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Air Quality-Related Health and Environmental Trade-off of Electrification: Evidence from Vietnam

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Abstract

Abundant evidence has shown that expanding access to electricity dramatically widens access to education, healthcare, and equality. However, the literature on the direct impacts of electrification on air quality and health is still in its infancy. While electricity access can lead to higher outdoor air pollution due to increased reliance on fossil fuel combustion, its usage lowers indoor air pollution as households switch from burning solid fuels to using electricity and become distanced from the source of pollution. Contributing to the nascent literature, this article represents the first quantitative examination of this trade-off between the overall emission level and the degree of population exposure to pollution due to electrification. The study draws on the representative Vietnam Household Living Standards Surveys to examine environmental and health outcomes and estimates a satellite-based measure of commune electrification rate using the DMSP/OLS nighttime satellite images and Landscan population grid. I find that although electrification increases the probability that air pollution is among the most pressing environmental issues in a commune, it reduces the probability that a commune reports air quality-related illnesses as one of its top three main health concerns. Thus, as hypothesized, this paper presents evidence that electrification alleviates air pollution-related health problems even as it worsens outdoor air quality.

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1 Introduction

In recent decades, universal access to electricity has emerged as an aspiration for developing countries to eradicate poverty, alleviate gender inequality, and bridge the gap between urban and rural areas. Recognizing the immense benefits of electrification early on, the Vietnamese government has rigorously committed to extending the electrical grid to every household in the country during the past two decades. From the starting point of 14% in 1993, Vietnam has reached 99% rural electrification in 2018, achieving one of the highest electrification rates among developing countries worldwide.[1] Thus, the country's rapid success in widening electricity access provides an insightful preview of what to expect for other developing countries seeking to eliminate their access deficits. According to the Tracking SDG 7: The Energy Progress Report (2020), 789 million people worldwide lack access to electricity in 2018, 78% of whom concentrate in 20 countries with the lowest electrification rates. The report further estimates that by 2030, 620 million people will still live without electricity.

While the pronounced economic gains of grid connectivity are well-established, little attention has been paid to its potentially large impacts on air quality and consequently health. This is particularly important as, according to the World Health Organization (2014), air pollution is responsible for seven million premature deaths every year primarily from respiratory and cardiovascular diseases.[2] Cohen et al. (2017) attributes an annual loss of 103 million disability-adjusted life-years (DALYs) or 4.2% of global DALYs to air pollution in 2015, making it the world's most threatening environmental health risk. In particular, household indoor air pollution (IAP)

[1]"Country Director of World Bank in Viet Nam: 'Rural Electrification in Viet Nam Is a Miracle'." Vietnam Electricity (EVN).

[2]"7 Million Premature Deaths Annually Linked to Air Pollution." World Health Organization. World Health Organization, March 25, 2014. https://www.who.int/mediacentre/news/releases/2014/air-pollution/en/.

poses one of the greatest health concerns in developing countries, whose vast populations rely on cheap and locally-available solid fuels for indoor heating, cooking, or lighting (Duflo, Greenstone, and Hanna, 2008; Fullerton, Bruce, and Gordon, 2008). As of 2018, 2.8 billion people remain without access to clean fuels and technologies for cooking (SDG 7).

Grid extension directly impacts air quality and human health through two conflicting routes. Electrification increases the access and demand for fossil fuel-based electricity but also enables the gradual transition away from indoor combustion of biomass fuels such as wood, effectively distancing households from the source of air pollution. While the former implies an increase in outdoor air pollution at the local and national levels, the latter entails reductions in the exposure to indoor air pollution at the household level. This trade-off between the overall emission levels and the population exposure to pollution indicates that there are potential health gains from electrification.

Understanding the effects of electrification on health outcomes in Vietnam, where electrification is complete, can help inform policymakers in other developing countries, who are considering investing in extending electricity access. While there is a growing literature on the economic benefits of electrification, few studies have devoted attention to the direct health consequences of electrification. This is due to the scarcity of publicly available micro-level data on air quality measurement, health, and electrification rates - an especially germane issue for developing countries (Pinder et al. 2019).

In this study, I overcome the data constraint in two ways. First, I estimate the electrification progress of Vietnamese communes by combining the satellite-based remote sensing and population distribution data as done in Elvidge et al. (2011). Second, given the absence of air quality monitoring and traditional health data such as mortality or hospital admission statistics in Vietnam, I utilize representative longitudinal surveys to construct indicators of air quality and air quality-related health status. As hypothesized, this paper demonstrates that although electrification increases the overall emission level, it also yields air quality-related health gains due to lower population exposure to pollution.

The paper proceeds as follows: Section 2 provides a literature review on the socioeconomic consequences of electrification, Section 3 discusses the data and summary statistics, Section 4 presents my empirical strategy, and Section 5 shows the estimation results.

2 Literature Review

This section provides a brief review of the existing literature on the socioeconomic outcomes of electrification and discusses the contributions of this study to the literature.

The growing body of both qualitative and quantitative research on access to electricity has primarily focused on the welfare improvements in rural economies of developing countries. Indeed, empirical evidence suggests that grid expansion substantially raises rural per-capita income and expenditures (Khandker et al., 2013; Khandker et al., 2014), encourages female and, to a lesser extent, male employment and working hours (Dinkelman, 2011; Khandker et al., 2014), while improving educational attainment including children's school attendance, years of education, and literacy rate (Khandker et al., 2013, Khandker et al., 2014; Kanagawa and Nakata, 2008). A small margin of the recent literature extends the question to examine the advancements in health-related outcomes. Chen et al. (2019) suggest that reliable electricity access substantially improves the equipment and infrastructure of health centers while raising the likelihood that children and pregnant women acquire vaccinations and antenatal care. In line with Chen et al. (2019), Esteban et al. (2018) find that electricity access leads to a higher percentage of the population with healthcare affiliation. Both studies examine the connection between electricity access and health utilization and provision. However, these measures of health treatment, though important, neglect the consequential impacts of electrification on the causes of health issues, particularly its effects on air quality, and thus, air pollution-related illnesses. I am only aware of two studies that examine the relationship between electrification and air quality-related health.

Investigating the impacts of an electrification program on IAP and children's health in northern El Salvador, Barron and Torero (2017) conduct a randomized encouragement experiment by randomly assigning grid-connection discount vouchers to households. After two years of the implementation of the electrification program, the encouraged groups who received the discount vouchers observe a 19% increase in grid connectivity, a 66% reduction in overnight particulate matter 2.5 ($PM_{2.5}$) concentration in the main living household area, and 8 - 14% fewer children with acute respiratory illnesses compared to the households who did not receive vouchers. As the first experimental study that examines the relationship between electrification and IAP, Barron and Torero (2017) serves to fill the huge gap in the literature on the health impacts of grid expansion; however, as the scope of the study is limited to only two areas in the whole nation, the research does not take into account the possible trade-offs between indoor and outdoor air pollution in the context of electrification previously discussed.

Spalding-Fecher (2005) presents the first cost-benefit analysis of electrification at the national level. He develops a framework to evaluate changes in fuel consumption patterns and the consequential health benefits stemming from the 1999 South African National Electrification Programme using the "benefit-transfer" method. When comparing the study's estimated health benefits from reduced household-level combustion of solid fuels to the localized health costs from coal-based electricity generation in the existing literature, the study finds that the magnitude of the health benefits is only slightly lower than the size of the costs. Thus, Spalding-Fecher (2005) demonstrates that electrification, indeed, yields substantial improvements in health that may even justify the increased use of coal. However, to facilitate the analysis, Spalding-Fecher (2005) relies on a wide range of strong assumptions that can significantly alter the outcome estimates and thus, lower the adaptability of the established framework. For instance, to unravel the "ceteris paribus" changes in fuel consumption patterns as a result of grid connectivity, Spalding-Fecher (2005) simply compares the amounts of fuels consumed between connected and unconnected households on the premise that income and price changes would be held constant. However, there are potential issues of unobserved endogeneity between connected and unconnected households using this method, which can exacerbate the observed differences and consequently, overestimate the health benefits of electrification. More importantly, Spalding-Fecher (2005) does not establish a relationship between electrification and health, as he attributes all increases in coal-based electricity generation and decreases in household solid fuel consumptions to electrification; however, there could be other factors unrelated to electrification that induces these outcomes. For instance, frequent wildfire impeding households from acquiring woods may lead to not only lower household solid fuel consumption, but also greater reliance on electricity.

Thus, it is clear where the literature on electricity access excels and where it falls short. The body of research generally agrees that electrification alleviates rural poverty, reduces social inequality, and enhances educational outcomes across countries. However, the overriding focus on economic development has led to the neglect of health outcomes associated with electrification. Among those that do make the connection between health and electrification, only a handful of studies examine the direct impacts of electrification on air-quality related health. Rather than attempting to weigh the health costs and benefits of electrification, which can be problematic, my study aims to isolate the causal impacts of electrification on air pollution-related health concerns, and thus complements and expands on Barron and Torero (2017). My research augments and fits into the current literature in four ways. First, I provide the first quantitative assessment of the trade-offs between population exposure and overall emission from electrification. Second, my work contributes to the underexplored question of the direct effects of grid connectivity on health. Third, my longitudinal national data allows for more robust findings than most of the data employed by past studies, which often rely on limited samples of electrified households (Barron and Torero, 2017) or short-term surveys (Khandker et al., 2013) that may not capture the spillover effects of electrification and gradual transition of fuel consumption pattern over time. Lastly, by taking steps to solve the data scarcity problem, my study helps fill in the gap in the literature on the micro-level impacts of electrification on air quality and health.

3 Data and Summary Statistics

This study employs representative commune-level data to explore the trade-offs between air pollution and population exposure from electrification. I further utilize spatial data to complement the commune data and construct more robust and accurate measures of electrification progress. This section discusses data sources and provides descriptive statistics.

3.1 Vietnam Household Living Standards Surveys

This research utilizes the ongoing longitudinal biennial Vietnam Household Living Standard Survey (VHLSS) from 2004 to 2008, conducted by the General Statistics Office (GSO) of Vietnam with the aim of examining living standards and socioeconomic factors across regions at both the household and commune-level. The VHLSSs between 2004 and 2008 sample from the Population and Housing Census 1999 using a two-stage sampling design with commune as the primary sampling unit and the enumerated areas (EAs) in the Census as the secondary sampling unit. Commune is the smallest subdivision in Vietnam with population ranging between 5,493 and 79,658. The mean commune has a population of 8191 and the median commune has a population of 9104. Although households are the third stage sampling units, the sampling design is still effectively two-stage, as only one EA per commune is selected and 50% of the EAs are rotated in each wave. The probability of being sampled for communes and EAs is proportional to the number of households within the sampling unit (ISM and SINFONICA, 2015; GSO, 2017). Thus, the sample surveyed is representative of the population. Although the VHLSS comprises three main questionnaires: the short and long household questionnaires and the commune questionnaire, this work primarily draws on the commune dataset, which spans from the commune's general characteristics, economic factors, employment, infrastructure and transportation, education, health, social issues, to credit/savings.

I construct binary outcome variables using the VHLSS questions to study communes' health and environmental outcomes. To investigate changes in population exposure to air pollution, I utilize the survey question which asks the respondent to select the top three main health concerns, in order of importance, from a list of 17 possibilities. The "Disease 1", "Disease 2^{+}", and "Disease 3^{+}" dummy variables are assigned a value of one if a commune reports at least one air quality-related illness in their top one, top two, top three health concerns, respectively, in a given year. I define air quality-related illnesses to consist of cardiovascular, tuberculosis, and other respiratory illnesses based on the findings of the World Health Organization (WHO) report, *Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks*. I select the three health concerns as the report suggests that the main environmental intervention areas of cardiovascular, tuberculosis, and other respiratory illnesses include household and/or ambient air pollution. Further, to study the changes in the overall emission levels, I construct the Air Pollution dummy that has a value of one if a commune reports having pressing air quality concerns.

The survey also contains two questions on communes' electrification status, including whether the commune has access to electricity and whether its electricity originates from the national grid. However, I encounter a number of issues while utilizing these indicators to examine electrification progress. First, a large number of connected communes exhibit no variation in electrification status over the study period and, therefore, get necessarily dropped when controlling for commune fixed effects. Further, while a commune's grid access predates household's grid access (Khandker et al., 2013), connection to the grid at the commune level does not guarantee that every household within the commune is connected, nor does it reflect the extent to which households are using electricity. Thus, I reserve these two binary variables as robustness checks rather than including them in my main specifications.

3.2 Satellite-Based Measure of Electrification Rate

Publicly available cloud-free nighttime satellite imagery provided by the Defense Meteorological Satellite Program's Operational Linescan System (DMSP-OLS) offers a more dynamic measure of electrification progress at the subnational units. The DMSP-OLS data assigns each pixel cell a digital number (DN), ranging between 0 and 63 to reflect nighttime light brightness. Nightlight values have been extensively used in social science research to measure numerous aspects of economic activity and social welfare such as gross domestic product, poverty, and electrification rate (Ghosh et al., 2013, Zhao et al. 2019). Several studies have validated the use of

DMSP nighttime light values as proxies for electrification at the subnational levels. Min and Gaba (2014) finds a one-point increase in the nightlight value is associated with 240 to 270 additional electrified households in Vietnam. Dugoua, Kennedy, and Urpelainen (2017) contend that nightlight values accurately capture rural electrification, but fall short as a proxy for other socioeconomic outcomes. Incorporating the US Department of Energy Landscan population grid into the satellite imagery, Elvidge et al. (2011) estimate the number of people without electricity access to be 1.62 billion, an estimate close to the International Energy Agency's figure of 1.58 billion.

In this paper, I follow Elvidge et al. (2011) and replicate their electrification rate measure. They define the electrification rate to be the fraction of the population with DMSP nightlight values greater than one [3] and combine the DMSP nighttime imagery with the Landscan grid to estimate the satellite-based measure of electrification. The DMSP-OLS and Landscan data are particularly compatible as they share the spatial resolution of 30 arc-second (approximately 1 km) grids. I layerize and overlay the nighttime imagery over the Landscan population grid to calculate the number of people with detected positive nightlight. I further use the Database of Global Administrative Areas (GADM) boundary data to extract the total population and population with nightlight in each commune. Finally, dividing the population with positive nightlight values to the total population provides the commune electrification rate.

Figure 1 displays the DMSP nightlight values while Figure 2 shows the Landscan population distribution of Vietnam for 2004, 2006, and 2008. Indeed, the concentration of people and light are synchronous. Hanoi located in Northern Vietnam and Ho Chi Minh in Southern Vietnam are not only the most populous but also the "brightest" cities of the country with high nightlight value. Light and high popula-

[3] Population Electrification Rate (%)= (Population with DMSP lighting)/(Total Population) x 100

tion density are also detected along the coastline.

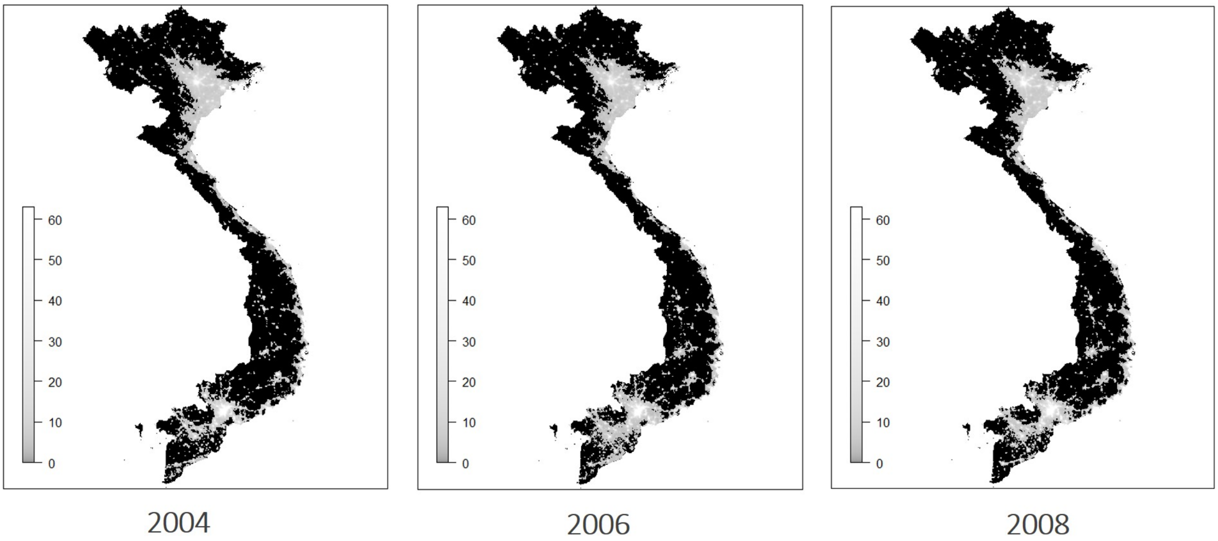

Figure 1: DMSP-OLS Nightlight Imagery for Vietnam (2004 - 2008)

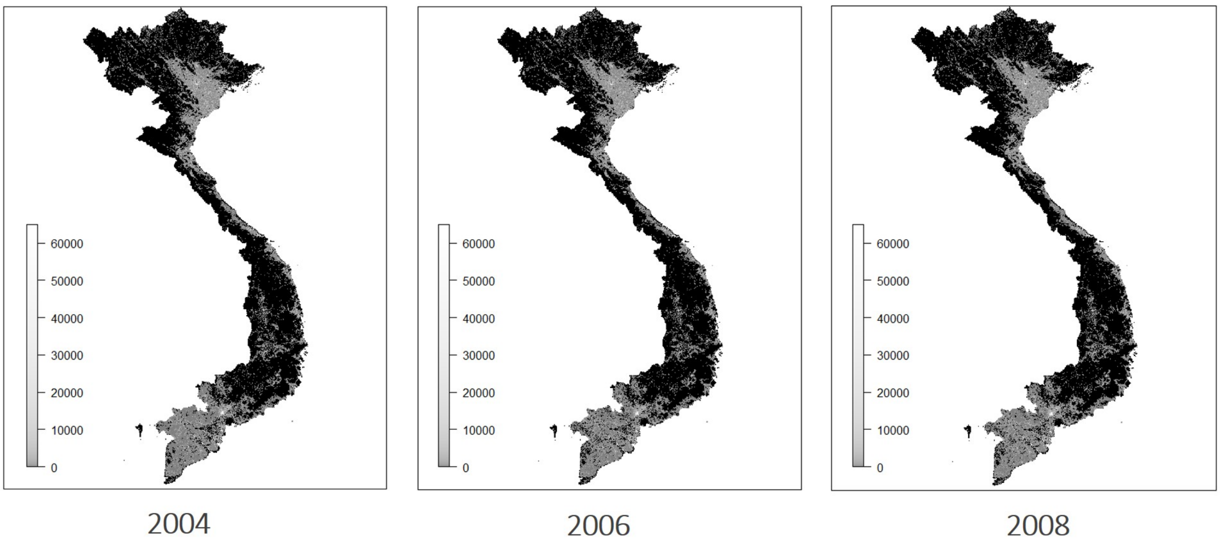

Figure 2: Landscan Population Distribution for Vietnam (2004 - 2008)

3.3 Summary statistics

Table 1 presents the summary statistics for the variables used in this study. After merging across waves, I retain 1821 communes, which represent roughly 16.5% of the total communes in Vietnam. The survey data indicates that around one-third of communes list air quality-related illnesses as the number one main health concern and two-thirds list them among their top three health concerns. We also see a general upward trend in the fraction of air quality-related health concerns over time. The survey question used to construct the Air Pollution dummy was not included in the survey until 2008 and thus, was not available in the 2004 and 2006 waves of the VHLSS. Around 15.2% of communes in my sample report that air pollution is a pressing environmental issue they face. Lastly, satellite-based estimates of commune electrification rates range between 75.7% and 77.9%. It is unclear why the electrification rate decreased in 2008; however, this reduction is consistent with the aggregate estimates published in the World Bank World Development Indicators.

4 Empirical Strategy

This section describes the empirical strategy used to investigate the effects of electrification on total emission levels and population exposure to pollution.

4.1 Air Quality-Related Health Concerns (Population Exposure)

A salient challenge in examining the effects of grid extension lies in the initial non-random selection process that determines which communes gain early access to the grid. For instance, to facilitate grid extension, connected communes may tend to be those located near the national grid or more developed communes. Thus, unobserved endogeneity stemming from systematic differences between electrified and

Variables	Description	2004	2006	2008
1. Population Exposure & Overall Emission				
Disease 1^{+}	dummy variable denotes 1 if air quality-related illnesses are listed as the number one health concern, 0 otherwise	32.2%	33.1%	35.2%
Disease 2^{+}	dummy variable denotes 1 if air quality-related illnesses are listed in the top 2 main health concerns, 0 otherwise	49.5%	49.1%	51.9%
Disease 3^{+}	dummy variable denotes 1 if air quality-related illnesses are listed in the top 3 main health concerns, 0 otherwise	64.4%	62.3%	67.3%
Air Pollution	dummy variable denotes 1 if air pollution is the most or one of the most important environmental issues	NA	NA	15.2%
2. Electrification Progress				
Electrification Rate	fraction of population with DMSP lighting (%)	75.7%	77.9%	74.6%
3. Commune Characteristics				
Percent Poor Household	Percent poor households (according to HEPR)	8.97%	17.9%	13.4%
Density	Population/Total land area	662.4	660.1	662.6
Households received credits or loans	Number of households received credits/loans from social support programs in the previous year	206.8	225.7	249.0
People received school fees reduction	Number of people received exemption or reduction in school fees from social support programs in the previous year (excluding exemption for primary school pupils)	150.9	166.5	154.6
People received hospital fees reduction	Number of people received exemption or reduction in hospital fees from social support programs in the previous year	414.2	649.8	650.6
People received regular social assistance	Number of people receive regular social assistance	53.9	57.2	73.8
Daily wage to prepare land (1000 VND)	Daily wage to prepare land for a male farm worker (thousand VND)	26.8	35.2	56.5
Agricultural extension agents visit	Times agricultural extension agents visited/contacted the farmers in the last 12 months	8.5	8.3	9.2
Log of crop land area	Log of annual crop land area	2.7	2.7	2.7
Log of residential land area	Log of residential land area	1.7	1.7	1.7

Table 1: Summary Statistics

unelectrified communes can confound the impacts of electrification on health. Taking advantage of the panel data to account for the possible time-invariant bias, I apply a commune and year fixed effects (FE) linear probability model (LPM) to estimate the effects of commune-level electricity access on air quality-related health concerns between 2004, 2006, and 2008. The two-way FE control for individual commune's time-invariant traits and overtime trends.

With the aim of examining variations in population exposure to air pollution due to electrification, my empirical model is expressed as follows:

$$Disease_{it} = \beta_0 + \beta_1 Electrification_{it} + \beta_{it}\bar{X}_{it} + \lambda_i + \lambda_t + \epsilon_{it} \tag{1}$$

where $Disease_{it}$ denotes 1 if air quality-related illnesses are listed among the main health concern(s) of commune i in year t, 0 otherwise; $Electrification_{it}$ is the share of the population with positive nightlight value in commune i in year t; $\bar{X}_{it}$ is a vector for observable commune socio-economics characteristics; λ_i and λ_t are commune and year fixed effects, respectively; ϵ_{it} is the idiosyncratic error term.

The outcome variables of interest are dummy variables indicating whether or not air quality-related diseases are listed as one of the commune's top one, two, and three health concerns. This outcome variable has obvious shortcomings as the most pressing health concern in one commune may pose a relatively lesser issue in another commune even though the severity of the disease across the two communes are similar in absolute terms. However, these outcome variables also alleviate some of the issues associated with time-varying unobserved heterogeneity. For instance, evidence suggests that electrification yields improvements in health facilities and utilization (Chen et al., 2019; Esteban et al., 2018). However, improvements in health provisions do not only yield air quality-related health benefits but also health gains across all diseases. Thus, a regression of electrification on, say, air quality-related mortality, may pick up some of the omitted impacts of better health provision on air quality-related deaths and overestimate the estimated effects of electrification. In such cases, my outcome variables can mitigate issues with omitted variable bias, since changes in the top main health concerns likely stem from factors that disproportionately impact some diseases rather than those that affect all diseases. Therefore, the top three health concerns of the commune should not vary with higher quality health provision or changes in other time-variant variables that do not disproportionately affect one health concern over another.

4.2 Air Quality Concern (Overall Emission)

I now describe the empirical strategy to investigate the variations in air quality from extending electricity. As the survey question used to examine changes in commune air quality is only available for 2008, using commmune fixed effects are no longer possible. Instead, I use district and geography fixed effects to mitigate issues with omitted variable bias and control for unobserved differences between districts and communes' geographical characteristics. Geography characteristics include coastal, inland delta, hills/midlands, low mountains, and high mountains. Specifically, I estimate:

$$AirPollution_i = \alpha_0 + \alpha_1 Electrification_i + \alpha_i \bar{X}_i + \lambda_d + \lambda_g + \varepsilon_i \tag{2}$$

where $AirPollution_i$ denotes air pollution is the most or among the most pressing environmental concerns for commune i in 2008, 0 otherwise; $Electrification_i$ is the share of the population with positive nightlight value in a commune i in 2008; $\bar{X}_i$ is a vector for observable commune socio-economic characteristics; and λ_d and λ_g are district and geography fixed effects, respectively; ε_i is the error term.

5 Regression Results

This section estimates the effects of electrification on air quality-related health and environmental concerns and demonstrates that although electrification lowers the overall air quality, it also improves air quality-related health.

5.1 Estimated Effects of Electrification

Table 2 reports the results of my empirical models in equations (1) and (2). Column (1) to (3) include commune and year fixed effects to control for time-invariant unobservables and express the impacts of electrification on the probability that air quality-related illnesses are in a commune's top one, two, and three health concerns, respectively. Column (4) displays the effects of electrification on the likelihood that a commune reports air quality among its pressing environmental issues, controlling for district and geography fixed effects. While the LPM is easier to interpret and report, the model can predict probabilities outside of the [0, 1] interval. Therefore, I also estimate a logit model as a robustness check. Table A1 in the Appendix reports the marginal effects of the logit regression of equation (1) and yields results that are remarkably similar to the linear probability models both in terms of magnitude and statistical significance.

Column (1) to (3) suggests that electricity access is associated with improvements in air quality-related health outcomes, as hypothesized. A one percentage point increase in a commune's electrification rate is associated with a 0.108 percentage point reduction in the probability that the commune reports having air quality-related illnesses as their number one main health concern. This finding is significant at the 5% level. The effects of electrification are the most significant and largest when examining the top three health concerns. A one percentage point increase in a commune's electrification rate lowers the probability that the commune reports having air quality-related illnesses in their top three main health concerns by 0.211 percentage point. Thus, this result provides suggestive evidence that as households transition from solid fuels to electricity, they enjoy improvements in air quality-related health illnesses from lower exposure to indoor air pollution. These estimated effects of commune electrification rate also likely capture the spillover effects of electrification that may be missing from household-level examinations of grid connectivity. It is also important to note the insignificant findings across my control variables in all four models that contrast with the consistently statistically significant results for the commune electrification rate. These results show that electricity connectivity disproportionately improves air quality-related illnesses compared to other health concerns.

Column (4) examines the estimated effects of electrification on air quality concerns and provides suggestive evidence that extending access to electricity decreases

Table 2: Estimated Effects of Electrification on Population Exposure and Overall Emission

	Dependent variable:			
	Disease 1	Disease 2^{+}	Disease 3^{+}	Air Pollution
Commune Electrification Rate (%)	-0.00108**	-0.00112*	-0.00148**	0.00124***
	(0.00049)	(0.00061)	(0.00063)	(0.00036)
Percent Poor Household	-0.00112	-0.00096	-0.00053	-0.00184*
	(0.00098)	(0.00106)	(0.00100)	(0.00107)
Density (Population/Total Land Area)	-0.00002	-0.00003	0.00001	0.000004
	(0.00004)	(0.00004)	(0.00004)	(0.00002)
Households received credits or loans	0.00001	-0.00001	-0.00001	0.00003
	(0.00003)	(0.00004)	(0.00003)	(0.00004)
People received school fee reduction	0.00001	0.00002	0.00005	0.00001
	(0.00004)	(0.00003)	(0.00003)	(0.00005)
People received hospital fee reduction	-0.00001	-0.00001	0.000002	-0.000005
	(0.00001)	(0.00001)	(0.00001)	(0.00001)
People received regular social assistance	0.00001	-0.00002	-0.00002	-0.00009
	(0.00007)	(0.00007)	(0.00007)	(0.00007)
Daily wage to prepare land (1000 VND)	-0.00001	0.00061	-0.00028	0.00196**
	(0.00093)	(0.00094)	(0.00091)	(0.00089)
Agricultural extension agents visit	-0.00024	0.00161	0.00153**	-0.00356***
	(0.00092)	(0.00100)	(0.00077)	(0.00133)
Log of crop land area	-0.00819	0.03577	0.04560	0.02684
	(0.04356)	(0.05128)	(0.05313)	(0.02794)
Log of crop residential area	-0.00669	-0.01599	-0.03669	0.01799
	(0.03995)	(0.04401)	(0.04479)	(0.04244)
Commune and Year Fixed Effects	Yes	Yes	Yes	No
District and Geography Fixed Effects	No	No	No	Yes
Observations	5,465	5,465	4,896	1,799
R^2	0.0025	0.0033	0.0047	0.0283

*p<0.1; **p<0.05; ***p<0.01

Note: Robust standard errors in parenthesis, clustered at the commune level for model 1 to 3 the overall air quality. I find that a one percentage point increase in the commune electrification rate raises the probability that a commune reports having air quality problems by 0.124 percentage point. Although the result is significant at the 1% level, it is susceptible to a number of weaknesses, most notably omitted variable bias. Since only one wave of the data for the variable Air Pollution is available, I am unable to control for time-invariant commune-level unobservables.

5.2 Differential Effects of Electrification

There are several motivations to also examine the heterogeneous treatment effect of electrification on air quality-related health and environmental outcomes depending on the economic status of communes. First, determining who benefits the most from electrification can aid policymakers to design the most effective electrification programs and policies under financial constraints. Further, the results can be used to generalize to important subpopulations. Indeed, Spalding-Fecher (2005) suggests that the rate of conversion from biofuels to electricity for urban regions tends to be much faster than their rural peers. Thus, table 3 includes an interaction term between the electrification rate and the percent of poor households in each of the previous four models in table 2 to investigate the differential effects of grid connectivity on population exposure and overall emission levels.

As seen in Table 3, the effect of commune electrification on health does not seem to depend on the percent of poor households. While the coefficients on commune electrification rate remain similar to those in Table 2, the estimated interaction effects of electrification on air quality-related health and environmental concerns conditional on the percent of poor households are largely economically and statistically insignificant in table 3. The only statistically significant finding in column (3) suggests that communes with a higher share of poor households are less likely to see improvements in air quality-related health concerns from electrification. However,

Table 3: Differential Effects of Electrification on Population Exposure to Pollution and Overall Emission

	Dependent variable:			
	Disease 1	Disease 2^{+}	Disease 3^{+}	Air Pollution
Commune Electrification Rate (%)	-0.00135**	-0.00149**	-0.00211***	0.00138**
	(0.00059)	(0.00069)	(0.00071)	(0.00054)
Percent Poor Household	-0.00160	-0.00161	-0.00160	-0.00153
	(0.00111)	(0.00121)	(0.00114)	(0.00099)
Commune Electrification Rate x Percent Poor Household	0.00001	0.00002	0.00003*	-0.00001
	(0.00002)	(0.00002)	(0.00002)	(0.00002)
Density (Population/Total Land Area)	-0.00002	-0.00003	0.00001	0.000003
	(0.00004)	(0.00004)	(0.00004)	(0.00002)
Households received credits or loans	0.00001	-0.00001	-0.00001	0.00003
	(0.00003)	(0.00004)	(0.00003)	(0.00004)
People received school fee reduction	0.00001	0.00002	0.00005	0.00001
	(0.00004)	(0.00003)	(0.00003)	(0.00005)
People received hospital fee reduction	-0.00001	-0.00001	0.000002	-0.000005
	(0.00001)	(0.00001)	(0.00001)	(0.00001)
People received regular social assistance	0.00001	-0.00002	-0.00002	-0.00009
	(0.00007)	(0.00007)	(0.00007)	(0.00007)
Daily wage to prepare land (1000 VND)	-0.00004	0.00057	-0.00035	0.00197**
	(0.00093)	(0.00094)	(0.00091)	(0.00089)
Agricultural extension agents visit	-0.00024	0.00161	0.00154**	-0.00356***
	(0.00092)	(0.00100)	(0.00077)	(0.00133)
Log of crop land area	-0.00680	0.03769	0.05015	0.02715
	(0.04352)	(0.05111)	(0.05300)	(0.02791)
Log of crop residential area	-0.00826	-0.01816	-0.04011	0.01786
	(0.03996)	(0.04404)	(0.04489)	(0.04243)
Commune and Year Fixed Effects	Yes	Yes	Yes	No
District and Geography Fixed Effects	No	No	No	Yes
Observations	5,465	5,465	4,896	1,799
R^2	0.00269	0.00365	0.00598	0.02839

*p<0.1; **p<0.05; ***p<0.01

Note: Robust standard errors in parenthesis, clustered at the commune level for model 1 to 3 the magnitude of the coefficient for the interaction term is negligible. This result indicates that electrification does not produce or add to the inequality between communes with a low and high share of poor households in terms of air quality-related health and environmental concerns.

6 Conclusions

Achieving universal access to electricity has become one of the primary goals for developing countries to eradicate poverty and spur economic growth. Indeed, the literature suggests electricity access substantially improves various dimensions of human development; however, few prior studies have looked into the effects of electrification on the sources of health problems.

Although electrification gives rise to the reliance on fossil-based electricity generation, it also enables the transition from on-site combustion of solid fuels to electricity usage, effectively distancing the source of pollution away from energy users to large thermal power plants. Thus, the average end-users of electricity benefit from lessened exposure to IAP at the expense of high OAP near coal power plants.

This study examines the air quality-related health and environmental trade-off of electrification and finds that electrification alleviates air pollution-related health problems even as it worsens outdoor air quality. Specifically, a one percentage point increase in a commune's electrification rate raises the probability that a commune reports having air quality problems by 0.124 percentage point and lowers the probability that a commune reports having air quality-related illnesses in their top three main health concerns by 0.211 percentage point. These results bear implications for policymakers in countries looking to extend electricity access as they weigh the benefits and costs of electrification. The findings should also factor in the countries' decision whether to adopt a centralized or decentralized power system.

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A Appendix

Table A1 shows the marginal effects from the logit model as a robustness check for the result shown in Table 2. The logit regression yields results that are remarkably similar to the LPM both in terms of magnitude and statistical significance.

Table A1: Effects of Electrification on Population Exposure to Pollution and Overall Emission

	Dependent variable:		
	Disease 1	Disease 2^+	Disease 3^+
Commune Electrification Rate (%)	-0.00108**	-0.00112*	-0.00148**
	(0.00049)	(0.00061)	(0.00063)
Observations	2,635	2964	2115
R^2	0.00269	0.00365	0.00598

*p<0.1; **p<0.05; ***p<0.01

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