WINPEC Working Paper Series No.E2109
May 2021

Returns to Grid Electricity on Firewood Consumption and Mechanism

Ngawang Dendup

Waseda INstitute of Political EConomy
Waseda University
Tokyo, Japan

Returns to Grid Electricity on Firewood Consumption and Mechanism

Ngawang Dendup*

Abstract

The unprecedented stock of greenhouse gases in the atmosphere is changing the traditional role of the forest into that of a carbon sink. However, dependence on firewood for household energy is ubiquitous in developing countries, undermining the carbon services that forests provide. One of the options to address this problem is to provide access to alternatives such as electricity. This study examines the effect of grid electricity on firewood consumption by using an instrumental variable (IV) estimation strategy, and it evaluates the mechanisms underlying the causal effect. I use three waves of large sample household surveys from Bhutan and other administrative data to complement the main results. The results show that grid electricity reduces firewood consumption by approximately 0.37 – 2.65 cubic meters per month and that electrified households are approximately 83 – 90% more likely to use electricity instead of kerosene as lighting fuel. Households respond to electricity provisions by adjusting household technology, particularly in terms of shifting to the newly available source of household fuel and adopting basic electrical appliances.

Key words: electricity, firewood, household technology, instrumental variables, electrical appliances

JEL: O12, Q5

*Faculty of Political Science and Economics, Waseda University, Tokyo, Japan; E-mail: ngawangdendup@gmail.com (or) ngawang.dendup@toki.waseda.jp

1 Introduction

Climate discussions are centered around identifying policy measures to reduce the emissions of greenhouse gases (GHGs) and reverse the increase in GHGs, especially carbon dioxide, in the atmosphere. This policy debate is changing the conventional role of the forest, which was primarily conceived as a resource for consumption (e.g., commercial logging, fuel for household energy, and recreational services), into that of a carbon sink. Deforestation has been estimated to contribute approximately 6 to 17% of the total global carbon emissions (Werf et al., 2009). However, developing countries depend on firewood for household energy, undermining the carbon services that forests can provide. For instance, Hosonuma et al. (2012) states that firewood and charcoal production are responsible for approximately 31% of global forest degradation.

A number of studies have linked forest degradation to the unsustainable and inefficient harvesting of firewood in developing countries (Baland et al., 2010; Heltberg et al., 2000; Specht et al., 2015), and Baland et al. (2018) report that firewood harvesting is the primary reason for forest degradation in Nepal. Approximately 2.7 billion people, especially in developing countries, depend on solid fuels for cooking and heating (IEA, 2015), and forests are among the primary sources of such fuels. Heltberg et al. (2000) indicates that 59% of households in India report collecting firewood from common forests, suggesting that forests are the major source of firewood. Similarly, Kissinger et al. (2012) states that, in Africa, firewood and charcoal production are the primary causes of forest degradation. Furthermore, Chettri et al. (2002) relates that the health of forests near human settlements in Northern India is poor due to firewood and timber extraction. Therefore, firewood extraction is one of the drivers of forest degradation in developing countries. Similarly, in our study area, UNDP (2012) reports that Bhutan has the highest per capita firewood consumption in the region, with 1.3 tons consumed annually.

To benefit from forests in terms of carbon services, households must reduce their dependence on firewood. One option to reduce household dependence on firewood or biomass is to increase accessibility to alternative sources of energy, such as electricity. Studies by Dendup and Arimura (2019) and Dinkelman (2011) report that the use of firewood for cooking is negatively associated with electricity provision. Similarly, Meeks et al. (2019) and Somanathan and Bluffstone (2015) show that biogas users consume less firewood than nonusers, and Brooks et al. (2016) reports a reduction in firewood consumption by adopting clean cookstoves (mostly liquified petroleum gas (LPG) users) in Northern India, suggesting that households respond positively to new forms of cooking fuels. Conversely, electricity has the potential to directly influence household technology by enabling households to use basic electrical appliances for home production, which could reduce the dependence on firewood. However, in the economic literature, studies of the benefits of electrification have concentrated on how grid electricity enhances private welfare, whereas the benefits in terms of firewood conservation are largely unclear, with the exception of the study by Litzow et al. (2019). The available studies suggest that access to electricity improves (female) labor outcomes (Dinkelman, 2011; Grogan and Sadanand, 2013; He, 2019), increases household consumption (or expenditure) (Khandker et al., 2013; Van de Walle et al., 2017; Thomas et al., 2020), increases housing prices and human development indices (Lipscomb et al., 2013), decreases indoor air pollution (Barron and Torero, 2017), has positive returns for education (Barron and Torero, 2014; Kumar and Rauniyar, 2018; Lipscomb et al., 2013; Thomas et al., 2020) and increases manufacturing output (Rud, 2012), while electricity shortages reduce firm revenue (Allcott et al., 2016). On the other hand, recent evidence from field experiment in Kenya show little or no impact on number of household outcomes(Lee et al., 2020).

The primary objective of this study is to examine the effect of household electrification on firewood consumption by exploiting the variation in household electrification status. I use three waves of nationally representative household surveys conducted in Bhutan in 2007, 2012 and 2017 and other administrative data. The second objective is to examine the mechanism of the relationship between electricity and firewood consumption. The understanding of such a mechanism would allow governments to prescribe meaningful complementary policies. For instance, rural electrification could stimulate economic development and enhance household welfare, whereas complementary policies, such as improving road connectivity and providing access to financial services and reliable information infrastructure, may be necessary for households to take full advantage of the potential of electricity. Aklin et al. (2018) also emphasizes the significance of complementary interventions in household technology adoption in developing countries.

However, examining the effect of grid electricity is challenging because it is confounded by both household and community or neighborhood characteristics. Who receives electricity depends on factors such as the cost of building the (electrification) infrastructure, the political importance of the community, and the development status of the area. For the electricity utilities and agencies responsible for building infrastructure, it makes economic sense to target extensive margins in economically viable communities for cost recovery and affordability reasons. In addition, community or neighborhood characteristics are important determinants of the villages that are electrified, and the impact of electricity on household outcomes can differ. For instance, the impact of electricity on firewood consumption may be different between environmentally conscious communities and less environmentally conscious communities, which can determine the community that is prioritized for electrification. When a community is electrified, whether a household connects to electricity is also an endogenous decision. In this study, to account for the nonrandom assignment of electricity provision, I use an IV strategy, using the distance to a substation and proximity to power plants as instruments. The locations of substations and power plants can also be driven by potentially endogenous individual, household and community or neighborhood characteristics that could affect household outcomes. To address this concern, first, I show that, conditional on controlling for potentially endogenous individual, household and community-level characteristics, the location of substations and power plants is driven by factors not correlated with the factors that affect the electricity provisions in the community. Second, based on anecdotal evidence and conversations with electricity utilities in Bhutan, I argue that the location of substations and power plants is largely affected by exogenous geological and engineering parameters, such as seismic fault lines and ground stability. Third, one of the key identification assumptions is not a question of whether households are electrified or not but whether the communities closer to substations and power plants are connected to the grid first. It is less expensive to provide electricity to communities that are closer to substations and power plants, and they are likely to be the first communities to acquire electricity provisions, which is the case for Bhutan (see Kumar and Rauniyar, 2018). Further, data also clearly support this key identification assumption.

This study contributes to the literature on the effect of grid electricity on firewood conservation and the understanding of the mechanism in poor rural villages of developing country settings. However, this study differs from Litzow et al. (2019) in three ways. First, this study uses recent survey data obtained in 2017, resulting in a larger sample size. Second, this study uses an IV strategy (not propensity score matching as in Litzow et al. (2019)). Third, this study examines the mechanism of changes in firewood consumption through the adoption of basic electrical appliances. This study also provides new evidence of the effect of community electricity on the adoption of basic electrical appliances by poor rural households. The overall results show that compared to nonelectrified households, electrified households consume less firewood by approximately 0.37 – 2.65 cubic meters per month. Households that are electrified for more than five years are approximately 10 – 23% and 9 – 21% more likely to adopt rice cookers and refrigerators, respectively. Similarly, electrified households are approximately 29 – 47% less likely to use kerosene as lighting fuel and 83 – 90% more likely to use electricity for lighting. Therefore, this study provides empirical evidence of the effect of grid electricity on firewood conservation and the mechanism underlying the causal relationship through changes in household technology.

This paper is arranged as follows. Section 2 discusses the rural electrification program in Bhutan, and section 3 describes the data and summary statistics. Section 4 discusses the effect of electricity on firewood consumption. Section 5 discusses the mechanisms of firewood consumption through changes in household technology. Section 7 concludes the study.

2 Rural Electrification Program and Instruments

In Bhutan, 99% of electricity is generated through hydropower plants. The Ministry of Economic Affairs acts as the primary agency for constructing new power plants and negotiating bilateral or international agreements for financing. The daily operation of hydropower plants, including the production of electricity, is undertaken by Druk Green Power Corporation Limited (DGPC), and Bhutan Power Corporation Limited (BPC) is responsible for the distribution of electricity within the country and for developing an electricity distribution infrastructure (such as substations and distribution lines). DGPC and BPC are regulated by an autonomous agency called the Bhutan Electricity Authority (BEA)[1].

The rural electrification program in Bhutan started in the 1980s with the commission of the first mega-hydropower plant, although households' accessibility to the grid remained as low as 20% (ADB, 2004). The rural electrification program was intensified in the late 1990s and early 2000s (Kumar and Rauniyar, 2018), and less than 1% of households currently do not have access to grid electricity (BPC, 2016). The Asian Development Bank (ADB) was the key agency that financed the rural electrification program in Bhutan before 2005. Since 2005, the Japan International Corporation Agency (JICA) has been one of the key partners in terms of both financing and providing policy guidance on rural electrification. Rural electrification in Bhutan was predominantly targeted at improving living standards, education, and health; enhancing economic productivity; and reducing firewood consumption (ADB, 2003; JICA, 2005). In addition, the rural electrification program in Bhutan was bundled with subsidies for free connections

[1]The BEA is responsible for the review of electricity tariffs and the approval of electricity tariffs proposed by BPC, and it regulates performance standards and prescribes technical and safety requirements for electricity utility companies in Bhutan.

that may have reduced the time gap in the electrification status between the community and households, partially resolving concerns over self-selection at the household level.

The rural electrification documents of the ADB do not provide clear information about the criteria used for connecting communities to the grid. However, Litzow et al. (2019) and JICA (2005, chapter 13) suggest that economically more efficient villages and villages closer to roads were prioritized. Notably, the major implementation of this rural electrification plan was undertaken during the 10^{th} Five-Year Plan (2008 – 2013), during which considerable institutional change occurred, and the first democratically elected political party formed the government[2]. In contrast to the previously planned target of achieving 100% electrification by 2020, the target of the newly elected government was to electrify all households by 2013 (GNHC, 2009). In addition, the ambitious plan of the elected government regarding road infrastructure substantially reduced the variation in road accessibility across subdistricts[3].

BPC suggested that it initially electrified areas that require minimal cost to connect, and cost is largely determined by the distance of a community to the nearest substation and power plant[4]. Furthermore, Kumar and Rauniyar (2018) states that, before 2008, when the ADB was involved in the rural electrification program in Bhutan, BPC prioritized communities closer to substations. Obviously, the locations of substations and hydropower plants were not randomly assigned; however, discussions with the Ministry of Economic Affairs and BPC clearly indicated that engineering parameters such as ground stability, seismic fault lines, and river velocity determined the location of substations and power plants. In addition, before the 2005 census, Bhutan did not have reliable household data that could be used for location sorting(Kumar and Rauniyar, 2018). This evidence indicates that the locations of substations and power plants are not correlated

[2]Druk Phuensum Tshogpa (DPT) was the first democratically elected political party to form a government from 2008 to 2013.

[3]The emphasis on road development is also evident from the total budget overlay from the 10^{th} Five-Year Plan document. The Ministry of Works and Human Settlement, which is responsible for building roads in Bhutan, received approximately 19.23% of the total budget allocation, which was the second highest resource allocation among ministries (see GNHC, 2009, page 66).

[4]In fact, during discussions with BPC, its representatives did not mention the proposed criterion and instead repeatedly indicated that the availability of the budget and cost played crucial roles.

with firewood consumption.

The Bhutanese people are also one of the highest firewood consumers in the region. According to (UNDP, 2012), per capita firewood consumption is 1.3 tons annually. Similarly, a small sample study by Wangchuk et al. (2014) in Bhutan also suggests that the average firewood consumption per household is approximately 54 cubic meters annually, which is much higher than the per capita household consumption of 9 kg per day (or 16 cubic meters annually)[5] reported by Brooks et al. (2016) in Northern India, suggesting that Bhutanese households are among the greatest firewood consumers[6].

3 Data

I use three waves of the Bhutan Living Standard Survey (BLSS) conducted in 2007, 2012 and 2017 as pooled data for the main analysis. In this study, I use a subsample of rural households since the use of firewood is associated with rural households. I use administrative data from BPC regarding the location of each substation and power plant to construct the IV. I also use census data from the Population and Housing Census of Bhutan 2005 and data on forest coverage in each subdistrict published by the Ministry of Agriculture and Forestry to test the validity of the IV.

After omitting urban households and those that did not respond to the firewood consumption question, the pooled data consist of households from 204 of 205 subdistricts from all twenty districts in Bhutan. The pooled data used for this study have households from 199, 195 and 198 subdistricts in the BLSS 2007, 2012 and 2017, respectively. In the BLSS 2007, 2012 and 2017 surveys, 6,856, 4,986 and 6,854 households from rural areas were surveyed, respectively. In contrast, only 3,558 and 5,345 households reported firewood consumption in the BLSS 2012 and 2017, respectively. In addition, I omitted

[5]In **?**, firewood consumption is reported in kilograms. For comparison purposes, I used the official conversion rate of 1 cubic meter of firewood = 200 kg used in Bhutan.

[6]Further, problems with using firewood include the emission of black carbon, which contributes to global warming due to its radiative properties (Kandlikar et al., 2009) and has been identified as one of the primary causes of indoor air pollution, leading to approximately 4.3 million premature deaths (WHO, 2015).

the households that reported firewood consumption above the 99^{th} percentile as outliers and 64 households that reported unrealistically high per capita household expenditures. These exclusions resulted in a final sample of 15,502 households. Approximately 4% of the households also reported consuming zero units of firewood; therefore, I do not use the log transformation for firewood consumption in the analysis.

In the BLSS surveys, the dependent variable was collected via face-to-face interviews by directly asking households, "How many backloads or truckloads of firewood do you consume per month or year?" I used the official conversion factor to convert the firewood consumption reported in backloads and truckloads into cubic meters. The summary statistics and definitions of the other control variables are reported in Table 1A. The simple average of firewood consumption over time shows that firewood consumption decreased from approximately 2 cubic meters per month in 2007 to approximately 1.5 cubic meters in 2017 as the percentage of households connected to grid electricity increased from approximately 56% to 80% and 97% in 2007, 2012 and 2017, respectively. The monthly per capita household expenditure is deflated to 2017 prices by using the consumer price index of the respective year.

Geographic information system (GIS) data of the locations of substations are obtained from BPC. The instrument substation is the distance measured from the nearest substation to the centroid of each subdistrict. Therefore, the distance from substations varies only between subdistricts and not by household since I do not have access to georeferenced data at the household level. The distance from the substation is calculated as the straight-line distance in kilometers (KM) by using the GIS software package QGIS. Another instrument, plant, is a dummy variable that takes the value of 1 if the household belongs to a subdistrict that has a hydropower plant and 0 otherwise.

Along with the summary statistics in Table 1A, the group mean tests between households with and without electricity are reported. The mean differences from the pooled data between households with and without electricity are highly significant, and households without electricity consume approximately 0.73 cubic meters more firewood than electrified households. Moreover, the mean difference (and proportion of dummy variables) of the other household characteristics between households with and without electricity are significantly different from zero (with two exceptions for the variables of age and children in Table 1B). A critical examination of these results suggests strong evidence of self-selection in the program. Additionally, the mean differences in the instrumental variables (substation and plant) are statistically significant for all three years, which could indicate that the distance to a substation and proximity to a power plant play significant roles in connecting to grid electricity in all three years. In Figure 1, I report the locations of substations, and in Appendix, Table A1.1 and Table A1.2, I report the summary statistics of the substations and power plants, respectively, including the year of construction and the district and subdistrict in which they are located. In the next section, I discuss the estimation strategy.

4 Effect of Electricity on Firewood Consumption

4.1 Estimation Strategy

The causal effect of grid electricity on firewood consumption can only be estimated by comparing the consumption of households with and without electricity were electricity randomly assigned. In particular, there are two different levels of the nonrandomness of rural electricity provision: community and household. Which community receives electricity provision depends on the political importance (Dinkelman, 2011) of the community. In addition, in developing countries, such megainfrastructure developments are usually financed through borrowing; hence, government and utility firms might have to consider recovering both capital and operating costs. Therefore, governments and utilities may prioritize electricity provisions to affluent communities for affordability reasons. Another important source of endogenous electricity provisions at the community level is the cost of building infrastructure, such as distribution lines from the nearest substation or power plant. Once a community is connected to the grid, the second source of nonrandomness is the household decision to obtain a grid connection (Litzow et al., 2019). To circumvent the nonrandom assignment of electricity provision, I estimate the effect of grid electricity for household h in subdistrict d on firewood consumption as follows:

$$Firewood_{hd} = \beta_0 + \beta_1 Electricity_{hd} + \gamma X_{hd} + u \tag{1A}$$

The electrification status of the household is instrumentalized on the distance to the substation and the availability of a power plant in the first stage as follows:

$$Electricity_{hd} = \alpha_0 + \alpha_1 Substation_d + \alpha_2 Plant_d + \theta X_{hd} + v \tag{1B}$$

The above identification strategy relies on the assumption that households closer to substations and power plants obtain connections before households that are far away. As reported in Figure 2, the BLSS data show that, in 2007, approximately 75% of households located within the vicinity of a substation were connected to electricity, while only approximately 51% of households located farther from a substation were connected to the grid. Similar differences were observed in 2012, suggesting that households located closer to the substations received electricity provisions before households located farther from the substations. Subsection 4.4 further examines the validity of IV in greater detail.

The vector of other controls includes whether households have adopted LPG as a cooking fuel since LPG adoption can also affect the amount of firewood consumption. Other control variables include household characteristics, such as whether the head of household can read or write, the age and gender of the head of household, the presence of children younger than six years old, the household size and cattle ownership. The fuel adoption literature has well-documented evidence suggesting that women show greater preferences for clean cooking fuel (Dendup and Arimura, 2019; Rahut et al., 2017). In addition, firewood collection and cooking in developing countries are usually performed by women and children; thus, having children younger than the age of six prevents women from performing this daily household work. Household size measures the availability of a labor force to collect firewood. Additionally, firewood is used for preparing cattle feed in developing countries (Nepal et al., 2011; Heltberg et al., 2000); thus, I also control for cattle ownership.

In addition, to control for the financial constraints that rural households face, I control for access to financing, which is measured in terms of having access to loan services from banks. Household expenditures are also used as a proxy for income. The distance to markets and forests control for access to alternative fuels. In Bhutan, the southern belt is warmer than the northern belt, which might also affect the amount of firewood consumption. To control for such location effects, I use a location dummy (south). Household density controls for the pressure on the total amount of firewood available in the community. In addition, I control for regional and year fixed effects. In the next subsection, I discuss the results of the (electricity) reduced form equation.

4.2 First Stage Results: Effect of Instruments on Electrification

The results from the reduced-form electricity equation 1B are reported in Table 2. The distance to a substation and the existence of power plants in the resident subdistrict of a household are significant at 1%, indicating that the IVs have the potential to explain the variation in household electricity provision. The results show that every 10 kilometers farther that a household is located from a substation, households are approximately 3 – 7 percentage points less likely to connect to electricity, while having a power plant located in the resident subdistrict of the household increases the likelihood of connecting to electricity by approximately 3 – 13 percentage points. This finding serves as evidence that the IVs are highly correlated with the variable of electricity.

The variables of read/write, age and female are positive and significant, suggesting that literate household heads and senior citizens are more likely to obtain electricity connections. Variable expenditure is positive and significant, signifying that wealthier households are more likely to connect to electricity. The distance from the market is negative and significant, while the distance from the nearest forest is positive, indicating that households located farther from urban areas are less likely to connect to electricity, while households located closer to urban areas (or farther from forests) are more likely to connect to electricity.

4.3 Second Stage Results: Effect of Electricity on Firewood Consumption

The OLS results in columns 1 and 2 of Table 3 indicate that households connected to electricity consume less firewood than households without electricity. As shown by the OLS results in column 1, when controlled only for time fixed effects, households connected to electricity consume approximately 0.52 – 0.80 cubic meters per month less firewood than households without electricity. When controlling for all other variables, firewood consumption decreases by approximately 0.39 – 0.66 cubic meters per month. However, the preferred IV results suggest that firewood consumption decreases by approximately 0.37 – 2.65 cubic meters per month compared to households without electricity. However, this result does not suggest that electricity completely replaces the use of firewood; instead, the data indicate that households are stacking fuels. For example, approximately 38% of electrified households report firewood as the primary cooking fuel[7]. Figure 3 clearly shows that households consume firewood even when electricity, LPG, and kerosene are reported as the primary cooking fuels. Similarly, as reported in Figure 4, as the proportion of households connected to electricity increases, the average consumption of firewood by electrified households declines at a decreasing rate, although electricity does not completely replace firewood.

The IV result indicates that the OLS results underestimate the effect of electricity on firewood consumption, potentially due to the heterogeneous effect of electricity provision. Similar estimates of downward bias from the OLS estimates are reported by Card (1993) with respect to returns to education[8]. In line with Card (2001), the downward bias in

[7]When firewood users are redefined as households that have reported positive firewood consumption, our data show that approximately 96% of electrified households still use firewood.

[8]A survey of similar results is reported in Card (2001) along with possible explanations for such

OLS results could be due to the underlying heterogeneity in firewood consumption, and the returns on firewood conservation can be estimated for the subset of the population with the highest returns on firewood conservation. Therefore, I interpret the IV results as upper bound estimates[9].

The coefficient of the variable LPG is also negative and significant, indicating that firewood consumption can be minimized by adopting other cooking fuels, such as LPG[10]. Similarly, literate household heads are likely to consume less firewood than illiterate household heads. Moreover, elderly household heads are likely to consume more firewood, possibly due to more heating requirements and a stronger preference for firewood. Similarly, having a greater number of household members is positively correlated with firewood consumption due to the greater labor supply for firewood collection and the higher energy requirements. In rural areas, firewood is also used to prepare cattle feed, and the results show that cattle ownership is positively correlated with firewood consumption. Additionally, wealthier households are positively correlated with firewood consumption, possibly because the energy requirements for richer households are greater since richer households have different cooking habits and can own larger residences that require more heating. Similar observations are reported by Hanna and Oliva (2015) in India. The southern part of Bhutan is warmer than the northern part; thus, the variable south is negatively correlated with firewood consumption. Furthermore, a higher density of households in a community means greater demand for firewood and more pressure on the available firewood stock. The results show that higher household density is negatively correlated with firewood consumption, indicating that firewood scarcity is negatively

downward bias in the OLS results.

[9]Another possible concern is that the development of mega-hydropower power plants can affect the wealth of households within their vicinity and thus might also affect firewood consumption through changes in wealth. However, it does not bias the IV results because I control for household income. Furthermore, I re-estimated the IV results by eliminating households from subdistricts with mega-hydropower power plants, and the coefficient of electricity was -1.662, which is significant at 1% and lies within the 95% confidence interval of the results reported in Table 2.

[10]In this study, LPG is also a potential endogenous variable. However, due to a lack of IV, I estimate the firewood equation without including LPG as a control variable to assess the sensitivity of the coefficient of the interest variable, i.e., electricity. The results are reported in Appendix Table A2, and the coefficient of electricity is similar to the IV result reported in Table 2.

correlated with firewood consumption[11].

In addition, IV results are the local average treatment effect (LATE) for the units with behaviors that can be altered by varying the values of the IV (Angrist and Imbens, 1995; Angrist et al., 1996). That is, the causal effect of grid electricity on firewood consumption based on the IV strategy represents the effect on compliers (i.e., households closer to substations and residents of subdistricts with power plants obtaining an electricity connection, while households located farther away did not obtain an electricity connection). Therefore, following Angrist and Imbens (1995); Angrist et al. (1996), the effect of electricity on firewood consumption does not represent the causal effect of the entire population but only the compliers. However, one important assumption in the LATE is that there are no defiers (i.e., households that refuse to obtain a grid connection when living close to a substation and households that obtain a connection when living far from a substation). In this study, the assumption of no defiers is reasonable for two reasons. First, for households located farther away, the provision for connecting to electricity simply did not exist (at this specific time). Second, current universal access to electricity would not have been achieved in the presence of defiers. Further, the free connection scheme of the rural electrification program was also likely to induce households closer to substations to obtain connections to avoid uncertainty about connection fees in the future.

The external validity of the results (of this study) largely depends on dietary habits and whether the electrical appliances are available for cooking local foods because rural households cannot afford to purchase expensive electrical ovens. For instance, in Bhutan, the staple food is rice, which households can cook with basic electrical appliances, such as rice cookers. Therefore, a similar impact of rural electrification on firewood consumption in developing countries could be observed in areas with similar food cultures. In the next subsection, I examine the validity of the instruments in greater detail.

[11]The OLS results of the effect of electricity provision on firewood for each separate year are reported in Appendix Table A3, and the results are consistent with the results reported in Table 2.

4.4 Instrument Validity

The IV results are conditional on the validity of the assumptions of the instruments, and I conduct a number of checks to assess the validity of these assumptions. First, the asymptotic distributions of the IV estimators are different when the correlation between the endogenous variable(s) and instrument(s) is weak, rendering the standard test statistics invalid (Staiger, 1997). Since I have two instruments, I conduct the standard F test for the joint significance of the instruments, substations and plants. The test statistic is F(2, 15,481)=296.11, which is far greater than Yogo and Stock's critical value of 10 (when the number of instruments is two), thus rejecting the null hypothesis of no joint significance. In addition, having two instruments in a reduced-form equation results in one overidentifying restriction, which allows for the testing of the exclusion restriction. The Sargan-Hausman test statistic for the overidentification test is χ^2 (1,15,481)=0.588, which is less than the critical value (critical value=6.635), and the p-value is 0.443; thus, I fail to reject the null hypothesis that one of the instruments fails the exclusion restriction.

Further, identification requires that IVs have no direct effect on firewood consumption. In this study, the exclusion restriction could be violated if the locations of substations and power plants were related to factors that also enter the firewood equation. One such variable could be the availability of firewood or the health of the forest in a particular community. If rural electrification programs prioritized areas with more forest coverage (or deforested areas) for conservation reasons, the exogeneity of IVs would fail. Such possibilities are difficult to exclude since Bhutan has a long history of following very strict conservation policies. This possibility is further supported by the objective of rural electrification, which clearly states the reduction of firewood consumption as one of the objectives of the rural electrification program. To assess this possibility, I estimate the following equation:

$$Substation_d = \rho_0 + \rho_1 Forest_d + \delta + \epsilon \tag{2}$$

where $substation_d$ indicates whether a substation is located in subdistrict d, $Forest_d$ is the percentage of forest cover in subdistrict d, and ρ_1 is the coefficient to be estimated. I also include district fixed effects δ to control for the differences in income among districts.[12] Therefore, if ρ_1 is different from zero, the variable substation is not a valid instrument.

Another possible criticism of the instruments used in this study is that, if the locations of substations and power plants were determined based on the income or wealth of households in particular communities, then the exogeneity assumption of the instruments would be violated. Such location sorting could occur if the substations were constructed near affluent households for affordability and cost recovery reasons. To test for this possibility, I constructed a wealth index (w_{ij}) using the PHCB 2005 data set, which was collected before the data that I use for the main analysis, as follows: $w_{ij} = 1/11 \sum_{j=1}^{11} A_{ij}$, where $A_{ij} = 1$ if a household owns assets j and 0 otherwise. The assets included in computing w_{ij} are ownership of radios, phones, land, livestock, houses with metal roofs, concrete walls, and flush toilets, access to piped drinking water, whether the primary income source is the household's own business, household size and number of rooms[13]. Using this wealth index, I categorized subdistricts into in poor, middle and wealthy and re-estimate equation 2 by using the wealth index as an explanatory variable. I also estimate equation 2 for the locations of power plants. Next, I discuss the results of equation 2.

The results of equation 2 are reported in Table 3. In panel A, I report the results from equation 2 with forest cover as an explanatory variable, and in panel B, I report the results from equation 2 with the wealth index (poor, middle and wealthy) as the explanatory variables. In columns 1 and 3 of panels A and B, the linear probability model is estimated without controlling for district fixed effects, while district fixed effects are controlled for in columns 2 and 4. The coefficient of forest cover is close to zero and not significantly different from zero, indicating that there is no evidence of location sorting based on

[12]A subsequent poverty report published by the National Statistics Bureau of Bhutan suggests that there are differences in income among districts, and district dummies are included to capture such differences.

[13]For the number of rooms and household size, I created a binary variable for rooms if a household owns more than one room and a binary variable for household size if the total household members number fewer than five. Note that poor households are associated larger household sizes in developing countries.

forest coverage. In panel B, the excluded category is poor subdistrict; therefore, ρ_1 is the probability of installing a substation and plant in medium and wealthy subdistricts compared to poor subdistricts. However, the coefficients are not distinguishable from zero. Therefore, based on these results, I do not find evidence of location sorting based on the income of the community[14].

Furthermore, community characteristics that affect the electrification status and its benefits (including firewood consumption) could be correlated with the instruments. For instance, when a village is electrified, more environmentally aware and health-conscious communities may obtain electricity connections earlier than communities that are less environmentally aware or less health conscious. If such community characteristics were correlated with the IVs and use of firewood, the same community characteristics would also be correlated with the use of LPG as a cooking fuel and kerosene for lighting, suggesting that the instrumental variables could predict the use of LPG and kerosene. To examine whether the instruments (i.e., substations and power plants) are also strong predictors of LPG and kerosene use, I estimate a linear probability model of the adoption of LPG and kerosene. The results reported in Table 3, panel C, are estimated by including the same set of controls used in Table 2. In addition, I include a firewood dummy; therefore, the base category is electricity for cooking and lighting. The results from the LPG model suggest that substations and power plants are not correlated with the use of LPG as cooking fuel. Similarly, substations are not correlated with the use of kerosene as lighting fuel, whereas the coefficient of plant is marginally significant. The results indicate that such community characteristics are not correlated with the IV and does not bias the IV results [15]. In next section, I examine the underlying mechanism of causal

[14]As a robustness check, I also estimated equation 2 for each of the 11 wealth indicators used in computing the wealth index separately, and the results are reported in Appendix Table A4, panel A. Some of the coefficients of wealth indicators are significant; therefore, I use propensity score matching as an alternative identification strategy to account for the nonrandom assignment of electricity. The results are reported in panel B of Table A4, and both the average treatment effect and average treatment effect lie within the 95% confidence interval of the IV results.

[15]Since the coefficient of power plants in Table 3, panel C, is marginally significant, I re-estimated the firewood equation by using only substations as an instrument, and the coefficient of electricity is 0.19 – 2.80, which is comparable to the results when using both substations and power plants as instruments. Therefore, I used both instruments in this study.

relationship between firewood and electricity.

5 Mechanism

In this section, I examine the mechanism of how firewood consumption is reduced after connecting to electricity. If the underlying mechanism of the reduction in firewood consumption operates via a change in household technology by investing in cooking, lighting and basic household electrical appliances, the household must shift from the use of traditional fuel (firewood) to electricity for household production and adopt basic electrical appliances that enable the household to derive benefits from electricity. To examine this mechanism, I estimate bivariate probit models for the adoption of cooking fuel, lighting fuel and electrical appliances. In the cooking fuel model, I estimate bivariate probit models for the adoption of electricity and firewood for cooking, and for lighting fuel, I estimate bivariate probit models for the adoption of electricity and kerosene. Finally, I estimate a bivariate probit model for the adoption of electrical appliances, such as rice cookers and refrigerators. In the first two models, I use both instruments (substations and plants), and in the appliance model, I use only substations because power plants are insignificant in the appliance model. In all of the models, I control for same set of covariates used in Table 2, except for the variables of cattle, south and density.

In Table 4, panels A and B, I report the results of the adoption of cooking fuel and lighting fuel, respectively, and in panel C, I report the results of the adoption of electrical appliances. The bivariate probit results of electricity and firewood reported in panel A are positive and negative, respectively, suggesting that electrified households are approximately 61% more likely to adopt electricity as a cooking fuel and approximately 35% less likely to adopt firewood. Similarly, electrified households are 38% less likely to use kerosene and 86% more likely to use electricity as a lighting fuel. Similar results for the effect of electricity on lighting fuel are reported by Barron and Torero (2017), and the results indicate that the mechanism underlying the reduction in kerosene use is replacement for lighting fuel. The overall results suggest that households shift from using traditional fuels to electricity in response to electricity provision.

In the BLSS, the adoption of electrical appliances is observed only if households are electrified. Therefore, I estimate bivariate probit models for the adoption of two appliances, namely rice cookers and refrigerators, by using a sample of only the households connected to electricity. Therefore, in the appliance model, I redefine the variable electricity as electricity†, which is equal to 1 if a subdistrict is electrified for more than seven years. I choose five years of electrification or more because households may be accustomed to traditional fuels and appliances and may need a few years to adapt to a new form of energy. In addition, households may also require sufficient time to learn about the utility of electrical appliances. The bivariate probit coefficients are positive and significant, suggesting that households in subdistricts that have been electrified for more than five years are more likely to adopt rice cookers and refrigerators. The results show that households are approximately 17 and 15% more likely to adopt rice cookers and refrigerators, respectively. The adoption of these simple electrical appliances in rural settings has direct effects on household production technology. As a result, the energy obtained via firewood (and other traditional fuels) could be reduced. Therefore, one of the mechanisms of the reduction in firewood consumption from electricity provision in rural developing countries may operate through changes in household technology. I also report the results of a bivariate probit model of rice cooker and refrigerator adoption by using one to eight years of electrification in Figure 5. The coefficient of rice cooker is significant from year one through eight, while the refrigerator coefficient becomes significant starting in year 3. Appliances such as rice cookers are inexpensive and readily available in the rural markets of Bhutan, whereas refrigerators are expensive and not readily available, which could have contributed to the difference in the results.

6 Conclusions

This study examines the effect of household electrification on firewood consumption and the underlying mechanisms. I address the issue of endogenous household electricity provision by using the distance from substations and proximity to power plants as instruments in the reduced-form equation. The results indicate that electrified households consume approximately 0.37 – 2.65 fewer cubic meters of firewood per month than unelectrified households. I also conduct numerous checks for the validity of the instruments and show that, conditional on controlling for potentially endogenous household and community characteristics, the locations of substations and power plants (i.e., IVs) are driven by factors not correlated with the factors that affect firewood use. Further, I argue based on anecdotal evidence that the locations of substations and power plants are largely driven by exogenous factors, such as seismic fault lines and ground stability.

I also show that one possible mechanism for the reduction in firewood consumption operates through a change in household technology by adopting electricity for cooking and investing in electrical appliances. Rural households in Bhutan primarily use firewood for cooking (but a heating effect may also exist). However, the BLSS data enable us to examine the mechanism of firewood reduction through the replacement of cooking fuel only; therefore, the reduction mechanism is only through the replacement of firewood with electricity and the adoption of cooking appliances. To support this claim, I show that households change the use of household energy for cooking. Similarly, the results indicate that households shift from traditional lighting fuel (kerosene) to electricity; thus, the mechanism underlying the reduction in the use of kerosene appears to be the replacement of lighting fuel. Electrified households are approximately 32 – 39% and 29 – 47% less likely to use firewood and kerosene for cooking and lighting compared to unelectrified households, respectively. Similarly, electrified households are approximately 57 – 66% and 83 – 90% more likely to adopt electricity as cooking fuel and lighting fuel, respectively.

In addition, this study shows that electricity enables households to adopt basic electrical appliances for household production, such as cooking and storage. Thus, these results indicate that the reduction in firewood consumption may operate through a change in household technology. However, in my data, I do not observe the amount of electricity consumption; rather, only household electrification status is observed. Future research that examines the effect of the amount of electricity consumption on firewood conservation might further strengthen the results of this study.

Acknowledgements

I would like to thank Toshi H. Arimura, Yasushi Kondo, Shigeru Matsumoto and Nori Tarui for their insightful comments and suggestions. These suggestions and comments have helped to substantially improve this paper. This paper has also benefited from the conference participants of the 2019 annual conference of the European Association of Environmental and Resource Economists (EAERE) at the University of Manchester, UK, and the participants of the 2018 East Asian Economic Association Conference at National Taiwan University, Taipei. The author has no conflicts of interest to declare. This research did not receive any specific grants from funding agencies in the public, commercial or not-for-profit sectors. All errors are my own, and the opinions expressed in this manuscript do not reflect the opinions of the author's affiliated institution.

References

ADB (2003). Loan and technical assistance grants to the Kingdom of Bhutan for the rural electrification and network expansion.

ADB (2004). Project performance audit report on rural electrification project in Bhutan.

Aklin, M., Bayer, P., Harish, S., and Urpelainen, J. (2018). Economics of household technology adoption in developing countries: Evidence from solar technology adoption in rural India. Energy Economics, 72:35–46.

Allcott, H., Collard-Wexler, A., and O'Connell, S. D. (2016). How do electricity shortages affect industry? Evidence from India. American Economic Review, 106(3):587–624.

Angrist, J. D. and Imbens, G. W. (1995). Identification and estimation of local average treatment effects. Technical report, National Bureau of Economic Research.

Angrist, J. D., Imbens, G. W., and Rubin, D. B. (1996). Identification of causal effects using instrumental variables. Journal of the American statistical Association, 91(434):444–455.

Baland, J.-M., Bardhan, P., Das, S., Mookherjee, D., and Sarkar, R. (2010). The environmental impact of poverty: Evidence from firewood collection in rural Nepal. Economic Development and Cultural Change, 59(1):23–61.

Baland, J.-M., Libois, F., and Mookherjee, D. (2018). Forest degradation and economic growth in Nepal, 2003–2010. Journal of the Association of Environmental and Resource Economists, 5(2):401–439.

Barron, M. and Torero, M. (2014). Electrification and time allocation: Experimental evidence from northern El Salvador.

Barron, M. and Torero, M. (2017). Household electrification and indoor air pollution. Journal of Environmental Economics and Management, 86:81–92.

BPC (2016). Annual report, Bhutan power corporation.

Brooks, N., Bhojvaid, V., Jeuland, M., Lewis, J., Patange, O., and Pattanayak, S. (2016). How much do alternative cookstoves reduce biomass fuel use? Evidence from North India. Resource and Energy Economics, 43:153–171.

Card, D. (1993). Using geographic variation in college proximity to estimate the return to schooling. Technical report, National Bureau of Economic Research.

Card, D. (2001). Estimating the return to schooling: Progress one persistent econometric problems. Econometrica, 69(5):1127–1160.

Chettri, N., Sharma, E., Deb, D., and Sundriyal, R. (2002). Impact of firewood extraction on tree structure, regeneration and woody biomass productivity in a trekking corridor of the Sikkim Himalaya. Mountain Research and Development, 22(2):150–159.

Dendup, N. and Arimura, T. H. (2019). Information leverage: The adoption of clean cooking fuel in Bhutan. Energy Policy, 125:181–195.

Dinkelman, T. (2011). The effects of rural electrification on employment: New evidence from South Africa. American Economic Review, 101(7):3078–3108.

GNHC (2009). Tenth five year plan 2008-2013, volume 1: Main document. Thimphu, Bhutan: Gross National Happiness Commission, Royal Government of Bhutan.

Grogan, L. and Sadanand, A. (2013). Rural electrification and employment in poor countries: Evidence from Nicaragua. World Development, 43:252–265.

Hanna, R. and Oliva, P. (2015). Moving up the energy ladder: The effect of an increase in economic well-being on the fuel consumption choices of the poor in India. American Economic Review, 105(5):242–46.

He, X. (2019). China's electrification and rural labor: Analysis with fuzzy regression discontinuity. Energy Economics, 81:650–660.

Heltberg, R., Arndt, T. C., and Sekhar, N. U. (2000). Fuelwood consumption and forest degradation: a household model for domestic energy substitution in rural India. Land Economics, pages 213–232.

Hosonuma, N., Herold, M., De Sy, V., De Fries, R. S., Brockhaus, M., Verchot, L., Angelsen, A., and Romijn, E. (2012). An assessment of deforestation and forest degradation drivers in developing countries. Environmental Research Letters, 7(4):044009.

IEA (2015). World energy outlook 2015.

JICA (2005). The integrated master plan study for dzongkhagwise electrification in bhutan. Tokyo: Japan International Cooperation Agency.

Kandlikar, M., Reynolds, C. C., Grieshop, A. P., et al. (2009). A perspective paper on black carbon mitigation as a response to climate change. Copenhagen: Copenhagen Consensus Center.

Khandker, S. R., Barnes, D. F., and Samad, H. A. (2013). Welfare impacts of rural electrification: A panel data analysis from Vietnam. Economic Development and Cultural Change, 61(3):659–692.

Kissinger, G., Herold, M., and De Sy, V. (2012). Drivers of deforestation and forest degradation: A synthesis report for REDD+ policymakers. Technical report, Lexeme Consulting.

Kumar, S. and Rauniyar, G. (2018). The impact of rural electrification on income and education: Evidence from Bhutan. Review of Development Economics, 22(3):1146–1165.

Lee, K., Miguel, E., and Wolfram, C. (2020). Experimental evidence on the economics of rural electrification. Journal of Political Economy, 128(4):1523–1565.

Lipscomb, M., Mobarak, A. M., and Barham, T. (2013). Development effects of electrification: Evidence from the topographic placement of hydropower plants in Brazil. American Economic Journal: Applied Economics, 5(2):200–231.

Litzow, E. L., Pattanayak, S. K., and Thinley, T. (2019). Returns to rural electrification: Evidence from Bhutan. World Development, 121:75–96.

Meeks, R., Sims, K. R., and Thompson, H. (2019). Waste not: Can household biogas deliver sustainable development? Environmental and Resource Economics, 72(3):763–794.

Nepal, M., Nepal, A., and Grimsrud, K. (2011). Unbelievable but improved cookstoves are not helpful in reducing firewood demand in Nepal. Environment and Development Economics, 16(1):1–23.

Rahut, D. B., Behera, B., Ali, A., and Marenya, P. (2017). A ladder within a ladder: Understanding the factors influencing a household's domestic use of electricity in four African countries. Energy Economics, 66:167 – 181.

Rud, J. P. (2012). Electricity provision and industrial development: Evidence from India. Journal of Development Economics, 97(2):352–367.

Somanathan, E. and Bluffstone, R. (2015). Biogas: Clean energy access with low-cost mitigation of climate change. Environmental and Resource Economics, 2(62):265–277.

Specht, M. J., Pinto, S. R. R., Albuquerque, U. P., Tabarelli, M., and Melo, F. P. (2015). Burning biodiversity: Fuelwood harvesting causes forest degradation in human-dominated tropical landscapes. Global Ecology and Conservation, 3:200–209.

Staiger, D. (1997). Instrumental variables regression with weak instruments. Econometrica, 65:557–586.

Thomas, D. R., Harish, S., Kennedy, R., and Urpelainen, J. (2020). The effects of rural electrification in india: An instrumental variable approach at the household level. Journal of Development Economics, page 102520.

UNDP (2012). Bhutan sustainable rural biomass energy. Available at https://info.undp.org/docs/pdc/Documents/BTN/Sustainable%20Rural%20Biomass%20Energy%20Project%20Document.pdf.

Van de Walle, D., Ravallion, M., Mendiratta, V., and Koolwal, G. (2017). Long-term gains from electrification in rural India. The World Bank Economic Review, 31(2):385–411.

Wangchuk, S., Siebert, S., and Belsky, J. (2014). Fuelwood use and availability in Bhutan: Implications for national policy and local forest management. Human Ecology, 42(1):127–135.

Werf, G., Morton, D., DeFries, R., Olivier, J., Kasibhatla, P., Jackson, R., Collatz, G., and Randerson, J. (2009). CO2 emissions from forest loss. Nature Geoscience, 2:737–738.

WHO (2015). WHO guidelines for indoor air quality: household fuel combustion. World Health Organization.

Table 1A: Summary Statistics and Group Mean Comparison

		Pooled		2007		2012		2017		Group Mean		
Variables	Definition	Mean	SD	Mean	SD	Mean	SD	Mean	SD	No	Yes	(No−Yes)
Firewood	Firewood consumption in cubic meters	1.748	1.544	1.96	1.564	1.686	1.599	1.519	1.441	2.30	1.57	0.731***
Electricity	1 if connected to grid electricity	0.753	0.431	0.559	0.497	0.799	0.400	0.970	0.172			
LPG	1 if LPG is used for cooking	0.328	0.470	0.125	0.330	0.372	0.484	0.558	0.497	0.07	0.41	-0.347***
Read/write	1 if head can read and write	0.300	0.458	0.275	0.446	0.285	0.451	0.342	0.474	0.23	0.32	-0.097***
Age	Age of head of household	49.86	14.53	48.62	14.59	51.05	14.74	50.66	14.19	49.13	50.10	-0.975***
Female	1 if head is female	0.369	0.483	0.345	0.475	0.358	0.480	0.409	0.492	0.29	0.39	-0.102***
Children	1 if child below age 6 is present	0.378	0.485	0.416	0.493	0.372	0.483	0.333	0.471	0.41	0.37	0.040***
Size	Household size	4.943	2.280	5.269	2.400	4.983	2.231	4.501	2.073	5.24	4.85	0.392***
Loan	1 if availed loan from bank	0.227	0.419	0.154	0.361	0.221	0.415	0.325	0.468	0.12	0.26	-0.145***
Cattle	1 if owns cattle	0.738	0.440	0.721	0.449	0.768	0.422	0.739	0.439	0.75	0.73	0.165***
Expenditure	Per capita monthly household expenditure	4,170	3,998	3,385	2,947	2,143	3,053	6,532	4,545	2815	4613	-1798***
Market	Distance to market in hours	1.956	5.696	2.883	6.955	1.771	5.862	0.898	2.930	4.88	1.00	3.886***
Forest	Distance to forest in hours	1.245	2.185	1.312	1.887	1.093	2.250	1.261	2.471	1.33	1.22	0.114***
South	1 if located in southern belt	0.295	0.456	0.301	0.459	0.280	0.449	0.298	0.457	0.35	0.28	0.076***
Density	Household density	7.170	8.688	7.886	9.735	7.187	8.090	6.245	7.491	5.11	7.84	-2.734***
Substation	Distance to substation in KM	18.20	12.92	18.07	13.39	17.91	12.44	18.58	12.61	23.73	16.4	7.332***
Plant	1 if power plant located in a subdistrict	0.148	0.355	0.138	0.345	0.145	0.352	0.164	0.370	0.08	0.17	-0.093***
N		15,502		6711		3531		5260				

Note: No and Yes refer to households not connected and connected to electricity, respectively. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Table 1B: Summary Statistics With and Without Electricity over Year

	2007					2012					2017				
	No Grid (a)		Grid (b)		(a-b)	No Grid (a)		Grid (b)		(a-b)	No Grid (a)		Grid (b)		(a-b)
Variables	Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Firewood	2.295	1.525	1.696	1.544	0.599***	2.340	1.667	1.522	1.539	0.817***	2.173	1.829	1.498	1.422	0.675***
LPG	0.046	0.209	0.187	0.390	-0.141***	0.0847	0.279	0.445	0.497	-0.360***	0.362	0.482	0.564	0.496	-0.202***
Read/write	0.226	0.418	0.313	0.464	-0.087***	0.220	0.415	0.301	0.459	-0.080***	0.263	0.441	0.344	0.475	-0.082**
Age	48.93	14.39	48.36	14.74	0.57	50.00	14.87	51.31	14.70	-1.306**	48.84	13.52	50.71	14.21	-1.87
Female	0.295	0.456	0.384	0.486	-0.089***	0.275	0.447	0.379	0.485	-0.104***	0.331	0.472	0.411	0.492	-0.080**
Children	0.426	0.495	0.408	0.492	0.018	0.357	0.480	0.376	0.484	-0.019	0.294	0.457	0.334	0.472	-0.041
Size	5.328	2.478	5.222	2.335	0.107*	5.113	2.452	4.951	2.172	0.162*	4.131	2.210	4.512	2.067	-0.381**
Loan	0.115	0.319	0.185	0.388	-0.071***	0.126	0.332	0.245	0.430	-0.119***	0.156	0.364	0.330	0.470	-0.174***
Cattle	0.763	0.425	0.687	0.464	0.076***	0.750	0.433	0.773	0.419	-0.023	0.512	0.501	0.746	0.435	-0.234***
Expenditure	2,850	2,531	3,807	3,175	-956.2***	1,712	2,945	2,250	3,071	-538.0***	7,050	5,723	6,516	4,502	533.7
Market	5.092	9.535	1.143	2.826	3.949***	4.460	11.70	1.096	2.535	3.364***	2.894	12.57	0.835	1.950	2.059***
Forest	1.266	2.339	1.348	1.433	-0.083*	1.220	3.960	1.061	1.548	0.159*	3.016	4.942	1.206	2.331	1.809***
South	0.332	0.471	0.277	0.447	0.055***	0.432	0.496	0.241	0.428	0.191***	0.369	0.484	0.296	0.456	0.073**
Density	5.479	6.006	9.782	11.53	-4.303***	4.018	3.652	7.982	8.681	-3.964***	3.137	5.139	6.343	7.533	-3.206***
Substation	22.97	15.23	14.20	10.18	8.772***	25.36	14.86	16.04	10.99	9.319***	30.41	17.11	18.20	12.26	12.21***
Plant	0.082	0.274	0.183	0.386	-0.101***	0.0579	0.234	0.167	0.373	-0.109***	0.106	0.309	0.165	0.372	-0.059**
N	2,958		3,753			708		2,823			160		5,100		

Note: "No Grid" and "Grid" indicate nonelectrified and electrified households, respectively. N is the number of observations, and (a-b) is the mean difference between nonelectrified and electrified households for each year. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Table 2: Effect of Grid Electricity on Firewood Consumption

			2SLS		
	OLS		1^{st} Stage	2^{nd} Stage	
Variables	Firewood	Firewood	Electricity	Firewood	Firewood
Electricity	-0.656***	-0.522***		-1.757***	-1.512***
	(0.071)	(0.068)		(0.468)	(0.581)
Substation			-0.005***		
			(0.001)		
Plant			0.082***		
			(0.025)		
LPG		-0.428***	0.053***		-0.358***
		(0.052)	(0.013)		(0.055)
Read/write		-0.122***	0.034***		-0.082**
		(0.031)	(0.009)		(0.039)
Age		0.003**	0.001**		0.004***
		(0.001)	(0.000)		(0.001)
Female		-0.029	0.029***		0.009
		(0.037)	(0.010)		(0.036)
Children		0.030	-0.001		0.030
		(0.032)	(0.008)		(0.033)
Size		0.065***	0.003		0.068***
		(0.008)	(0.002)		(0.008)
Loan		-0.034	0.011		-0.011
		(0.041)	(0.009)		(0.040)
Cattle		0.277***	0.009		0.296***
		(0.047)	(0.012)		(0.043)
Expenditure (ln)		0.034	0.031***		0.064
		(0.031)	(0.010)		(0.039)
Market (ln)		0.045***	-0.071***		-0.034
		(0.017)	(0.006)		(0.050)
Forest (ln)		-0.019	0.031***		0.011
		(0.023)	(0.006)		(0.030)
South		-0.537***	-0.021		-0.566***
		(0.077)	(0.026)		(0.087)
Density		-0.016***	0.002*		-0.011***
		(0.003)	(0.001)		(0.003)
Constant	2.327***	1.765***	0.333***	2.943***	1.971***
	(0.069)	(0.280)	(0.096)	(0.286)	(0.358)
Observations	15,502	15,502	15,502	15,502	15,502
R-squared	0.044	0.118	0.337		0.066
Year FE	Y	Y	Y	Y	Y
Region FE	N	Y	Y	N	Y
Stock and Yogo's test for weak instruments: 301.41 [F(2, 15482), F critical=10]					
Hausman's test for overidentification restriction: 0.050 [$\chi^2(1)$ Critical=6.635]					

Note: Standard errors in parentheses are clustered at the subdistrict level. ***, ** and * indicate significance at the 1% 5% and 10% levels, respectively.

Table 3: Effect of Forest Cover and Wealth on the Locations of Substations and Plants

	Mean	Dep Var: Substation (0/1)		Dep Var: Plant (0/1)	
Variables	(SD)	No District	District	No District	District
Panel A					
Forest	78.177	-0.001	-0.001	0.001	0.002
	(18.933)	(0.001)	(0.001)	(0.001)	(0.001)
Observations		205	205	205	205
Panel B					
Middle	0.234	-0.022	-0.019	0.029	0.039
	(0.426)	(0.046)	(0.056)	(0.053)	(0.050)
Rich	0.049	0.002	0.080	0.002	0.083
	(0.216)	(0.109)	(0.136)	(0.109)	(0.121)
Observations		205	205	205	205
Panel C					
		LPG (0/1)		Kerosene (0/1)	
Substation	0.328	-0.0003		0.000	
	(0.470)	(0.0005)		(0.001)	
Plant	0.194		0.030		-0.040*
	(0.396)		(0.018)		(0.023)
Observations		15,502	15,502	15,502	15,502

Note: Robust standard errors appear in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. In panel B, subdistricts are first categorized as poor, middle and wealthy based on the wealth index, which is first calculated at the household level using eleven different wealth indicators as $1/11 \sum_{j=1}^{11} A_{ij}$ using whether the house has a metal roof, concrete walls, toilet facilities, and a piped water connection, number of rooms, household size, whether it owns a radio, phone, land, and livestock and whether the primary income is from a business or not. The wealth index at the subdistrict level is calculated as the average of the household level wealth index within each subdistrict. The base category is the poor subdistrict. In panel C, the outcome variable LPG is 1 if the primary cooking fuel is LPG and zero otherwise. Similarly, kerosene is 1 if the lighting fuel is kerosene and zero otherwise. In panel C, the same set of control variables as in Table 2 are included, and primary cooking fuel as firewood is added; therefore, the excluded category is electricity (district dummies are not included in panel C). All of the regression coefficients are estimated including intercepts but are not reported for brevity purposes.

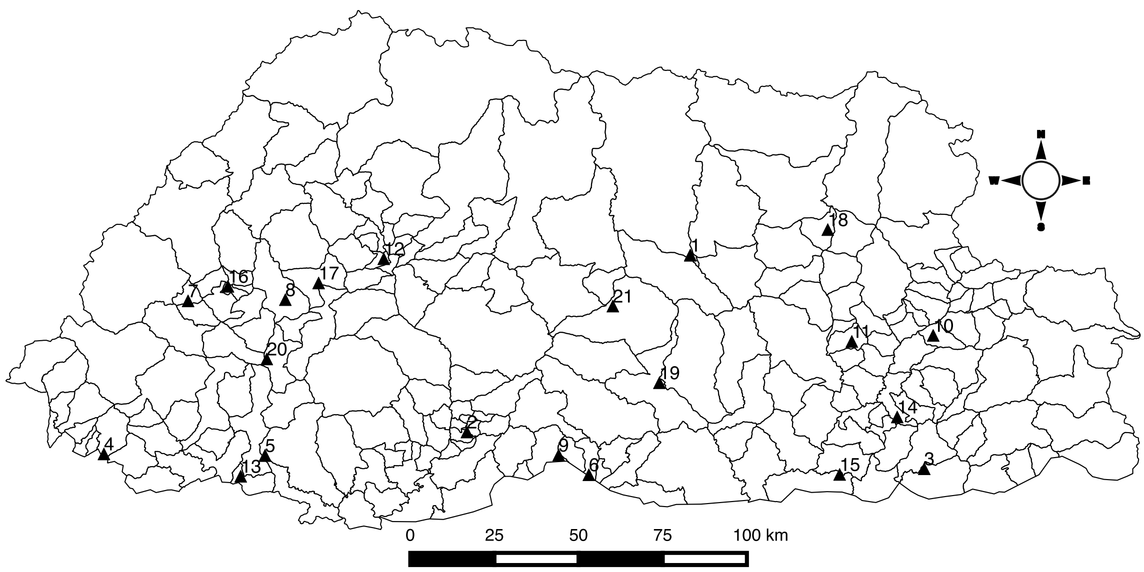
Table 4: Effect of Grid Electricity on the Adoption of Cooking Fuel, Lighting Fuel and Appliances

	Electricity Is Cooking Fuel	Firewood Is Cooking Fuel
Panel A: Cooking Fuel Model		
Electricity	2.503***	-1.820***
	(0.252)	(0.172)
APE	0.613***	-0.353***
	(0.024)	(0.019)
Controls	Yes	Yes
Observations	15,502	15,502
Mean (SD)	0.596(0.491)	0.514(0.500)
	Lighting Fuel Is Electricity	Lighting Fuel Is Kerosene
Panel B: Lighting Fuel Model		
Electricity	3.475***	-1.811***
	(0.126)	(0.565)
APE	0.864***	-0.377***
	(0.018)	(0.048)
Controls	Yes	Yes
Observations	15,502	15,502
Mean (SD)	0.758(0.428)	0.195(0.396)
	Rice Cookers	Refrigerators
Panel C: Appliance Model		
Electricity†	0.681**	0.680***
	(0.289)	(0.292)
APE	0.166***	0.154***
	(0.339)	(0.031)
Controls	Yes	Yes
Observations	11,676	11,676
Mean (SD)	0.811(0.392)	0.289(0.454)

Note: Standard errors in parentheses are clustered at the subdistrict level. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. The coefficients reported above are from bivariate probit models, and the full results are reported in Appendix Tables A5 & A6. APE stands for the average partial effect, and standard errors are bootstrapped (by drawing a sample with replacement) with 500 replications by setting the seed at 123. Mean (SD) is the mean and standard deviation of the respective outcome variables. The variable electricity † in panel C is defined as 1 if the subdistrict has been electrified for more than seven years. Panel C includes only households that have reported that they are connected to electricity.

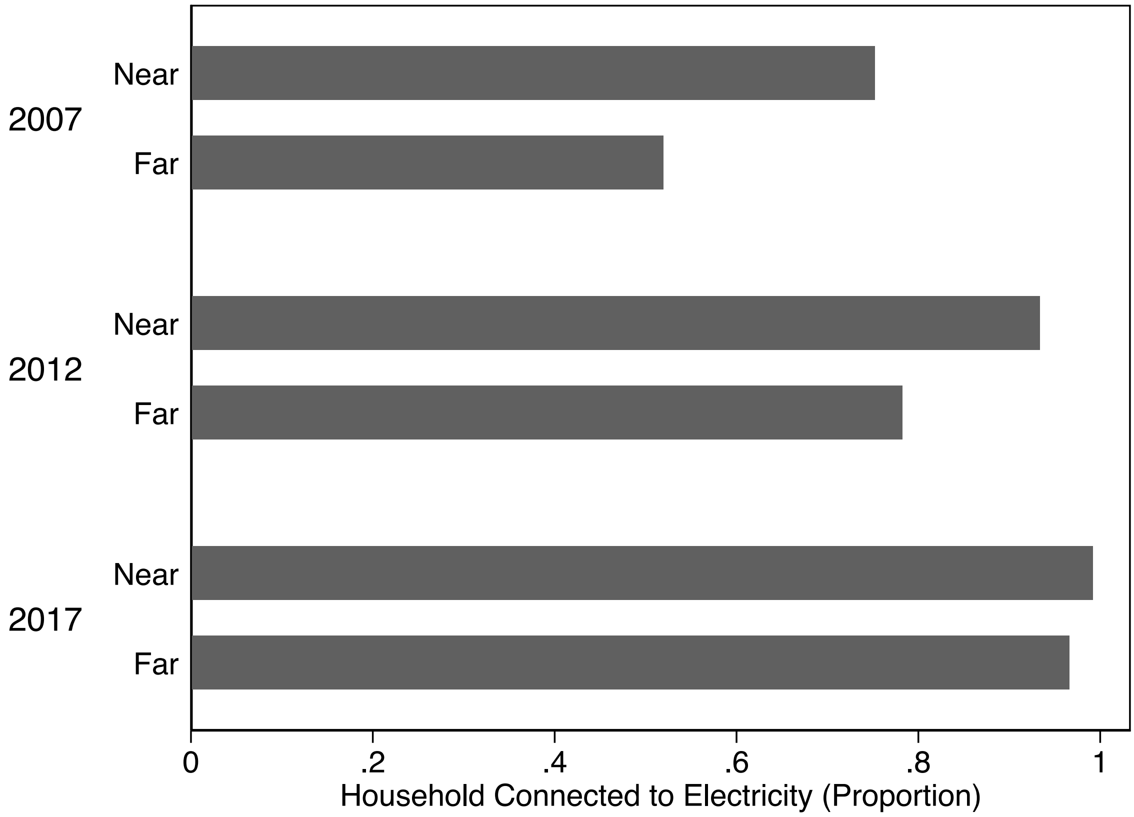
Figure

Figure 1: Bhutan Map Showing the Location of Substations with a Subdistrict Boundary



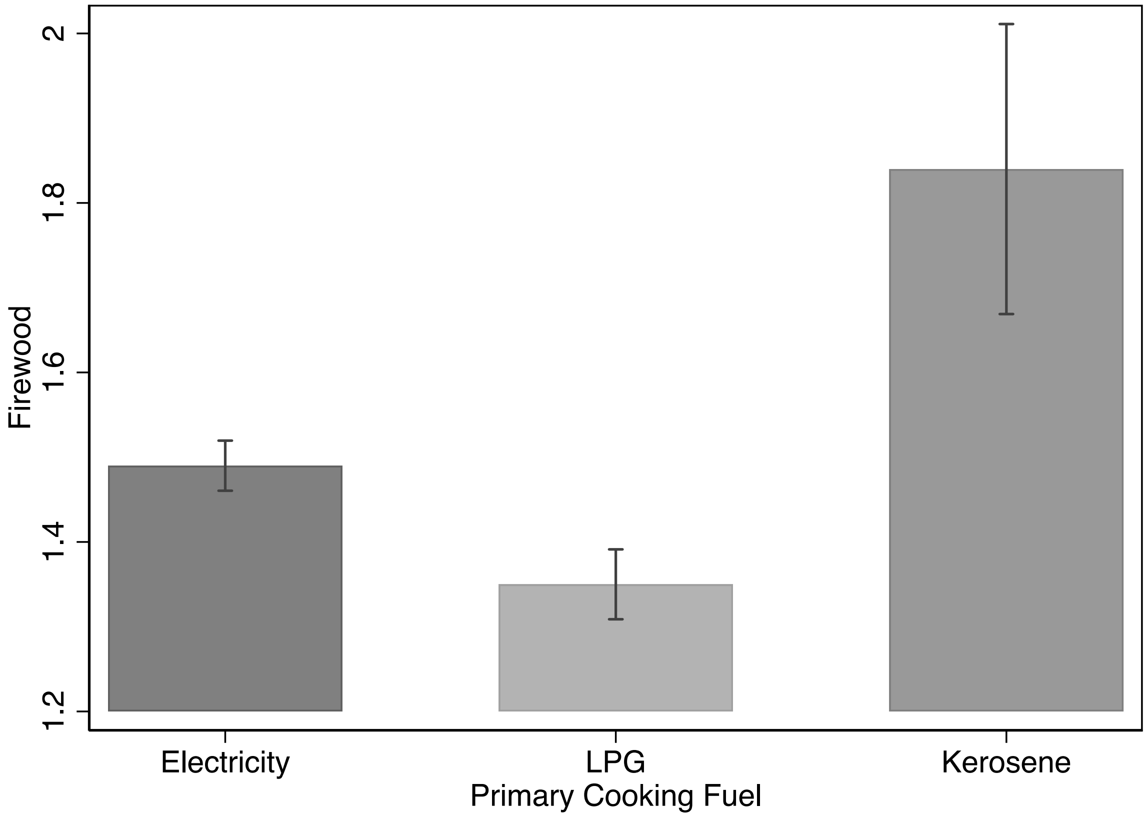
Note: The names of the substations from 1 through 21 are Bumthang, Darjey, Dewathang, Dhamdum, Gedu, Gelephu, Haa, Jemina, Jigmeling, Kanglung, Kilikhar, Lobesa, Malbase, Nangkhor, Nganglam, Paro, Simtokha, Tangmachu, Tingtibi, Watsa and Yurmo. The substations included in this study are only those used for rural electrification, and the above list does not include the substations built exclusively for supplying electricity to urban households, such as the Dechencholing and Olakha substations, which were built for supplying electricity to the capital city of Thimphu. The Phuntsholing substation is also not included since it was primarily built to supply electricity to the commercial town of Phuntsholing. Similarly, I also did not include the Gomtu and Shinhigoen substations since the Gomtu substation was built for industrial purposes, while the Shinhigoen substation was used to export excess electricity to India. In addition, the Darjey, Dhamdum, Jigmeling and Yurmo substations were built in 2015, 2014, 2015 and 2016, respectively, and were not used for calculating the distance from the nearest substation to the subdistrict since it was not clear whether these substations contributed to the electrification status of households for the BLSS 2017 (when data collection started in 2016). Other details in terms of the year of substation construction and location (i.e., district and subdistrict) are provided in Appendix Table A1.1.

Figure 2: Proportion of Household Electrification Status by Distance to a Substation



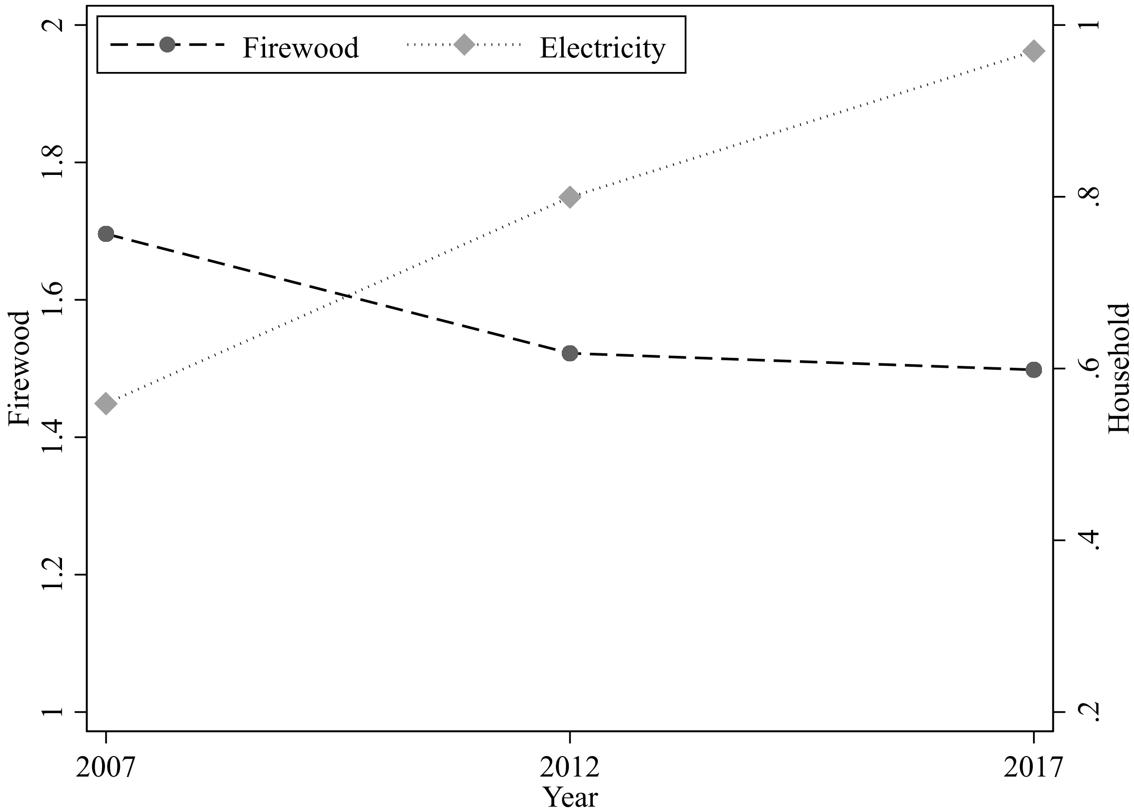
Note: Households located in the same subdistrict as the substation are defined as near, and households located in a subdistrict that does not have a substation are defined as far.

Figure 3: Firewood Consumption Compared to Other Cooking Fuels



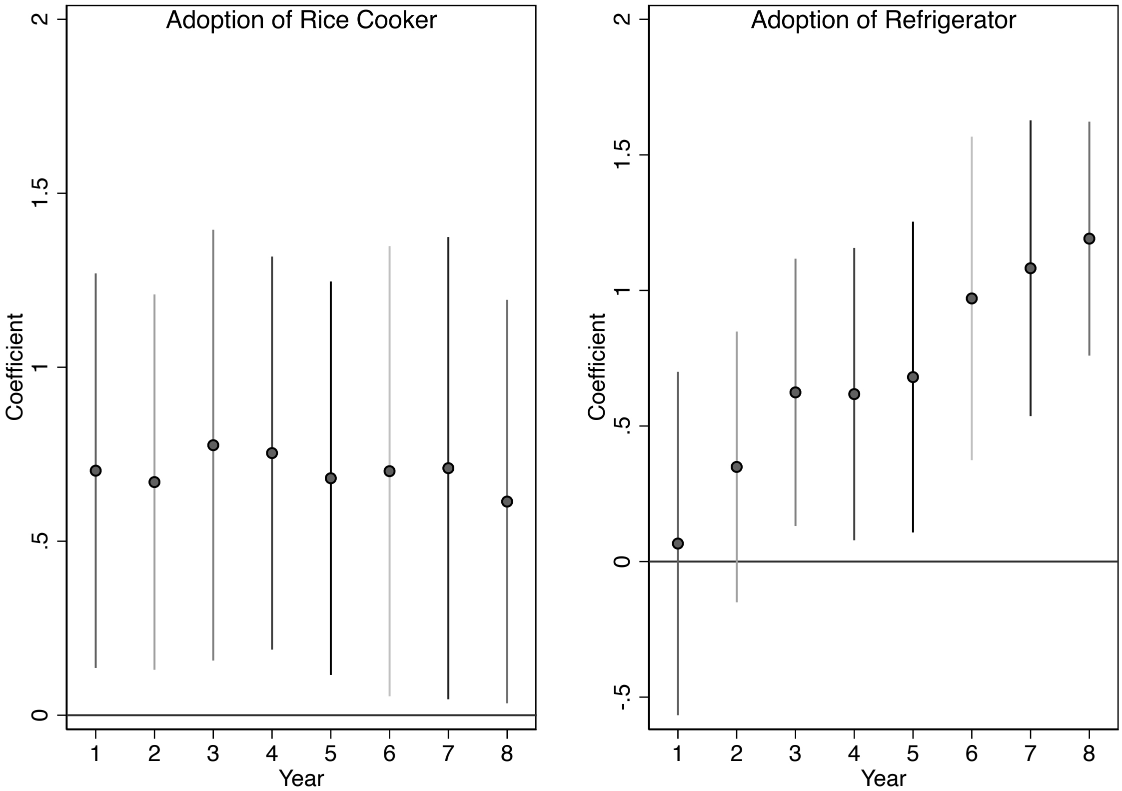
Note: Firewood consumption is the average consumption (in cubic meters) by households that have reported their primary cooking fuel as electricity, LPG and kerosene.

Figure 4: Change over Years in Firewood Consumption by Electrified Households



Note: Firewood consumption is the monthly firewood consumption by electrified households only (while the proportion of electrified households includes both electrified and nonelectrified). The primary axis (or left y-axis) is monthly firewood consumption in cubic meters, and the secondary axis (or right y-axis) is the proportion of households connected to grid electricity.

Figure 5: Effect of Electrification on Appliance Adoption



Note: The left figure shows the adoption of rice cookers, and the right figure shows the adoption of refrigerators with a 95% confidence interval. The y-axis in each figure shows the coefficient of the bivariate probit model. Each coefficient (and 95% CI) is plotted from a separate bivariate probit model of one year of electrification to eight years of electrification.

Table A1.1: Summary Statistics of Substations

Sl.No	Station	Built Year	District	Subdistrict
1	Bumthang	1989	Bumthang	Chhoekhor
2	Darjey	2015	Tsirang	Rangthangling
3	Dewathang	2003	Samdrupjongkar	Dewathang
4	Dhamdum	2014	Samtse	Chengmari
5	Gedu	1983	Chukha	Bongo
6	Gelephu	1989	Sarpang	Chuzagang
7	Haa	1988	Haa	Katsho
8	Jemina	2002	Thimphu	Mewang
9	Jigmeling	2015	Sarpang	Dekiling
10	Kanglung	2003	Tashigang	Kanglung
11	Kilikhar	2003	Mongar	Mongar
12	Lobesa	1986	Punakha	Bapisa
13	Malbase	2006	Chukha	Sampheling
14	Nangkhor	2003	Pemagatshel	Shumer
15	Nganglam	2003	Pemagatshel	Norbugang
16	Paro	1988	Paro	Wangchang
17	Simtokha	1983	Thimphu	Chang
18	Tangmachu	2004	Lhuentse	Menbi
19	Tingtibi	2002	Zhemgang	Trong
20	Watsa	1997	Chukha	Watsa
21	Yurmo	2016	Yurmo	Langthil

Note: The substations included in this study are only those used for rural electrification, and the above list does not include the substations built exclusively for supplying electricity to urban households, such as the Dechencholing and Olakha substations, which were built for supplying electricity to the capital city of Thimphu. The Phuntsholing substation is also not included since it was primarily built to supply electricity to the commercial town of Phuntsholing. Similarly, I also did not include the Gomtu and Shinhigoen substations since the Gomtu substation was built for industrial purposes, while the Shihigoen substation was used for exporting excess electricity to India. In addition, the Darjey, Dhamdum, Jigmeling and Yurmo substations were not used when calculating the distance from the nearest substation to the subdistrict since it was not clear whether they had contributed to the electrification status of households for the BLSS 2017 (when data collection actually started in 2016).

Table A1.2: Summary Statistics of Hydropower Plants

Sl	Name	Capacity	Built Year	District	Subdistrict
1	Basochu Hydropower Plant	64 MW	2005	Wangdiphodang	Gatetshowom & Daga
2	Chukha Hydropower Plant	336 WM	1988	Chukha	Darla
3	Kurichu Hydropower Plant	60 WM	2001	Mongar	Drepong
4	Tala Hydropower Plant	1020 MW	2006	Chukha	Bjachog
5	Ura Mini Hydel	50 kW	1987	Bumthang	Ura
6	Tamzhing Mini Hydel	30 kW	1987	Bumthang	Chumey
7	Chumey Mini Hydel	150 kW	1989	Bumthang	Chumey
8	Darachu Mini Hydel	200 kW	1992	Dagana	Tseza
9	Gangzur Mini Hydel	120 kW	2000	Lhuntse	Gangzur
10	Khalangzi Mini Hydel	300 kW	1992	Mongar	Mongar
11	Sengor Mini Hydel	100 kW	1992	Mongar	Saling
12	Thimphu Mini Hydel	360 kW	1967	Thimphu	Mewang
13	Thinleygang Mini Hydel	30 kW	1987	Thimphu	Chang
14	Chenangri Mini Hydel	750 kW	1987	Tashigang	Samkhar
15	Rangjung Mini Hydel	2.2 MW	1996	Tashigang	Shongphu
16	Tangsibji Mini Hydel	30 kW	1987	Trongsa	Tangsibji
17	Trongsa Mini Hydel	50 kW	1987	Trongsa	Nubi
18	Bubja Mini Hydel	30 kW	1987	Trongsa	Dragteng
19	Chachey Mini Hydel	200 kW	1991	Tsirang	Gosarling
20	Rukhubji Mini Hydel	40 kW	1987	Wangdiphodang	Sephug
21	Khekhar Mini Hydel	20 kW	1987	Zhemgang	Nangkhor
22	Tintibi Mini Hydel	200 kW	1992	Zhemgang	Trong

Note: The hydropower plants that were completed after 2017 are not included in the above list, and no plants were completed between 2007 and 2017.

Table A2: Effect of Electricity on Firewood Consumption without LPG

Variables	Electricity	Firewood
Electricity		-1.690***
		(0.578)
Read/write	0.039***	-0.107***
	(0.009)	(0.041)
Age	0.001**	0.004***
	(0.000)	(0.001)
Female	0.033***	-0.012
	(0.010)	(0.038)
Children	-0.001	0.026
	(0.008)	(0.034)
Size	0.004*	0.061***
	(0.002)	(0.009)
Loan	0.015	-0.034
	(0.009)	(0.042)
Cattle	0.006	0.318***
	(0.012)	(0.043)
Expenditure (ln)	0.040***	0.015
	(0.010)	(0.040)
Market (ln)	-0.072***	-0.037
	(0.006)	(0.050)
Forest (ln)	0.030***	0.023
	(0.006)	(0.030)
South	-0.029	-0.521***
	(0.026)	(0.089)
Density	0.003**	-0.011***
	(0.001)	(0.003)
Substation	-0.005***	
	(0.001)	
Plant	0.085***	
	(0.025)	
Constant	0.272***	2.426***
	(0.096)	(0.351)
Observations	15,502	15,502
R-squared	0.335	0.038
Year FE	Y	Y
Region FE	Y	Y

Note: Standard errors in parentheses are clustered at the subdistrict level. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Table A3: OLS Results of the Effect of Grid Electricity on Firewood by Year

Variables	Pooled	2007	2012	2017
Electricity	-0.522***	-0.461***	-0.585***	-0.433***
	(0.068)	(0.101)	(0.107)	(0.160)
LPG	-0.428***	-0.470***	-0.547***	-0.240***
	(0.052)	(0.097)	(0.088)	(0.077)
Read/write	-0.122***	-0.218***	-0.077	-0.049
	(0.031)	(0.051)	(0.063)	(0.046)
Age	0.003**	0.004**	0.004*	-0.001
	(0.001)	(0.001)	(0.002)	(0.002)
Female	-0.029	-0.027	0.082	-0.104**
	(0.037)	(0.056)	(0.066)	(0.048)
Children	0.030	0.041	0.024	0.036
	(0.032)	(0.042)	(0.063)	(0.051)
Size	0.065***	0.078***	0.054***	0.039***
	(0.008)	(0.014)	(0.015)	(0.014)
Loan	-0.034	-0.085	-0.037	-0.006
	(0.041)	(0.074)	(0.069)	(0.057)
Cattle	0.277***	0.414***	0.177**	0.118*
	(0.047)	(0.069)	(0.075)	(0.061)
Expenditure (ln)	0.034	0.014	0.045	0.057
	(0.031)	(0.057)	(0.039)	(0.061)
Market (ln)	0.045***	0.001	0.070**	0.076***
	(0.017)	(0.027)	(0.028)	(0.026)
Forest (ln)	-0.019	-0.035	-0.048	0.040
	(0.023)	(0.035)	(0.039)	(0.033)
South	-0.537***	-0.593***	-0.266**	-0.523***
	(0.077)	(0.097)	(0.124)	(0.103)
Density	-0.016***	-0.017***	-0.007	-0.018***
	(0.003)	(0.005)	(0.005)	(0.006)
Constant	1.765***	1.640***	1.513***	1.995***
	(0.280)	(0.450)	(0.355)	(0.585)
Observations	15,502	6,711	3,531	5,260
R-squared	0.118	0.161	0.121	0.060
Year FE	Y			
Region FE	Y	Y	Y	Y

Note: Standard errors in parentheses are clustered at the subdistrict level. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Table A4: Effect of Wealth Indicators on the Locations of Substations and Plants

	Mean	Dep Var: Substation (0/1)		Dep Var: Plant (0/1)	
Variables	(SD)	No District	District	No District	District
Panel A: Wealth Indicators					
Roof	0.529	0.222**	0.290***	0.173**	0.339***
	(0.212)	(0.098)	(0.109)	(0.076)	(0.095)
Wall	0.381	0.009	0.042	0.007	-0.041
	(0.251)	(0.075)	(0.154)	(0.080)	(0.119)
Room	2.524	0.028	0.056	0.068***	0.062*
	(0.696)	(0.033)	(0.046)	(0.025)	(0.033)
Toilet	0.838	-0.161	-0.111	0.089	0.066
	(0.136)	(0.180)	(0.193)	(0.090)	(0.118)
Water	0.741	0.182*	0.218	0.284***	0.271***
	(0.190)	(0.108)	(0.132)	(0.074)	(0.090)
Size	4.682	-0.050*	-0.065	-0.009	-0.027
	(0.573)	(0.028)	(0.050)	(0.032)	(0.043)
Radio	0.649	-0.071	-0.164	0.260**	0.172
	(0.121)	(0.192)	(0.261)	(0.130)	(0.184)
Business	0.030	0.797	0.464	0.654	0.563
	(0.036)	(0.787)	(0.931)	(0.677)	(0.917)
Phone	0.063	0.945***	1.575***	0.579**	1.209***
	(0.100)	(0.296)	(0.395)	(0.267)	(0.332)
Land	0.742	-0.287**	-0.207	-0.178	-0.158
	(0.181)	(0.134)	(0.169)	(0.110)	(0.118)
Livestock	0.562	-0.420***	-0.376**	-0.158	-0.220*
	(0.179)	(0.136)	(0.144)	(0.117)	(0.113)
Observations		205	205	205	205

	NNM w/ ematch	NNM w/o ematch	OTO	OLS
Panel B: Propensity Score Matching				
ATE	-0.541***	-0.540***	-0.608***	-0.510***
	(0.059)	(0.059)	(0.098)	(0.100)
ATT	-0.627***	-0.628***	-0.650***	
	(0.073)	(0.073)	(0.126)	
Controls				Yes
Observations				23,352

Note: In panel A, the coefficients of all of the wealth indicators are estimated from each separate regression with the intercept but are not reported for brevity purposes. In panel B, the first three columns are estimated using treatment effect syntax "teffects" implemented in Stata. NNM stands for nearest neighbor matching, and OTO stands for one to one matching. NNM w/ is estimated using the nearest neighbor matching estimator by comparing households from the same region and same district, while NNM w/o does not impose this restriction. ATE and ATT stand for average treatment effect and average treatment effect of electricity on firewood consumption, respectively. The propensity score is estimated using the logit model by conditioning it on the following covariates: substation, plant, read/write, age, female, children, size, cattle, expenditure, market, forest, south, regional dummy and year dummy. For the last column, I first matched each connected household with one unconnected households using the propensity score. Then, using only matched samples, the effect of electricity on firewood consumption is estimated by controlling for the same set of covariates included in Table 2 by linear regression. The standard errors of first three columns are default robust Abadie to Imbens standard errors, and standard errors of the last column are clustered at the subdistrict level. For all of the coefficients, ***, ** and * indicate significance at 1%, 5% and 10%, respectively.

Table A5: Bivariate Probit on the Adoption of Cooking Fuel & Lighting Fuel

	Cooking Fuel			Lighting Fuel	
Variables	Electricity	Electricity Is Cooking Fuel	Firewood Is Cooking Fuel	Electricity Is Lighting Fuel	Kerosene Is Lighting Fuel
Electricity		2.503***	-1.820***	3.475***	-1.811***
		(0.252)	(0.172)	(0.126)	(0.565)
LPG	0.502***	-0.561***	-2.746***	0.153*	-0.390***
	(0.083)	(0.098)	(0.077)	(0.087)	(0.108)
Read/write	0.146***	0.121***	-0.122***	0.074	-0.143***
	(0.043)	(0.044)	(0.037)	(0.053)	(0.056)
Age	0.004***	-0.005***	0.006***	0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)
Female	0.177***	0.187***	-0.225***	0.039	-0.108*
	(0.052)	(0.044)	(0.042)	(0.046)	(0.056)
Children	-0.012	0.006	-0.023	0.011	0.003
	(0.036)	(0.035)	(0.034)	(0.047)	(0.044)
Size	0.029***	0.069***	-0.028***	0.017	-0.051***
	(0.010)	(0.009)	(0.010)	(0.011)	(0.013)
Loan	0.118**	0.083**	-0.121***	0.014	-0.106*
	(0.052)	(0.038)	(0.044)	(0.057)	(0.059)
Expenditure (ln)	0.177***	0.414***	-0.305***	0.140**	-0.320***
	(0.048)	(0.035)	(0.041)	(0.055)	(0.062)
Market (ln)	-0.306***	-0.117***	0.074***	-0.001	0.061
	(0.027)	(0.022)	(0.023)	(0.028)	(0.073)
Forest(ln)	0.042	-0.034	0.008	0.036	-0.065**
	(0.028)	(0.021)	(0.022)	(0.026)	(0.028)
Substation	-0.026***				
	(0.004)				
Plant	0.376***				
	(0.129)				
Constant	-1.177***	-6.158***	3.991***	-2.951***	3.251***
	(0.442)	(0.329)	(0.367)	(0.420)	(0.426)
Observations	15,502	15,502	15,502	15,502	15,502
ρ		-0.021	0.086	-0.517***	-0.258
		(0.133)	(0.095)	(0.119)	(0.298)
Year FE	Y	Y	Y	Y	Y
Region FE	Y	Y	Y	Y	Y

Note: Standard errors in parentheses are clustered at the subdistrict level. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. The results of the electricity equation are for firewood, while cooking fuel and lighting fuel are not reported for brevity purposes.

Table A6: Bivariate Probit Results of the Adoption of Appliances

Variables	Electricity†	Rice Cookers	Refrigerators
Electricity†		0.681**	0.680**
		(0.289)	(0.292)
LPG	0.148	0.394***	0.743***
	(0.095)	(0.054)	(0.052)
Read/write	-0.092**	0.214***	0.300***
	(0.046)	(0.042)	(0.040)
Age	0.001	-0.004***	0.003**
	(0.002)	(0.001)	(0.001)
Female	0.165**	0.116**	-0.001
	(0.076)	(0.049)	(0.040)
Children	0.031	0.014	-0.043
	(0.032)	(0.038)	(0.036)
Size	0.008	0.084***	0.080***
	(0.018)	(0.011)	(0.010)
Loan	-0.026	0.050	0.149***
	(0.052)	(0.052)	(0.039)
Expenditure (ln)	0.136**	0.456***	0.470***
	(0.066)	(0.041)	(0.047)
Market(ln)	-0.067**	-0.078***	-0.106***
	(0.028)	(0.018)	(0.019)
Forest (ln)	0.003	-0.012	-0.053***
	(0.037)	(0.021)	(0.018)
Substation	-0.024***		
	(0.008)		
Constant	-1.028*	-4.400***	-5.832***
	(0.608)	(0.325)	(0.403)
ρ		-0.223	-0.301
		(0.179)	(0.185)
Observations	11,676	11,676	11,676
Year FE	Y	Y	Y
Region FE	Y	Y	Y

Note: Standard errors in parentheses are clustered at the subdistrict level. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. The variable electricity† in the above model is defined as 1 if the subdistrict has been electrified for more than seven years. The appliance model includes only households that have electricity connections. The results of the electricity† equation for electricity are not reported for brevity purposes.