2012 and 2019. These are created by weighing the sum of both wind direction and speed in their respective periods.[13]

The area under study shows wind patterns that are consistent over time, especially in the summer and spring seasons when winds come from the southwest. In mid-winter and fall, this pattern changes with the addition of northeasterly winds, which could counteract or even eliminate the southeasterly winds. However, these northeasterly winds arrive in the early hours of the school day (7:00-11:00 a.m.) and then switch to the regular wind pattern from the southwest. This would indicate that in these months with different winds, within the 9 hours described above, at least in nine of them the air pollution from the plants would move in the direction of the schools to which it regularly travels (school in a northeast direction from plants).

[11] The 2010 earthquake in Chile had its epicenter in Gran Concepción, affecting this area to a great extent and in a quasi-homogeneous way.

[12] The details of this decree are in the resolution S-1-2014 available on the Third Environmental Court of Chile web page.

[13] See Figures A3, A4, A5 and A6, for summer, fall, winter and spring, respectively

Because of the predictable pattern, we are able to categorize schools as upwind or downwind, with downwind schools being those between north (cardinal degree 0) and east (cardinal degree 90) from a plant and upwind being those who are in a path between south and west (180 and 270 cardinal degrees) from a plant.[14]

4.2 Empirical approach

In both quasi-experiments we will use two approaches to the coal power-plant use variation. The previously mentioned opening and shutdown variables and one of generation leverage, using the "accumulated year pollution received"[15]. Considering elevated power production from coal power plants is associated with high levels of pollution, this allows us to incorporate more variation in the treatment of our analysis. It is expected that students who study closer to these plants had more deficient performance in the years of increased energy coal-based production.

The following regression is related to quasi-experiments 1 (plant opening and closure):

$$\sigma_{i,s,t} = \beta_0 + \beta_j \mathbb{1}_t\{PO_t\} * N_s + \gamma_s + \delta_t + \alpha_1 X_{i,t,s} + \varepsilon_{i,s,t} \tag{1}$$

Where σ is the standard deviation from the average test score for the "i" student who attended the "s" school during the "t" period[16]. Variable $\mathbb{1}\{PO_{s,t}\}$ is a "dummy variable" that takes the value one if one of the plants is open except if that year a plant shutdown, in which case take the value 0. N is a dummy variable that indicates if the student goes to a s school near the treatment area and takes the value 0 otherwise. γ_s and δ_t are the school (or individual in the case of attendance estimations) and time-fixed effects. $X_{i,t}$ is a vector of control variables at the student level (books at home, preschooler level, gender, and others.) related to the student, their tutors, their school, and their teachers.[17]

We also estimate using variation in power generation level, as shown by Equation (2):

$$\sigma_{i,s,t} = \beta_0 + \beta_1 \mathbb{G}_t * N_s + \gamma_s + \delta_t + \alpha_1 X_{i,t,s} + \varepsilon_{i,s,t} \tag{2}$$

[14] Colleges in other directions from plants (from 91 to 179 and 271 to 359 cardinal degrees) are not considered in the sample when the analysis incorporates wind direction.

[15] This is the sum of the energy generation for what the student has when exposed on his scholar year.

[16] In the SIMCE estimates, each period corresponds to a year, while in the attendance ones they correspond to a month.

[17] Student controls are not used for tenth-grade students because this will reduce the window of years for the estimation. Instead, control was applied for the previous SIMCE test scores obtained in fourth grade.

The difference with Equation (1) is that now the treatment variable N interacts with the accumulated generation of what the individual "i" has been exposed at each "t" period. This allows us to control the level of the treatment that is being assigned and search for more variation in the treatment assignment. Other elements of Equation (2) remain similar.

For school attendance opening variable changes in the empirical model converting itself into a categorical variable with 3 options: closed, functional, and recently opened or reopened. To estimate the effects on school attendance with leverage generation as variable, we use the sum of the month generation as the variable. This is possible due to the greater variation and detail of the data, which for attendance are monthly. This data enables us to apply fixed effects at the student level, replacing the use of school fixed effects (on both estimations). Furthermore, attendance is in percent, the rest of the equation is similar to (1) and (2).

To apply the second quasi-experiment (wind direction) on both (1) and (2) we will estimate adding a downwind variable $\mathbb{W}_,$ interacting with the treatment variables (N and $\mathbb{1}\{PO_{s,t}\}$ or $\mathbb{G}_t$, depending which level of variation in the treatment is being estimated). $\mathbb{W}_,$ is a dummy variable that takes the value one if the school s is in the area defined as downwind and 0 if it is in the area defined as upwind[18], in another case, it will have misvalue. This variable is stable throughout the periods, defining the same area (northeast) as downwind, although there may be occasional exceptions in certain periods.

It will be expected that only our results in the estimations that include this variable show statistical significance since there are clearly defined wind patterns that guide the path of contamination. Likewise, it will be expected that estimated results are greater the closer they are to the source of contamination, in this case, the power plants.

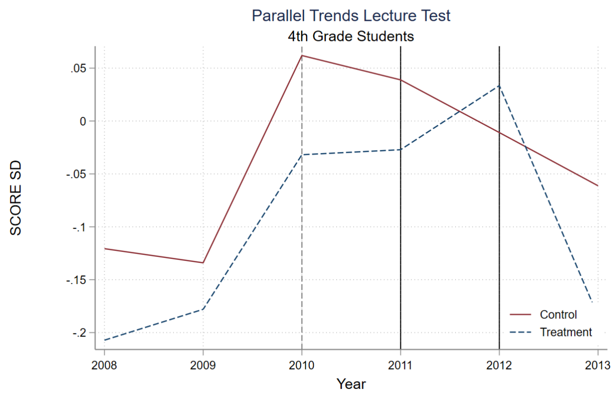
5 Results

The goal of this paper is to test the relationship between air pollution from thermal generation and students' educational achievement. To that end, we leverage variation in the opening and closing of three coal-fired generators in Southern Chile following a difference-in-difference approach. The validity of this approach relies on the parallel trends assumption meaning that trends in the treatment and control groups had stayed the same in the absence of the treatment. The figures 3 and 4 show the trends in SIMCE score for the treatment, control, and downwind groups in the years used in the estimations. On these maps, the vertical gray dotted lines mark

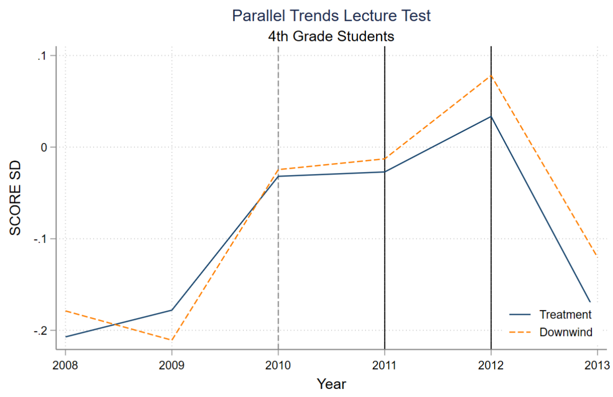
[18] As explained in the "Second Quasi-Experiment" subsection downwind and upwind is defined as the area between north and east and south and west from the plants respectively.

the years in which a plant is shutdown, and the solid black lines mark the years in which a plant was opened or reopened.

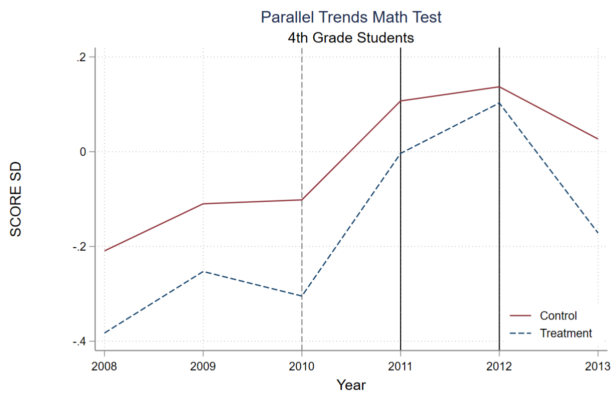
Figure 3: Average fourth grade SIMCE score trend



(a)



(b)



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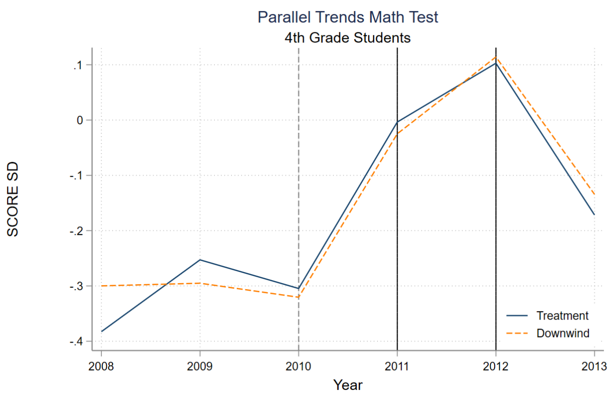


(d)

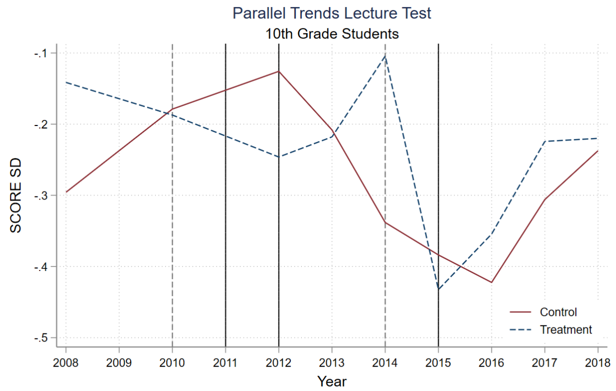
Note: This graph shows the trends of average SIMCE scores (lecture and mathematics) for fourth-grade students. Dotted gray vertical lines show years were a plant shutdown and black solid vertical lines show years were one or more plants open (or reopened). Periods are in years. Subfigures (a) and (b) compare control and treatment (near plants) groups trends, while subfigures (c) and (d) compare treatment (near plants) and downwind (near and downwind plants) trends. The study categorizes the treatment group as students who attend schools located within a 10-kilometer radius of any plant, while the control group consists of students attending schools between 50 and 75 kilometers away. The Downwind group is defined as students from the treatment group who study downwind of a plant. Data were obtained from the SIMCE database.

The four Subfigures of Figure 3 indicate that between 2008 and 2010, period where only Bocamina I operated at low levels or did not operate at all (the year 2010), score trends were similar, changing as of the year 2011 with the reopening of Bocamina I and the opening of Santa María. On control and downwind groups both lecture and mathematic test trends show similarities between the years 2009-2010, period before the first treatment (opening of Santa

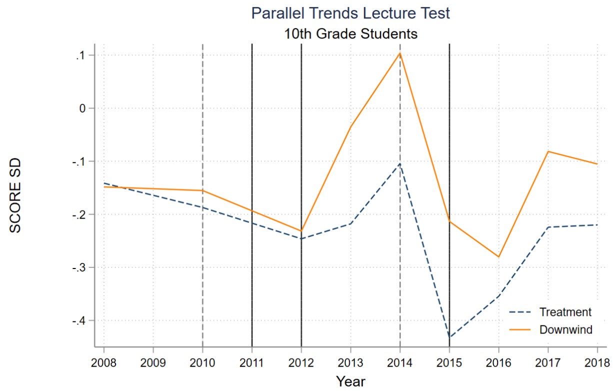
María and reopening of Bocamina I).

The case for tenth-grade students (Figure 4) shows a similar trend between the control and treatment group between 2008 and 2010 in the mathematic SIMCE test, with a slight change in the year 2012 (opening of Bocamina II) and an abrupt change of the trends in the year 2014 (both Bocamina's shutdown). The case of the SIMCE reading test in tenth-grade students is less favorable, with different trends throughout the sample. Control and downwind trends show similarities on both lecture and mathematics tests.

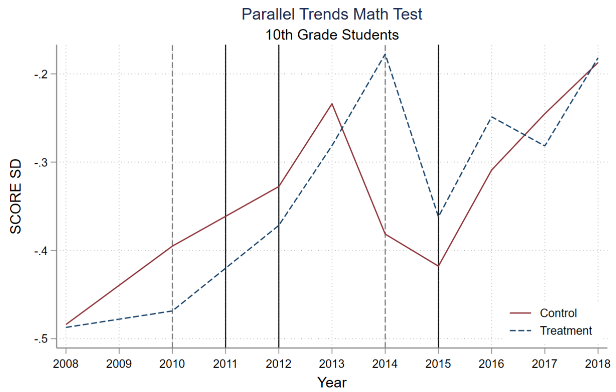
Figure 4: Average tenth-grade SIMCE score trend



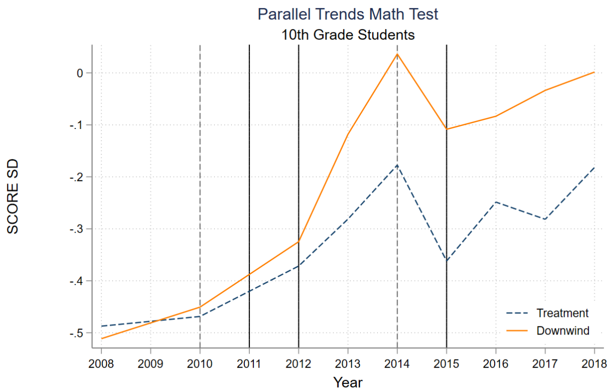
(a)



(b)



(c)



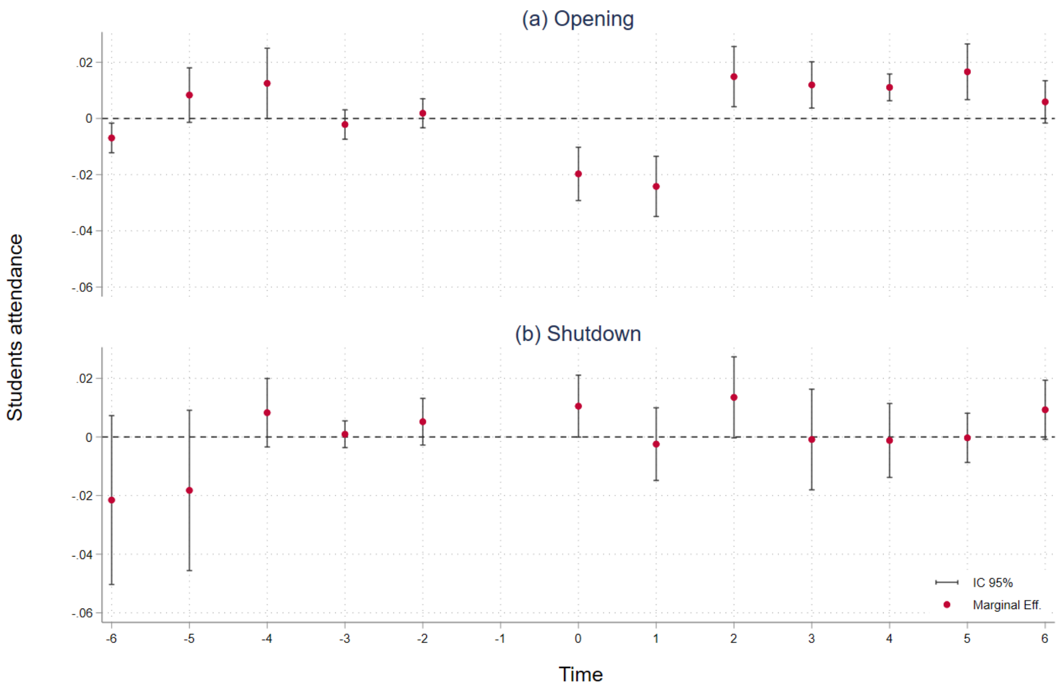
(d)

Note: This graph shows the trends of average SIMCE scores (lecture and mathematics) for tenth-grade students. Dotted gray vertical lines show years were a plant shutdown and black solid vertical lines show years were one or more plants open (or reopened). Periods are in years. Subfigures (a) and (b) compare control and treatment (near plants) groups trends, while subfigures (c) and (d) compare treatment (near plants) and downwind (near and downwind plants) trends. The study categorizes the treatment group as students who attend schools located within a 10-kilometer radius of any plant, while the control group consists of students attending schools between 50 and 75 kilometers away. The Downwind group is defined as students from the treatment group who study downwind of a plant. Data were obtained from the SIMCE database.

Non-conditional trends for school attendance groups are also shown in appendix Figure A7. In these graphs black vertical lines show the opening or reopening of power plants and the gray zones show the period where at least one plant where shutdown[19]. Panel (b) shows that trends between treatment and downwind groups are almost equivalent with the exception of two months after the inauguration of Santa María and two months before the shutdown of Bocamina II.

For an easier distinction from the assumption of parallel trends in school attendance, we conducted a panel event study. Figure 5 shows the results of the estimations for opening (a) and shutdown (b) treatments. On both treatments, although the post-treatment results do not show significance or the expected sign, we must be cautious when interpreting these results because periods in which the treatment had been reversed were included in the analysis.

Figure 5: Panel Event-Study: Coal power plants on school attendance



Note: This graph shows estimated coefficients and their 95% confidence interval of opening and shutdown lagged and lead effects. X-axis shows the time period relative to the treatment, where period -1 was omitted. Y-axis shows the percentage of school attendance. To estimate these effects, subsequent periods in which the treatment was reversed were not omitted. The treated group was considered students who attend a school at a 10-kilometer range downwind of a coal-power plant. The estimate corresponded to a two-way fixed effects difference in differences, with fixed effects at the student and month levels. Data is from 2011-2018 and was obtained from Datos Abierto (Mineduc).

[19] The gray zones were made only with shutdowns that lasted at least for two months.

The shutdown treatment (panel b) shows that between the sixth and second pre-treatment periods there are no significant differences at the 95% confidence level, as in the post-treatment periods[20]. This is strong evidence of the existence of parallel trends before the shutdown treatment.

The estimated coefficients before the opening treatment are presented on panel (a). The fourth lagged period is slightly significant, with a confidence level of 95% (p-value of 0.0495) and an associated positive value, while the sixth lagged period is also statistically significant but with a negative value. Although there are two significant estimated lagged coefficient estimates of six, they do not show distribution patterns such that there are endogenous modifications prior to treatment.

5.1 Attendance achievement

Opening/Shutdown Treatment

Our results for estimating Equations (1) and (2) without a downwind variable on school attendance are shown in Table A10. Closing and opening estimates are made in monthly periods and simultaneously[21] as explained in the section 4.2. The results of Equation (1), suggest a generalized improvement in area school attendance with plant closure and a worsening of it when plants open. Both effects are in line with our hypotheses of power plants affect in a negative way school attendance and that this effect depends negatively on the distance to the plant.

The results for estimations on Equation (1) including downwind variable are presented in Table 3. This shows estimated effects for 5 and 10 kilometers treatment areas, where column (4) includes controls and time and student-fixed effects.[22] Results show a decrease in school attendance of 1.88 pp when coal-based power plants open and an increase of 0.17 pp when they shutdown. This effect is greater the closer the school is to the plant, which goes in line with the literature and our previously mentioned hypothesis.[23].

[20] Although this is true, the effect on the lower bound in the same month as the treatment is marginal lower to zero with a value of $4.5E-5$ and a p-value of 0.0509, marginally not statistically significant at a 95% confidence level.

[21] The empirical approach for school attendance use a categorical variable with 3 states: standard use, closure and (re)opening. This variable explain the status of the three plants on each period.

[22] This estimation is made with a "Two-way fixed effects differences-in-differences-in-differences" (TW-DDD), but the coefficients associated with other interactions or variables alone are not included in the table.

[23] These effects are greater in closer areas having a magnitude of 2.25 (shutdown) and -3.39 (opening) pp in a treatment area of 5 kilometers.

Table 3: Estimated Effects of Coal-Fueled Power Plant Openings and Shutdown on School Attendance

	(1)	(2)	(3)	(4)
Panel A: 5 km treatment area				
[Shutdown]X[Near]x[Downwind]	0.00173	0.00282	0.0228***	0.0225***
	(0.00321)	(0.0031)	(0.00287)	(0.00286)
[Opening]X[Near]x[Downwind]	-0.0422***	-0.0319***	-0.0344***	-0.0339***
	(0.00503)	(0.00486)	(0.00429)	(0.00428)
Obs.	2,507,211	2,507,211	2,507,211	2,507,079
Control obs.	1,703,524	1,703,524	1,703,524	1,703,392
Treatment obs.	803,687	803,687	803,687	803,687
Panel B: 10 km treatment area				
[Shutdown]X[Near]x[Downwind]	-0.0103***	-0.0129***	0.00367***	0.00173*
	(0.001)	(0.000962)	(0.000868)	(0.000866)
[Opening]X[Near]x[Downwind]	-0.0317***	-0.0242***	-0.0196***	-0.0188***
	(0.00157)	(0.0015)	(0.00133)	(0.00132)
Obs.	3,288,245	3,288,245	3,288,245	3,288,113
Control obs.	1,703,524	1,703,524	1,703,524	1,703,392
Treatment obs.	1,584,721	1,584,721	1,584,721	1,584,721
Time FE		X	X	X
Student FE			X	X
Controls				X

Notes: Standard errors in parentheses. ** $p<0.05$, ** $p<0.01$, *** $p<0.001$.* This table shows the results of two-way fixed effects estimation on coal-powered plant opening effects on SIMCE scores in two treatment area levels (5 and 10 kilometers in Panel A and B). Data is from between the years 2011 and 2018. Estimations are shown as percent. All estimations have a month, year, and student-fixed effects and controls. Control variables include characteristics from their school, parents, teachers, meteorology, and student gender.

The results about plant opening are one-tenth of those estimated by Komisarow and Pakhtigian (2022). However, their estimates were calculated based on annual effects and ours are monthly effects with shutdown cases of only one or a few months, which could explain, together with the disparity in the generation capacity of the plants[24], the minor effect of "Gran Concepción" plants.

[24] The authors of the paper examine the impact of three power plants with a generation capacity of 614, 597, and 374 MW/h, and in our study, the biggest plant in which we focus is Santa María, which has a capacity of 370 MW/h.

Generation Treatment

Our results of estimating the eq (2) specifications are in Table A11. Our results are opposite to those found in the related literature, showing a positive effect of generation on school attendance per GW/month produced on both 5 and 10 kilometers specifications estimations. However, non of these effects are statistically significant at a 90% confidence level.

Table 4 shows estimations of eq (2) which include the downwind variable. Column (4), which includes fixed effects and controls, shows a decrease in school attendance of 9 and 8 percentage points at 5 and 10 kilometers of treatment area per TW generated. Both estimated coefficients are statistically significant with a 99% confidence interval, also their coefficient indicates that the effect of the power plant on school attendance decreases as the distance between the school and the plant increases.

Table 4: Estimated Effects of Coal-Fueled Power Plant Generation on School Attendance

	(1)	(2)	(3)	(4)
Panel A: 5 km treatment area				
[Near]x[Generation]x[Downwind]	-0.202*	-0.219*	-0.0758***	-0.0932***
	(0.0873)	(0.0893)	(0.0194)	(0.021)
Obs.	2,507,211	2,507,211	2,507,211	2,507,079
Control obs.	1,703,524	1,703,524	1,703,524	1,703,392
Treatment obs.	803,687	803,687	803,687	803,687
Panel B: 10 km treatment area				
[Near]x[Generation]x[Downwind]	-0.141*	-0.154**	-0.0797**	-0.0878**
	(0.0592)	(0.0558)	(0.0257)	(0.0296)
Obs.	3,288,245	3,288,245	3,288,245	3,288,113
Control obs.	1,703,524	1,703,524	1,703,524	1,703,392
Treatment obs.	1,584,721	1,584,721	1,584,721	1,584,721
Time FE		X	X	X
Student FE			X	X
Controls				X

Notes: Standard errors in parentheses. ** p <0.05, ** p <0.01, *** p <0.001.* This table shows the results of two-way fixed effects estimation on coal-powered plant generation effects on school attendance in two treatment area levels (5, and 10 in Panels A and B). Data is from between 2013 and 2018. Estimations are shown as percent. Variables included in each estimation are indicated in the panel below Panel B with an ex (X). Control variables include characteristics from their school, parents, teachers, meteorology, and gender.

5.2 SIMCE TEST SCORES

Opening treatment

Our estimations results for Equation (1) are presented in Table A6 for fourth-grade students between 2008 and 2013, and in Table A7 for 10-th grade students between 2008 and 2018. Summary statistics on control variables are in Table A1.

For students in fourth grade in the nearby area, there is no evidence of a negative effect of the opening of coal-based power plants neither in math nor lecture test. There is a positive and non-significant coefficient related to studying in a close area of 10 kilometers during the year of a plant opening. The estimations for tenth-grade students do not show evidence for a generalized effect around 5 and 10-kilometer areas either, having negative but not statistically significant at a 90% confidence level.

Both fourth and tenth-grade estimations do not find general effects of the contamination. In an area with a strong wind pattern for much of the year, it is not surprising that effects were not found in a generalized way around the area. To clarify, our estimation of effects may have been biased by our decision to consider only students studying near the plants but not downwind, as they were classified as treated.

Table 5 showcases the outcomes of Equation (1) when the downwind variable is incorporated, with panels A and B displaying the results for fourth-grade students, while panels C and D showing the results for tenth-grade students. Table 5 demonstrates a negative relation between the opening of a nearby coal-based plant and the academic performance of fourth-grade students in downwind schools, as evidenced by the reduced scores in both lecture and mathematics tests. For the lecture results, is visible that this effect is statistically significant at only 25 and 50 kilometers area. On the contrary, all mathematic results are statistically significant at a 90% confidence interval level.

These results for fourth-grade students are in line with the previously mentioned literature, which indicates the negative effects of studying near coal power plants. However, we should expect that the effect would be greater the closer the school is to the plant, which we do not find in these estimations. This could be explained by a small bias caused by measurement errors in the independent variables given the periodicity of the data (annual), given that the variables had to be compressed to annual variables by means of averages losing estimation capacity. An example of this could be the average rainfall variable, which in theory should mitigate the effects of pollution, but since it is an average, it does not explain whether the days when it rained were actually the days when the plants operated and to what extent, which happen and is more precise with monthly attend estimations.

The findings for tenth-grade students, as presented in panels C and D, indicate a negative impact on the performance of students from downwind schools on the lecture test, whereas mixed results are observed in the math examination. However, only one of these results is statistically significant at a 90% confidence interval, being the negative effect of a downwind-open power plant on a treatment area of 10 kilometers.

Our findings show consistently negative and statistically negative effects for fourth-grade students on mathematics tests (only half of the lecture tests are statistically significant), while the results of the tenth graders are less probative of a causal relationship. These results are similar to those of Miller and Vela (2013), where the authors find a negative effect of different types of air pollution in fourth and eighth graders, but this effect is not observed in tenth graders. Although in that paper the authors argue that this lack of significance is due to fewer observations in tenth grade (which could also explain the tenth-grade results in this paper), other possibilities are that they possess greater resistance to the immediate effects of contamination due to their age as is explained in 2.1.

Generation treatment

The estimation results on Equation (2) are presented in Table A8 and A9 for students of fourth and tenth grade. Estimations in column 3 do not include student-level controls but have control for their past SIMCE test scores.

The results in fourth-grade students show that there is no generalized effect of carbon-based generation in the 10-kilometer areas, being the associated coefficients positive and no-significant at a 90% level of confidence for lecture and mathematics tests. Furthermore, the tenth-grade assessment results also do not provide sufficient evidence to suggest a widespread negative impact on overall academic performance, as the negative coefficient estimated is not statistically significant at the 90% confidence level.

The estimated results on the Equation (2) including the downwind variable are presented in Table 6 for students in fourth and tenth grades. In line with our results shown above, the inclusion of a downwind variable helps to isolate the treated students and find more statistically significant results, which suggest a widespread negative impact of coal-based electricity generation on the academic performance of downwind students of fourth grade. A statistically significant effect is observed but only within the 50 km treatment area with a magnitude of

Table 5: Estimation of coal-powered plants opening effects on SIMCE scores.

Treatment area	5 km	10 km	25 km	50k
4th Grade students:				
Panel A (Lecture scores)				
[Open]x[Near]	0.117	0.252*	0.213	0.228*
	(0.17)	(0.12)	(0.12)	(0.09)
[Open]x[Near]x[Downwind]	-0.148	-0.275	-0.278*	-0.280*
	(0.197)	(0.154)	(0.131)	(0.113)
Obs.	9,274	10,832	25,982	44,332
Control obs.	6,222	6,222	6,222	5,844
Treated obs.	3,052	4,610	19,760	38,488
Panel B (Mathematic scores)				
[Open]x[Near]	0.340*	0.341*	0.282*	0.330**
	(0.15)	(0.13)	(0.13)	(0.11)
[Open]x[Near]x[Downwind]	-0.332*	-0.341*	-0.386*	-0.417**
	(0.166)	(0.154)	(0.150)	(0.130)
Obs.	9,289	10,862	26,045	44,479
Control obs.	6,236	6,236	6,236	5,859
Treated obs.	3,053	4,626	19,809	38,620
10th Grade Students:				
Panel C (Lecture Scores)				
[Open]x[Near]	0.0549	0.0563	-0.0238	-0.182
	(0.38)	(0.13)	(0.13)	(0.13)
[Open]x[Near]x[Downwind]	-0.377	-0.335*	-0.168	-0.0182
	(0.386)	(0.145)	(0.137)	(0.14)
Obs.	4,091	5,225	14,787	23,678
Control obs.	3,053	3,053	3,053	2,774
Treated obs.	1,083	2,172	11,734	30,904
Panel D (Mathematic Scores)				
[Open]x[Near]	-0.333	-0.348*	-0.359*	-0.429**
	(0.32)	(0.16)	(0.16)	(0.16)
[Open]x[Near]x[Downwind]	0.289	-0.114	0.0252	-0.136
	(0.324)	(0.244)	(0.184)	(0.127)
Obs.	3,247	4,282	12,007	19,261
Control obs.	3,076	3,076	3,076	2,793
Treated obs.	1,033	2,172	11,788	21,030

Notes: Standard errors in parentheses. ** $p<0.05$, ** $p<0.01$, *** $p<0.001$.* This table shows the results of two-way fixed effects estimation on coal-powered plant opening effects on SIMCE scores in four treatment area levels (5, 10, 25, and 50 kilometers).The data for 4th-grade students are from the period between 2008 and 2013, while the data for 10th-grade students covers the period between 2008 and 2018. Estimations are shown as standard deviations from the mean scores. Panel A and B shows estimation on lecture and mathematics test for 4th grade students, and Panel C and D show results for lecture and mathematics for 10th grade students. All estimations have a year, and student-fixed effects and controls. Control variables include characteristics from their school, parents, teachers, and students (for 10th grade students this is replaced with 4th grade past scores).

-0.168 and -0.218 standard deviations, on lecture and math tests for fourth-grade students (see fifth column in panels A and B).

Table 6: Estimation of coal-powered generation effects on SIMCE scores.

Treatment area	5 km	10 km	25 km	50k
4th Grade Students:				
Panel A (Lecture scores)				
[Generation]x[Near]x[Downwind]	-0.00563	-0.0903	-0.105	-0.168*
	(0.114)	(0.0979)	(0.0862)	(0.083)
Obs.	9,274	10,832	25,982	44,332
Control obs.	6,222	6,222	6,222	5,844
Treated obs.	3,052	4,610	19,760	38,488
Panel B (Mathematic scores)				
[Generation]x[Near]x[Downwind]	-0.0471	-0.102	-0.130	-0.215**
	(0.107)	(0.102)	(0.0904)	(0.0827)
Obs.	9,289	10,862	26,045	44,479
Control obs.	6,222	6,236	6,236	5,859
Treated obs.	3,052	4,626	19,809	38,620
10th Grade Student				
Panel C (Lecture Scores)				
[Generation]x[Near]x[Downwind]	-0.279	-0.0156	0.0404	0.0642
	(0.382)	(0.154)	(0.145)	(0.124)
Obs.	4,091	5,225	14,787	23,678
Control obs.	3,053	3,053	3,053	2,774
Treated obs.	1,083	2,172	11,734	30,904
Panel D (Mathematic Scores)				
[Generation]x[Near]x[Downwind]	0.276	-0.171	-0.00243	-0.22
	(0.31)	(0.259)	(0.201)	(0.136)
Obs.	4,109	5,248	14,864	23,030
Control obs.	3,076	3,076	3,076	2,793
Treated obs.	1,033	2,172	11,788	21,030

Notes: Standard errors in parentheses. ** $p<0.05$, ** $p<0.01$, *** $p<0.001$.* This table shows the results of two-way fixed effects estimation on coal-powered plant generation effects on SIMCE scores in four treatment area levels (5, 10, 25, and 50 kilometers). The data for 4th-grade students is from the period between 2008 and 2013, while the data for 10th-grade students covers the period between 2008 and 2018. Estimations are shown as standard deviations from the mean scores. Panel A and B shows estimation on lecture and mathematics test for 4th grade students, and Panel C and D show results for lecture and mathematics for 10th grade students. All estimations have year, and student-fixed effects and controls. Control variables include characteristics from their school, parents, teachers, and students (for 10th grade students this is replaced with 4th grade past scores).

The estimated effects presented in panels C and D reveal an ambiguous effect and lack of statistically significant impact associated with exposure to annual coal-based generation (TW) levels. While a negative impact on mathematics performance is observed within the 50 km treatment area whit a similar magnitude as previously reported in Table 4, the estimates in this instance do not achieve statistical significance at the 90% confidence level.

5.3 Robustness

For robustness, we estimate the past regressions in different specifications of treatment zones and separate the treatment for each plant. For school attendance, the tables A12 show previous estimations with variations in the treatment areas. Equations (1) and (2) estimations are presented in panels A and B, including interaction with downwind variables.

Panel A shows that the opening of a power plant has a negative effect on school attendance at decreasing rates with respect to the distance to it. Panel B illustrates the effects of power plant generation (measured in TW levels), all of which are statistically significant with negative coefficients (at least at the 95% confidence level). The estimated effects are consistent with previous research, showing a decrease in impact as the distance from the power plants increases and are in line with our identification assumption. The estimated shutdown effect is less straightforward, with positive estimates observed at distances between 5 and 10 kilometers, and negative estimates at greater distances (between 25 and 50 kilometers).

The results on attendance by each plant for 25 and 50 kilometers area treatment are in Table A13, where estimations for openings of Santa María and Bocamina I at a 25 kilometers range are statistically associated with lower attendance levels and the shutdown of Bocamina II is associated with higher attendance levels at 50 kilometers range (the other estimations presents no significance at 90% confidence level). Estimations with interest areas of 5 and 10 are not shown because all the relevant estimations were omitted due to multicollinearity. The estimations using power generation as an independent variable (PanelB) yield conflicting results. Specifically, the analysis indicates that the generation of the Bocaminas plant is associated with increased attendance within a 25 km radius, whereas the Santa María plant is associated with a negative effect on attendance within a 50 km radius.

Additionally, we realized a test to search for possible bias on our estimations given the nature of TWFE difference-in-differences with staggered treatment and heterogeneous effects on time developed by De Chaisemartin and d'Haultfoeuille (2020). The results are presented in Table A5. There we can see that the estimations for SIMCE scores on both grades are not biased, but on attendance estimations both closure and opening coefficients present a bias. This bias should not be a problem in the case of opening estimation (because there are 114 positive weights in contrast to 11 negative ones), but the estimation of closure presents almost one-third of negative weights which could indicate an important bias in our estimation. This is due to one school which is in Bocamina plants 10 kilometers area but not in Santa María area[25]. The observations for this school in the SIMCE bases are small, with 151 and 191 for fourth and tenth grade (0.1% and 0.08% of the data), while for the attendance data this school has 22,570 observations (0.15% of the data), which could explain why the attendance estimates are biased and the SIMCE ones are not.

To fix the bias problem we estimate the effect of plant closure and opening to school attendance with the DID_M estimation (De Chaisemartin et al., 2019). However, this method poses several challenges, including limitations in using multiple treatments, only being able to utilize one type of time fixed effect, and constraints in incorporating controls. For this reason, the results shown in Table 7 are estimated only using one treatment at a time, year as fixed time effect, and as controls the economic status of the school (as a way to control for the economic level of the student) and the precipitation levels. While the results show no statistically significant effects associated with either the opening or shutdown of these plants, it is important to note that the estimation method used in this study has certain limitations, as discussed earlier, and therefore, the results should be interpreted with caution.

Table 7: Estimated effect of coal-powered plants on school attendance using DID_M

Treatment	**Estimate**	**SE**	**LB CI**	**UB CI**	**N**	**Switchers**
Shutdown	0.0226874	0.0563163	-0.0876926	0.1330673	6447172	256375
Opening	-0.052998	0.066106	-0.1825657	0.0765697	7643257	311391

Notes: Bounds are made with 95% confidence level. This table shows the results of DID_M estimation on coal-powered plant opening and shutdown effects on school attendance in a 10 kilometers treatment area. Data is from between 2013 and 2018. Estimations are shown as percent point of school attendance. Controls included in this estimation were the economic status of the school and the precipitation month level.

6 Conclusion

The objective of this study was to find empirical evidence of the effects of coal-based power plants on school achievement and attendance in the Gran Concepción. For this purpose, we employed an approach of two-way fixed effects regressions and our dependent variables were school attendance and the SIMCE lecture and mathematics test scores between the years 2008 and 2013 for fourth grade and between the years 2008 and 2018, which are standardized for every student in Chile. For school attendance as a mechanism for school achievement and a

[25]This is the *Scuola Italiana Di Concepcion*

relevant outcome per see we use data between the years 2011 and 2019.

We take advantage of three forms of quasi-experiments in the location of *Gran Concepción* in Chile to apply a difference in differences with two-way fixed effects. The first one is the installation, closure, and reopening of 3 coal-based plants which gives us 22 treatments, the second one is the power generation variation which allows us to find more heterogeneity in the treatment assignment and the third one is the location of the school relative to the wind direction from power plants.

Our results on estimations about the effects of being downwind on a coal-power plant opening on SIMCE test scores are negative and statistically significant on both lecture and mathematics (with the exception of effects on lecture score on 5 and 10 kilometers treatment area) for fourth grade and for tenth grade there is a negative and statistically significant effect on lecture test at the 10-kilometer treatment area. The opening of a plant has a negative impact on school attendance, reducing it by 3.39 percentage points (pp) in the 5 kilometer treatment area and by 1.88 pp in the 10 kilometer treatment area. Contrarily, the shutdown of a plant has a positive impact on school attendance, increasing it by 2.25 pp in the 5 kilometer treatment area and by 0.17 pp in the 10 kilometer treatment area. This estimation shows that the effect of an opening is greater in absolute terms than the one of a shutdown.

The results of estimations using plant generation as the independent variable are less conclusive than those previously mentioned. The estimated effects on SIMCE scores only show statistical significance in fourth grade in the 50 kilometer treatment area, where they have a negative effect on both lecture and mathematic scores. The results for attendance indicate that an increase of one terawatt (TW) of generation decreases school attendance by 9.32 and 8.78 percentage points (pp) in the 5 and 10 kilometer treatment areas.

The results which include the downwind variable are in line with previous research which indicates that wind patrons have a major role on effects in this zone. The estimated effects are smaller in magnitude than those seen in previous literature, likely due to less intense treatment. This suggests the existence of heterogeneity in the effect given the difference in the treatment intensity. As an instrument for the creation of public policies, these estimates work as evidence and a measure of the cost of generation for the creation of reparation measures for the human capital of the affected areas.

To verify the robustness of our results, we tested estimating across a variety of treatment and area specifications. These estimations are in line with those previously mentioned with the exception of Bocamina's sum generation effect on a 25 kilometers treatment area which has a negative effect contrary to our hypothesis and previous results.

Additionally, we realized Chaisemartin and D'Haultfoeuille bias test and found that our results are not biased with the exception of school shutdown and opening in a minor case, both on attendance estimations. For this, we estimate using the DID_M model, but our results do not find statistically significant results, under our criteria due to the current limitations of the estimator.

Due to the aforementioned, we say that there is causal evidence of the negative effects of coal-plant opening and power generation on school achievements. There is also evidence that these coal power plants affect school attendance, but looking at the robustness tests we are more cautious in treating it as causal evidence for the case of plant opening and shutdown treatment.

We also expect that this study can help to improve Chilean legislation, specifically, the program "*Retiro de Centrales a Carbon*", which does not compensate for the lower future salary of those who studied near these plants, an effect caused by lower school attendance and achievements.

This work could be improved on several fronts: We suggest adding intertemporal lagged and accumulative effects to see further effects on tenth-grade school achievement. To solve the bias problem inherent to TWFE models we suggest trying to implement different estimations methods than the DID_m estimation (De Chaisemartin et al., 2019).

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Appendix

Table A1: Sumarry statistics of students

	4th-Grade			10th-Grade		
Area	Control	10km area	Downwind	Control	10km area	Downwind
Female (%)	48.1	49.1	49.4	47.2	49.2	57.0
	(50.0)	(50.0)	(50.0)	(49.9)	(50.0)	(0.495)
Have internet (%)	21.32	42.6	45.7			
	(40.7)	(49.4)	(49.8)			
Have computer (%)	45.6	61.4	63.4			
	(49.8)	(48.7)	(48.2)			
Father education*	2.083	2.454	2.517	1.767	2.057	2.133
	(1.177)	(1.206)	(1.223)	(1.163)	(1.297)	(1.362)
Mother education*	2.126	2.368	2.431	1.776	1.993	2.061
	(1.196)	(1.186)	(1.201)	(1.138)	(1.224)	(1.287)
Home income*	2.713	3.104	3.279	6.428	7.213	7.507
	(1.799)	(1.932)	(2.114)	(4.676)	(4.724)	(4.721)
Books in home*	1.461	1.611	1.630			
	(0.850)	(0.851)	(0.863)			
Preschool studies (%)	96.4	99.0	99.2			
	(18.7)	(10.2)	(8.7)			
Prescholar level	3.726	3.808	3.840			
	(0.854)	(0.633)	(0.568)			
Parents expectative*	2.414	2.630	2.639			
	(0.804)	(0.676)	(0.668)			
T. postgraduate (%)	68.3	94.0	99.5			
	(100.5)	(105.9)	(108.6)			
Rural (%)	28.7	0.00.5	01.2	03.4	00.0	00.0
	(45.2)	(07.1)	(10.8)	(18.2)	(00.0)	(00.00)
School income level*	2.161	2.416	2.587	1.647	1.973	2.069
	(0.743)	(0.768)	(0.804)	(0.673)	(0.787)	(0.942)
Past lecture score**				-0.135	-0.150	-0.079
				(0.986)	(0.997)	(0.997)
Past math score**				-0.104	-0.213	-0.175
				(0.999)	(0.971)	(0.979)

Note: This table shows the mean and standard deviation (on parenthesis) of control variables including student, teacher, parents, and school data between the years 2008 and 2013 for 4th-grade and 2008 and 2018 for 10th-grade. All statistics were truncated to the third decimal place. There were also used controls dummy variables about the specialization of the teacher and the dependency of the school. Data was obtained from SIMCE databases. The data which is blank does not have that information for that grade students. Variables with * have grouped values. Variables with ** show standard deviations from the mean as values

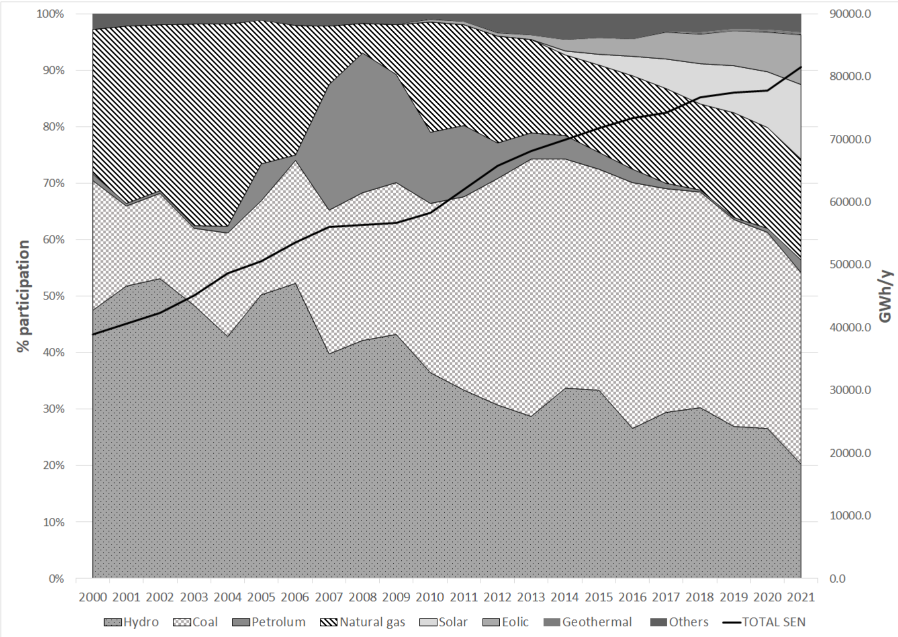


Figure A1: Chilean SEN generation by technology (GWh/year). *Note*: Areas show the percent of generation by technology (left vertical axes) and the gray line shows the total generation (GWh/year) in the Chilean national system (right vertical axis). Own elaboration based on data from the *Coordinador Eléctrico Nacional*.

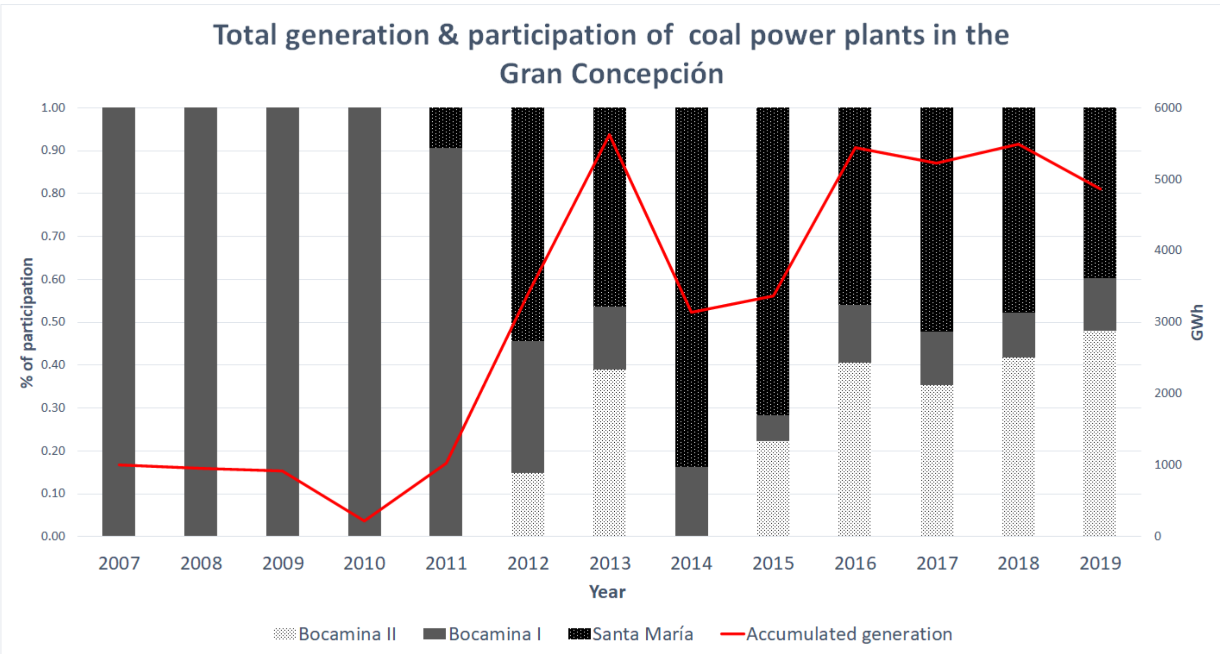
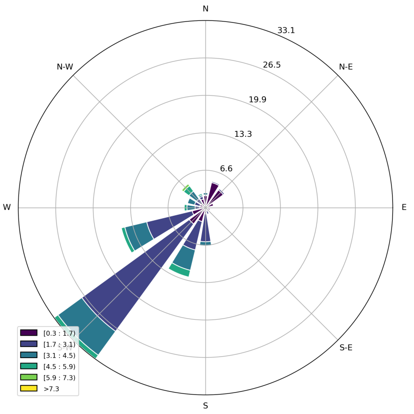
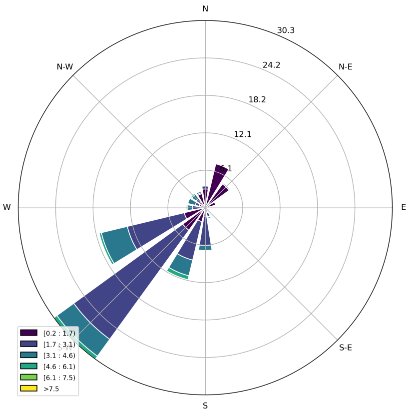


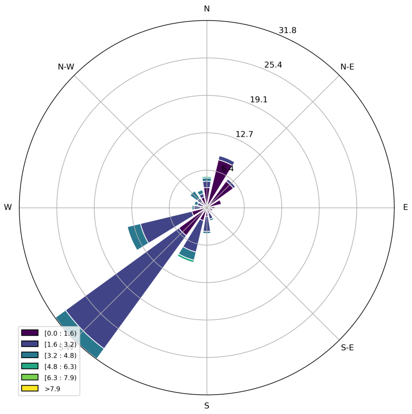
Figure A2: Total generation & participation of coal power plants in the Gran Concepción. *Note*: Elaborated using only hours in which kids assist to school with a 1-hour window. This figure shows the coal-based participation in the Gran Concepción grid in the bars and the total electric generation from these plants in the red line. Own elaboration based on data from the *Coordinador Eléctrico Nacional*.



January

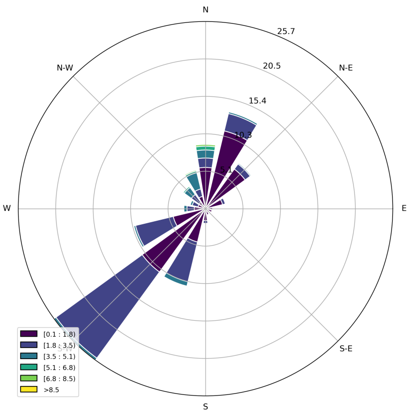


February

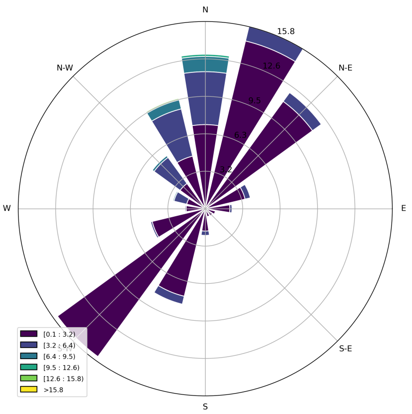


March

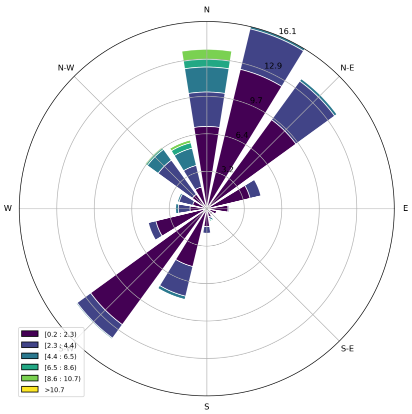
Figure A3: Wind Roses for summer season



April

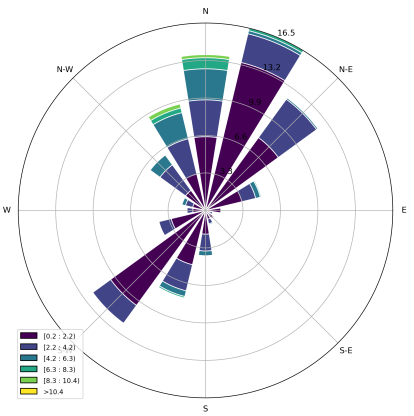


May

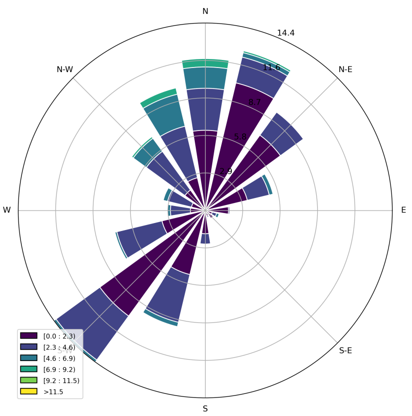


June

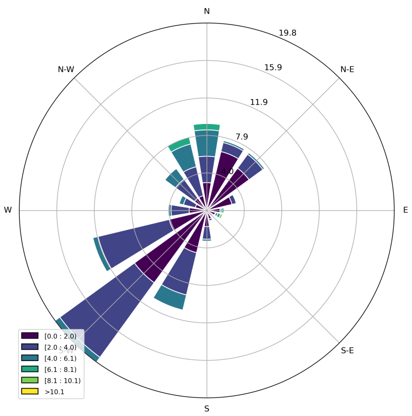
Figure A4: Wind Roses for fall season



July

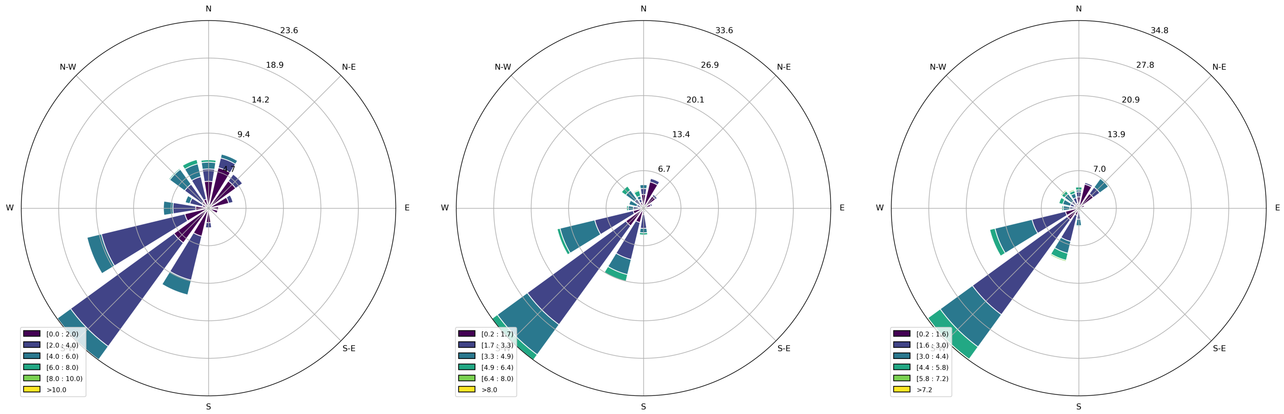


August



September

Figure A5: Wind Roses for winter season



October November December

Figure A6: Wind Roses for spring season

Note: These graphs show the on direction and speed of the wind as roses of wind. The direction of lines indicates from where the winds blow and the color indicates the speed of winds in each direction. Elaborated with *Sistema Nacional del Aire (SINCA)* databases.

Table A2: Rain descriptive statistic

Location:	Mean	SD	Max	Min
Caranpanhue	89.31	88.69	316.00	0.00
Concepcion	83.02	89.65	351.90	0.00
Curanilahue	143.74	149.08	646.50	0.00
Las Quintas	79.83	84.49	374.40	0.00
Las Pataguas	84.77	97.38	606.00	0.00
Ninhue	65.37	81.13	413.10	0.00
Caete	97.07	91.67	370.50	0.00
Laja	73.37	83.24	397.00	0.00
Quillon	73.49	85.94	507.00	0.00
Nueva Aldea	68.70	79.13	341.00	0.00
Dichato	72.79	76.10	281.00	0.00
Coelemu	62.67	77.78	358.10	0.00

Notes: This table shows descriptive statistics of rain precipitation on the twelve climate stations in the Gran Concepcion between the years 2008 and 2018. Statistics are in mm of water. Elaborated with Climate Explorer CR(2) databases.

Table A3: Participation in generation (%) - SEN

Year	Hydro	Coal	Petrolum	Natural gas	Solar	Eolic	Geothermal	Others
2000	47.5%	22.9%	1.2%	25.6%	0.0%	0.0%	0.0%	2.8%
2001	51.8%	14.1%	0.5%	31.5%	0.0%	0.0%	0.0%	2.1%
2002	53.1%	15.2%	0.4%	29.4%	0.0%	0.0%	0.0%	1.9%
2003	48.4%	13.6%	0.5%	35.7%	0.0%	0.0%	0.0%	1.8%
2004	42.9%	18.3%	1.3%	35.8%	0.0%	0.0%	0.0%	1.8%
2005	50.2%	16.7%	6.5%	25.5%	0.0%	0.0%	0.0%	1.1%
2006	52.3%	21.7%	1.1%	22.9%	0.0%	0.0%	0.0%	2.0%
2007	39.8%	25.4%	22.2%	10.4%	0.0%	0.0%	0.0%	2.1%
2008	42.1%	26.2%	24.6%	5.2%	0.0%	0.1%	0.0%	1.7%
2009	43.2%	26.9%	19.2%	8.7%	0.0%	0.1%	0.0%	1.9%
2010	36.4%	30.0%	12.6%	19.5%	0.0%	0.5%	0.0%	1.0%
2011	33.4%	34.2%	12.6%	17.9%	0.0%	0.5%	0.0%	1.4%
2012	30.7%	40.1%	6.3%	19.0%	0.0%	0.6%	0.0%	3.3%
2013	28.8%	45.6%	4.6%	16.5%	0.0%	0.8%	0.0%	3.7%
2014	33.7%	40.6%	4.3%	14.2%	0.7%	2.0%	0.0%	4.6%
2015	33.3%	39.2%	3.0%	15.4%	1.9%	2.9%	0.0%	4.2%
2016	26.5%	43.6%	2.4%	16.4%	3.5%	3.1%	0.0%	4.5%
2017	29.4%	39.6%	1.0%	16.8%	5.3%	4.8%	0.1%	3.1%
2018	30.2%	38.2%	0.4%	15.3%	7.1%	5.2%	0.3%	3.3%
2019	26.9%	36.7%	0.4%	18.5%	8.2%	6.2%	0.3%	2.8%
2020	26.5%	34.7%	0.7%	17.9%	9.8%	7.1%	0.3%	2.9%
2021	20.2%	33.9%	2.3%	17.8%	13.2%	8.8%	0.4%	3.3%

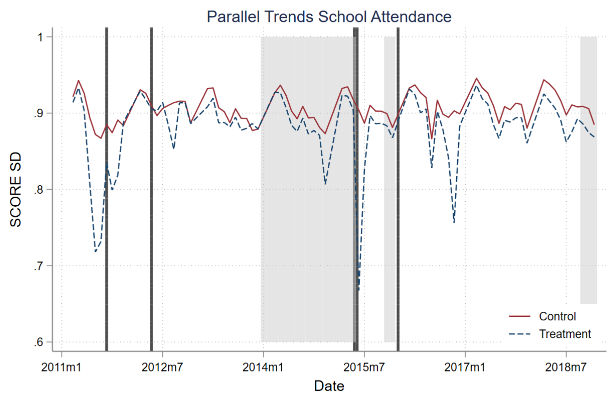
Notes: This table shows the percentual participation in the national grid by each type of generation. Own elaboration based on data from the *Coordinador Eléctrico Nacional*. For the years 2000-2015, the generation in the SING (*Sistema Interconectado del Norte Grande*) and SIC (*Sistema Interconectado Central*) were added.

Table A4: Participation in generation (%) - Bio-Bio region

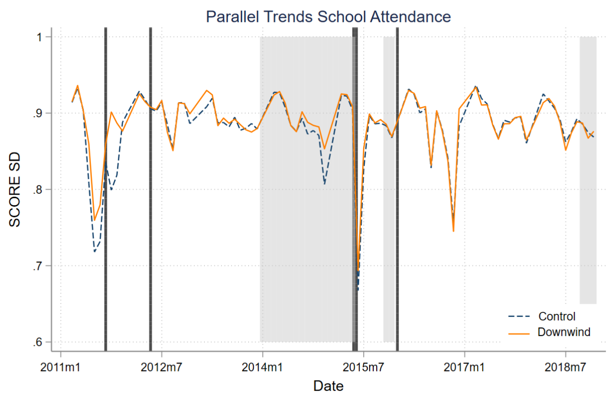
Type	Eolic	Hydraulic	Thermal	Solar
2000	0.0%	79.8%	20.2%	0.0%
2001	0.0%	85.3%	14.7%	0.0%
2002	0.0%	88.6%	11.4%	0.0%
2003	0.0%	90.0%	10.0%	0.0%
2004	0.0%	88.9%	11.1%	0.0%
2005	0.0%	91.8%	8.2%	0.0%
2006	0.0%	89.6%	10.4%	0.0%
2007	0.0%	82.0%	18.0%	0.0%
2008	0.0%	84.5%	15.5%	0.0%
2009	0.0%	86.6%	13.4%	0.0%
2010	0.1%	91.8%	8.1%	0.0%
2011	0.1%	80.0%	20.0%	0.0%
2012	0.1%	61.9%	38.0%	0.0%
2013	0.1%	50.6%	49.3%	0.0%
2014	0.7%	67.3%	32.0%	0.0%
2015	0.8%	67.7%	31.5%	0.0%
2016	1.4%	47.2%	51.4%	0.0%
2017	2.0%	55.5%	42.6%	0.0%
2018	1.7%	57.7%	40.6%	0.0%
2019	2.0%	61.9%	36.1%	0.0%
2020	2.6%	58.5%	38.9%	0.0%
2021	4.7%	46.7%	48.4%	0.2%
2022	7.9%	51.1%	40.7%	0.3%

Notes: This table shows the percent of participation in the regional electric generation according to its source. Own elaboration based on data from the *Coordinador Eléctrico Nacional*.

Figure A7: Average attendance tendency



(a)



(b)

Note: This graph shows the trends of school attendance between the March of 2011 and December of 2018. Periods are in months. Subfigure (a) compares the control and treatment groups while (b) compares the treatment and downwind groups. The study categorizes the treatment group as students who attend schools located within a 10-kilometer radius of any plant, while the control group consists of students attending schools between 50 and 75 kilometers away. The Downwind group is defined as students from the treatment group who study downwind of a plant. The gray areas on the chart indicate dates on which one or more plants have been shutdown, whereas the vertical black lines represent dates on which a plant was opened or reopened. Data were obtained from *Datos Abiertos Mineduc*

Table A5: Chaisemartin & D'Haultfœuille TWFE Bias Test

Treatment:	Positive weights	Negative weigths
4th-Grade		
Lecture SIMCE score:		
Opening	99	0
Generation	129	0
Math SIMCE score:		
Opening	99	0
Generation	130	0
10th-Grade		
Lecture SIMCE score:		
Opening	44	0
Generation	52	0
Math SIMCE score:		
Opening	44	0
Generation	52	0
School attendance		
Shutdown	70	59
Opening	114	11
Generation	204	0

Notes: This table shows the result of the Chaisemartin & D'Haultfœuille TWFE bias test for our treatments on our principal's estimations. The results show biases when are weights assigned to both signs, increasing the bias being greater the parity between them (therefore, a distribution of 50-50% would be the greatest possible bias).

Table A6: General area effects of coal-powered plants on 4th-grade SIMCE score.

	(1)	(2)	(3)	(4)
Panel A: Spanish lecture SIMCE				
[Open]	-0.0121*	0.0552	0.0292	-0.185***
	(0.035)	(0.058)	(0.055)	(0.037)
[Near]	-0.093	-0.093	0	0
	(0.063)	(0.078)	(.)	(.)
[Open]x[Near]	-0.176**	0	0	0.0802
	(0.063)	(.)	(.)	(0.063)
Obs.	34,284	34,284	34,284	15,714
Control Obs.	20,215	20,215	20,215	12,200
Treatment Obs.	14,069	14,069	14,069	7,566
Panel B: Mathematics SIMCE test				
	(1)	(2)	(3)	(4)
[Open]	0.0875*	0.132	-0.0573	0.0204
	(0.037)	(0.067)	(0.06)	(0.045)
[Near]	-0.203*	-0.203*	0	0
	(0.098)	(0.098)	(.)	(.)
[Open]x[Near]	-0.0432	0	0	0.0739
	(0.075)	(.)	(.)	(0.067)
Obs.	34,343	34,343	34,343	15,777
Control Obs.	20,243	20,243	20,243	12,246
Treatment Obs.	14,100	14,100	14,100	7,594
Year FE		X	X	X
School FE			X	X
Controls				X

Notes: Standard errors in parentheses. ** p <0.05, ** p <0.01, *** p <0.001.* This table shows the estimated effects of coal-powered plants opening on 4th-grade SIMCE lecture and mathematic scores in 10 kilometers treatment areas (Panel A and B, respectively) between the years 2008 and 2013. Effects are displayed as standard deviations from the mean score. Column 1 includes only school-fixed effects, column 2 includes school and year-fixed effects, and column 3 includes both fixed effects and controls. Control variables include characteristics from their school, parents, teachers, and students.

Table A7: General area effects of coal-powered plants on 10th-grade SIMCE scores.

	(1)	(2)	(3)	(4)	(5)
Panel A: Spanish languague SIMCE test					
[Near]	0.0762	0.0764	0	0	0
	(0.129)	(0.13)	(.)	(.)	(.)
[Open]	-0.0457	0.0303	0.237***	0.298**	0.427***
	(0.0406)	(0.0993)	(0.0594)	(0.0853)	(0.107)
[Open]x[Near]	-0.049	-0.0527	-0.0594	0.00404	-0.0482
	(0.0679)	(0.0669)	(0.0495)	(0.0532)	(0.0881)
Obs.	36,709	36,709	36,709	17,341	7,783
Control Obs.	19,957	19,957	19,957	9,542	4,490
Treatment Obs.	16,752	16,752	16,752	7,799	3,293
Panel A: Mathematics SIMCE test					
[Near]	0.0284	0.027	0	0	0
	(0.161)	(0.157)	(.)	(.)	(.)
[Open]	0.0698	-0.188	0.0729	0.188*	0.184
	(0.0426)	(0.108)	(0.0579)	(0.0873)	(0.0956)
[Open]x[Near]	-0.0369	-0.0297	-0.0478	0.0317	-0.097
	(0.0643)	(0.0646)	(0.0395)	(0.0938)	(0.121)
Obs.	36,903	36,903	36,903	15,025	6,429
Control Obs.	20,105	20,105	20,105	8,130	3,509
Treatment Obs.	16,798	16,798	16,798	6,895	2,886
Year FE		X	X	X	X
School FE			X	X	X
Controls				X	X
Past Scores					X

Notes: Standard errors in parentheses. ** p <0.05, ** p <0.01, *** p <0.001.* This table shows the estimated effects of coal-powered plants opening on 10th-grade SIMCE lecture and mathematic scores in 10 kilometers treatment areas (Panel A and B, respectively) between the years 2008 and 2018. Effects are displayed as standard deviations from the mean score. Variables included in each estimation are indicated in the panel below Panel B with an ex (X). Control variables include characteristics from their school, parents, teachers, and their gender. Past scores are from 4th-grade SIMCE scores.

Table A8: General area effects of coal-powered generation on 4th-grade SIMCE score.

	(1)	(2)	(3)	(4)
Panel A: Spanish lecture SIMCE test				
[Near]	-0.054	-0.055	0	0
	(0.063)	(0.063)	(.)	(.)
[Generation]	-0.0190	0.0315	0.0202	-0.0292
	(0.025)	(0.026)	(0.027)	(0.032)
[Near]x[Generation]	-0.0101	-0.00909	-0.0202	-0.00878
	(0.037)	(0.037)	(0.037)	(0.039)
Obs.	29,659	29,659	29,659	15,714
Control Obs.	17,517	17,517	17,517	9,636
Treatment Obs.	12,142	12,142	12,142	6,078
Panel B: Mathematic SIMCE test				
[Near]	-0.145	-0.145	0	0
	(0.0809)	(0.0799)	(.)	(.)
[Generation]	0.0911**	0.142***	0.133***	0.0219
	(0.028)	(0.032)	(0.033)	(0.036)
[Near]x[Generation]	0.00044	0.000855	-0.0164	-0.0181
	(0.048)	(0.047)	(0.047)	(0.045)
Obs.	29,676	29,676	29,676	15,777
Control Obs.	17,527	17,527	17,527	9,671
Treatment Obs.	12,149	12,149	12,149	6,106
Year FE		X	X	X
School FE			X	X
Controls				X

Notes: Standard errors in parentheses. ** p <0.05, ** p <0.01, *** p <0.001.* This table shows the estimated effects of coal-powered plants generation on terawatts (TW) levels on 4th-grade SIMCE lecture and mathematic scores in 10 kilometers treatment areas (Panel A and B, respectively) between the years 2008 and 2013. Effects are displayed as standard deviations from the mean score. Columns 1 and 4 include only school fixed effects, columns 2 and 5 include school and year fixed effects, and columns 3 and 6 include both fixed effects and controls. Control variables include characteristics from their school, parents, teachers, and students.

Table A9: General area effects of coal-powered generation on 10th-grade SIMCE score.

	(1)	(2)	(3)	(4)	(5)
Panel A: Spanish language SIMCE test					
[Near]	0.065	0.0674	0	0	0
	(0.127)	(0.126)	(.)	(.)	(.)
[Generation]	-0.0509	0.00675	-0.0629	-0.110*	0.267**
	(0.0322)	(0.0496)	(0.0488)	(0.0512)	(0.0789)
[Near]x[Generation]	-0.0208	-0.0227	-0.0609	0.00311	-0.0714
	(0.0505)	(0.0501)	(0.0355)	(0.0403)	(0.065)
Obs.	36,709	36,709	36,709	17,341	7,783
Control Obs.	19,957	19,957	19,957	9,542	4,490
Treatment Obs.	16,752	16,752	16,752	7,799	3,293
Panel B: Mathematic SIMCE test					
[Near]	-0.0337	-0.0289	0	0	0
	(0.145)	(0.141)	(.)	(.)	(.)
[Generation]	0.0435	0.169**	0.0707	-0.0272	-1.693**
	(0.0293)	(0.0526)	(0.0487)	(0.0567)	(0.513)
[Near]x[Generation]	0.024	0.0221	-0.0289	-0.00442	-0.0831
	(0.054)	(0.0531)	(0.0296)	(0.0635)	(0.131)
Obs.	36,903	36,903	36,903	15,025	6,429
Control Obs.	20,105	20,105	20,105	8,130	3,509
Treatment Obs.	16,798	16,798	16,798	6,895	2,886
Year FE		X	X	X	X
School FE			X	X	X
Controls				X	X
Past scores					X

Notes: Standard errors in parentheses. ** p <0.05, ** p <0.01, *** p <0.001.* This table shows the estimated effects of coal-powered plant generation on 10th-grade SIMCE lecture and mathematic scores in 10 kilometers treatment areas (Panel A and B, respectively) between the years 2008 and 2018. Effects are displayed as standard deviations from the mean score. Variables included in each estimation are indicated in the panel below Panel B with an ex (X). Control variables include characteristics from their school, parents, teachers, and their gender. Past scores are included in controls and are from 4th-grade SIMCE scores.

Table A10: General area effects of coal-powered opening/shutdown on school attendance.

	(1)	(2)	(3)	(4)
Panel A: Treatment area 5 km				
[Near]	-0.0343***	0	-0.0198***	-0.0166***
	(0.00024)	(.)	(0.0039)	(0.00389)
[Shutdown]	-0.00425***	-0.0007	0.00045	0.00200***
	(0.000276)	(0.000408)	(0.00036)	(0.000363)
[Opening]	-0.0122***	-0.0130***	-0.0121***	-0.0126***
	(0.000432)	(0.000463)	(0.000407)	(0.000406)
[Close]x[Near]	0.0120***	0.0103***	0.00776***	0.00741***
	(0.000466)	(0.000449)	(0.000404)	(0.000403)
[Opening]x[Near]	-0.0274***	-0.0288***	-0.0326***	-0.0322***
	(0.000727)	(0.000701)	(0.000618)	(0.000616)
Obs.	4,022,159	4,022,159	4,022,159	4,022,027
Control obs.	2,627,375	2,627,375	2,627,375	2,627,243
Treated obs.	1,394,784	1,394,784	1,394,784	1,394,784
Panel B: Treatment area 10 km				
[Near]	-0.0291***	0	-0.0156***	-0.0109***
	(0.000213)	(.)	(0.00329)	(0.00329)
[Shutdown]	-0.00425***	-0.0007	0.00228***	0.00306***
	(0.00028)	(0.000394)	(0.00035)	(0.000352)
[Opening]	-0.0122***	-0.0127***	-0.0118***	-0.0124***
	(0.000439)	(0.000462)	(0.000409)	(0.000407)
[Near]x[Shutdown]	0.0118***	0.0108***	0.00476***	0.00501***
	(0.000415)	(0.000398)	(0.00036)	(0.000359)
[Near]x[Opening]	-0.0159***	-0.0184***	-0.0222***	-0.0218***
	(0.000648)	(0.000623)	(0.000553)	(0.000551)
Obs.	4,803,193	4,803,193	4,803,193	4,803,061
Control obs.	2,627,375	2,627,375	2,627,375	2,627,243
Treated obs.	2,175,818	2,175,818	2,175,818	2,175,818
Time FE		X	X	X
Student FE			X	X
Controls				X

Notes: Standard errors in parentheses. ** p <0.05, ** p <0.01, *** p <0.001.* This table shows the estimated effects of coal-powered plant opening and shutdown on school attendance in 5 and 10 kilometers treatment areas (Panel A and B, respectively) between the years 2011 and 2018. These are short-term effects (same month of the treatment) and are shown as percentage points. Variables included in each estimation are indicated in the panel below Panel B with an ex (X). Control variables include characteristics from their school, parents, teachers, and their gender.

Table A11: General area effects of coal-powered generation on school attendance.

	(1)	(2)	(3)	(4)
Panel A: Treatment area 5 km				
[Near]	-0.0421	0	-0.0248*	-0.0207
	(0.0261)	(.)	(0.0124)	(0.0127)
[Generation]	0.0332***	0.00459	0.00102	4.26E-06
	(0.00897)	(0.0123)	(0.00623)	(0.00643)
[Near]x[Generation]	0.0244	0.017	0.0121	0.00894
	(0.038)	(0.037)	(0.0144)	(0.0163)
Obs.	4,022,159	4,022,159	4,022,159	4,022,027
Control obs.	2,627,375	2,627,375	2,627,375	2,627,343
Treated obs.	1,394,784	1,394,784	1,394,784	1,394,784
Panel B: Treatment area 10 km				
[Near]	-0.0426*	0	-0.0219*	-0.0173
	(0.0199)	(.)	(0.0104)	(0.0107)
[Generation]	0.0332***	-0.0164	-0.0117	-0.0088
	(0.00897)	(0.0158)	(0.00937)	(0.00941)
[Near]x[Generation]	0.044	0.0382	0.0161	0.0168
	(0.0298)	(0.0291)	(0.0128)	(0.0139)
Obs.	4,803,193	4,803,193	4,803,193	4,803,061
Control obs.	2,627,375	2,627,375	2,627,375	2,627,243
Treated obs.	2,175,818	2,175,818	2,175,818	2,175,818
Time FE		X	X	X
Student FE			X	X
Controls				X

Notes: Standard errors in parentheses. ** p <0.05, ** p <0.01, *** p <0.001.* This table shows the estimated effects of coal-powered plant generation in terawatts levels on school attendance in 5 and 10 kilometers treatment areas (Panel A and B, respectively) between the years 2011 and 2018. These are short-term effects (same month of the treatment) and are shown as percentage points. Variables included in each estimation are indicated in the panel below Panel B with an ex (X). Control variables include characteristics from their school, parents, teachers, and their gender.

Table A12: Effects of coal-powered plants on school attendance (by distance to plant).

Area	**5 km**	**10 km**	**25 km**	**50 km**
Panel A: Shutdown/Opening				
[Shutdown]x[Near]x[Downwind]	0.0225***	0.00173*	-0.00468***	-0.00639***
	(0.00286)	(0.000866)	(0.000768)	(0.000703)
[Opening]x[Near]x[Downwind]	-0.0339***	-0.0188***	-0.0135***	-0.00915***
	(0.00428)	(0.00132)	(0.00118)	(0.00108)
Obs.	2,507,079	3,288,113	7,491,924	1.26E+07
Control obs.	1,703,392	1,703,392	1,703,392	1,670,091
Treated obs.	803,687	1,583,721	5,788,532	1.92E+07
Panel B: Generation (TW)				
[Generation]x[Near]x[Downwind]	-0.0932***	-0.0878**	-0.0851***	-0.0846***
	(0.021)	(0.0296)	(0.025)	(0.0202)
Obs.	2,507,079	3,288,113	7,491,924	1.26E+07
Control obs.	1,703,392	1,703,392	1,703,392	1,670,091
Treated obs.	803,687	1,583,721	5,788,532	1.92E+07

Notes: Standard errors in parentheses. ** $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.* This table shows the estimated effects of coal-powered plant generation in terawatts levels on four treatment area levels (5, 10, 25, and 50 kilometers) between the years 2011 and 2018. These are short-term effects (same month of the treatment) and are shown as percentage points. Panel A shows estimation with the plant being shutdown or opened as the treatment variable, and Panel B shows the results of estimation with plant generation as the treatment variable. All estimations have month, year, and student-fixed effects and controls. Control variables include characteristics from their school, parents, teachers, and their gender.

Table A13: Effects of coal-powered plants on school attendance (by plant).

Area	**25 km**	**50 km**
Panel A: Generation		
Santa María	0.00267	-0.121***
	(0.0547)	(0.0343)
Bocamina's	0.0429***	-0.00711
	(0.0105)	(0.0164)
Obs.	1.01e+07	1.01e+07
Panel B: Shutdown/Opening		
SHUTDOWN:		
Santa María	-0.00502	0.0233
	(0.0181)	(0.0135)
Bocamina I	-0.00925	-0.0106
	(0.00738)	(0.00902)
Bocamina II	0.006	0.0146*
	(0.00683)	(0.00598)
OPENING:		
Santa María	-0.0451*	0.0342
	(0.0197)	(0.0364)
Bocamina I	-0.0194*	-0.00956
	(0.00795)	(0.00634)
Bocamina II	0.00985	0.0278
	(0.00834)	(0.0149)
Obs.	1.00e+07	1.00e+07

Notes: Standard errors in parentheses. ** $p<0.05$, ** $p<0.01$, *** $p<0.001$.* This table shows the estimated effects of each coal-powered plant in "Gran Concepcion" on attendance in four treatment area levels (5, 10, 25, and 50 kilometers) between the years 2011 and 2018. These are short-term effects (same month of the treatment) and are shown as percentage points. Panel A shows estimation with the plant being shutdown or opened as the treatment variable, and Panel B shows the results of estimation with plant generation as the treatment variable. All estimations have a month, year, and student-fixed effects and controls. Control variables include characteristics from their school, parents, teachers, and their gender.