The expansion of renewable energy technologies and their impact on household energy portfolios and sustainable development: A study of Nepal

by

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Abstract

Encouraging households to switch from traditional fuels to cleaner, modern fuels (e.g.; electricity, liquid petroleum gas (LPG), biogas) is a widespread policy focus due to its expected benefits for health and the environment. Many of these policies are based on the assumption that increasing modern fuel use automatically results in a decrease in the use on traditional fuels. However, this paper contributes to a growing body of literature showing that is not necessarily the case. Wood use remains fairly stable across most income categories even as adoption of modern fuels increases. Factors contributing to fuel choice vary in their direction and magnitude across countries and contexts. In this paper, I demonstrate that in the case of Nepal in the 2000s, household size, income, female education, forest management policies, and market access all influence household fuel choice, but that these associations differ depending on how fuel use is measured.

Introduction

Understanding and influencing household fuel choice behavior is a critical policy issue throughout much of the developing world. As many households in these countries still rely on traditional biomass fuels, the potential gains to transitioning to modern, cleaner fuels are likely large and could even achieve a "triple dividend" in terms of household health, local environmental quality, and regional climate (Lewis & Pattanayak, 2012). Throughout this paper, I refer to electricity, LPG, and biogas as modern or clean fuels and to wood, dung, and other biomass as traditional or dirty fuels. Kerosene is considered to be a transition fuel.

Policy instruments that promote adoption and use of modern fuels in attempt to reduce reliance on traditional fuels hinge on flawed understanding of how households make their fuel decisions. Namely, they rely on the assumption that a household that increases its consumption of modern fuels will automatically reduce its consumption of traditional fuels. A large body of anecdotal and quasi-experimental evidence built over the past two decades and spanning a wide variety of countries and contexts demonstrates that this is not necessarily, or even often the case (Foley, 1995; Masera, Saatkamp & Kammen, 2000; Heltberg, 2004; Heltberg, 2005; Hiemstra-van der Horst & Hovorka, 2008; Baland et al, 2010).

This assumption is reflected and reinforced by a series of hypotheses that deal with the relationship between poverty and the environment. These hypotheses have become so ingrained in energy policy thinking that they are often presumed to be fact. Each predicts that as households get richer they will (eventually) make decisions that are more environmentally friendly, and each can be applied to fuel choice. The energy ladder hypothesis, specifically designed to address household fuel consumption decisions, claims that energy sources are inherently ranked based on desirable qualities such as cleanliness, ease-of-use, speed of cooking, etc., and that households will choose to use the highest ranked fuel that they can access and afford. Thus, as households become wealthier, they will abandon dirty, traditional fuels in favor of cleaner modern fuels and move up the energy ladder. However, economic models of household fuel consumption show that the relationship between income and fuel choice is theoretically ambiguous and depends on the direction and magnitude of income and substitution effects, as well as other relevant factors such as how much households value health and time (Hanna & Oliva, 2015; Baland et al, 2010).

Understanding a household's fuel behavior is therefore an empirical question, and a complex one at that. Fuel choice is not only driven by economic and household factors, but also largely depends on local preferences and customs, making it hard to generalize findings or implement widespread policies. Many households use different fuels for different purposes, leading to low substitutability between fuels. In addition, switching to modern fuels often involves the adoption of a new technology, which has been shown to hinder the spread of otherwise promising innovations and policies, or other barriers such as new appliances or hook-ups, which can be costly and deter uptake. Finally, in many of these countries, just because a modern fuel is available does not mean it is reliable. Households must often employ a variety of fuels to deal with large price fluctuations or ubiquitous instances of electricity outages and load shedding. Thus, as Hiemstra-van der Horst and Hovorka stated (2008): "Theoretical models must recognize and incorporate the creativity, flexibility, and diversity of consumers in deciding how best to meet household energy needs."

Recent literature suggests that households employ a strategy of "fuel stacking" (Masera, Saatkamp & Kammen, 2010), where they adopt new fuels as they become available and affordable, but do not necessarily abandon the use of traditional fuels. Therefore, as income increases, households increase the size of the portfolio of fuels they apply to various energy needs. Yet it is still unclear what factors determine the use of various fuels. Evidence is mixed on the influence of modern fuel availability, price, household size, income, and other factors. This leads to ambiguity for researchers and policymakers alike as they attempt to understand and influence fuel behavior. Furthermore, it emphasizes the need to study fuel choice in individual contexts using the most complete fuel use data that can be obtained, rather than generalizing results from one or two studies to the rest of the world.

This paper uses rich household data from Nepal to identify the factors that predict fuel choice and use, measured in a variety of ways. In addition to factors that are often found to be relevant (e.g.; household size, income, caste), I also examine the influence of less studied factors such as female versus male education and forest access and management policies. I use a combination of descriptive and regression analysis to gain understanding of not only what influences fuel choice, but also how the influence of these factors changes depending on what types of fuel use data are analyzed. Because these household surveys contain multiple measures of fuel use, it allows for comparison between conclusions drawn using primary lighting and cooking fuel (often the only fuel information available in larger datasets), and more nuanced, often unavailable data.

I find that although results using primary fuel data support the energy ladder hypothesis (the proportion of households using electricity and LPG increase over time and with income), results exploiting more detailed information on household fuel use presents a complex story that follows the energy stacking model. The share of households using woodfuel remains high across both time and income groups. Rich households continue to use a significant amount of fuelwood, despite access to and use of modern fuels, possibly because wood is used for heating or as a backup for unreliable modern fuels. However, many do transition from collected wood to purchased wood. Women's education stands out as an important factor in predicting more modern fuel use and less traditional fuel use, much more so than men's education. Finally, I find that while fuel choice is overall income inelastic, this covers a wide range of elasticities that are visible when disaggregating by region and income class.

This paper is divided into 5 sections. In Section II, I provide an overview of household fuel choice models and the literature on the determinants of fuel behavior. Section III presents the data and methods used. Section IV summarizes the descriptive and regression results. Section V discusses and concludes.

Background and associated literature

Models for household fuel choice

As is the case with any household consumption decision, household fuel choice can be examined through the lens of a unitary household model, where the household chooses consumption levels of different fuel types (as well as any additional goods) to maximize utility subject to a set of constraints. Various forms of this model have been introduced and estimated in the economics literature. Hanna & Oliva (2015) consider a household choosing between consumption of a dirty fuel and all other consumption (which can include clean fuels). The undesirable traits of the dirty fuel enter the model through a reduction in health, which limits available hours of household labor. Therefore, as household capital increases, labor becomes more productive and households value health more, discouraging consumption of the dirty fuel. Applying this model to data from a previous randomized experiment that increased measures of household economic well-being, they find significant increases in electricity use, but no evidence for a transition to cleaner cooking fuels.

Baland et al (2010) propose a more complicated model where households choose levels of firewood (which must be collected), purchased fuel, leisure, and other goods to maximize utility subject to their given level of assets, fixed income, demographics, and time taken to collect firewood. They then apply the model to the 1995/96 Nepal Living Standards Survey (NLSS I) and find that the wealth and substitution effects depend on which assets are used to proxy for "living standards".

As demonstrated through these models, the relationship between wealth and fuel choice is theoretically ambiguous and depends on the strength and direction of the wealth and substitution effects, as well as the presence and strength of other possible effects (e.g. health). Yet even when these models are applied rigorously to real data, the results are varied and thus fail to provide conclusive information about how these effects interact.

Despite this ambiguity, there persists a strong belief in a fundamental connection between income level of the population and environmental outcomes. The Poverty-Environment Hypothesis (PEH), first proposed in 1993 by Jalal, posits that poverty is the “root cause “ of environmental degradation since the poor must rely on forest products for energy sources and fodder. The implication is that as households get wealthier, they will switch away from forest products and to more modern fuels, thus benefiting the environment.

A contrasting view is captured with the Environmental Kuznets Curve (EKC), which suggests an inverse-U shaped curve between income and environmental outcomes. In other words, the EKC assumes that the wealth effect dominates the substitution effect for poor households as they become richer, leading to increased use of dirty fuels. However, to the right of some income tipping point the EKC predicts substitution away from dirty fuels as income increases.

The Energy Ladder Hypothesis echoes the core assumptions of the PEH regarding the relationship between income and pro-environment decisions, but is more targeted in that it deals specifically with fuel use. It presumes that fuels are inherently ranked based on several characteristics including cleanliness and ease-of-use, and that households will choose the highest ranked fuel based on what they can access and afford. Although the energy ladder can be expanded to allow for different fuel applications such as lighting and cooking, it still is based on the idea that within each application, fuels are substitutes and have an inherent rank. It is easy to reconcile the different hypotheses: the PEH and Energy Ladder can be thought of as occurring on the right side of the EKC.

Each of these hypotheses is based on the following presumptions: modern fuels are always preferred to traditional fuels; households consume traditional fuels because they lack wealth or access to modern fuels; and traditional and modern fuels are highly substitutable. Policymakers trusting these hypotheses will thus conclude that increasing household income and availability of modern fuels with both 1) increase the use of modern fuels and 2) reduce reliance on traditional fuels. Although there is strong evidence that modern fuel use increases with wealth and availability, the literature is more equivocal when it comes to the relationship between wealth and abandoning traditional fuels.

Researchers studying fuel choice around the world have compiled a large amount of evidence suggesting that rather than switching fuels or moving up an energy ladder, households maintain a portfolio of fuels that they use for various tasks and different situations (Masera, Saatkamp & Kammen, 2000; Heltberg, 2004; Heltberg, 2005; Hiemstra-van der Horst & Hovorka, 2008; Baland et al, 2010). While new fuels are added to the portfolio as income increases, old fuels are not necessarily abandoned. As early as 1995, Foley suggested that rather than a ladder of energy types, there is a "ladder of energy *demand*" that runs from subsistence energy use to more diverse energy needs that arise as households get richer. While new energy sources are required to meet the new energy needs (e.g. appliances), traditional fuels are often still employed for basic uses. For instance, in Botswana, 68% of wood consumers use it mainly for cooking traditional foods that require long cooking times and 63% of gas consumers use it mainly for modern or store bought foods that cook quickly (Hiemstra-van der Horst & Hovorka, 2008). Masera, Saatkamp & Kammen (2000) coined the term "energy stacking" to refer to the accumulation of energy options they observed in Mexico.

The concept of energy stacking calls into question each of the main assumptions underlying the traditional income/environment hypotheses discussed above. First, modern fuels are not necessarily preferred to traditional fuels. This assumption relies on the premise that households value the qualities of modern fuels, such as cleanliness and ease of use, over qualities of traditional fuels, such as fuel-economy and easy access. However, evidence from Botswana shows that most households prioritize spending economy over convenience (Hiemstra-van der Horst & Hovorka, 2008). This sentiment is echoed in the improved cookstove (ICS) literature: ICS are more popular in areas where they are seen as saving money than in areas where they are seen as saving time and biomass (Arnold, Köhlin & Persson, 2005). Households often base fuel decisions on what is abundant and easily available rather than what they can afford[1] (Hanna & Oliva, 2015). Second, households continue to consume traditional fuels despite increases in wealth and access to modern fuels, contradicting the idea that wood is the "fuel of the poor" (Hiemstra-van der Horst & Hovorka, 2008; Heltberg, 2004; Heltberg, 2005). Finally, traditional and modern fuels may not be very good substitutes for each other due to inherent qualities or local context. As stated in Hiemstra-van der Horst and Hovorka (2008): "[wood] is not so much

[1] For instance, a household may be able to afford LPG, but will continue to use dung if they have it in surplus.

an energy source of last resort, but a fuel actively chosen for specific reasons" based on "preferences and broader lifestyle considerations".

Factors contributing to fuel choice

Since available evidence contradicts conventional hypotheses about fuel use and economic modeling is inconclusive, understanding the factors driving fuel choice becomes an empirical issue. Researchers have examined several factors with different levels of rigor and have arrived at varying conclusions. A 2012 review by Lewis and Pattanayak aggregates much of the more rigorous information on the adoption of improved fuels and cookstoves. They find that income, education, and urban location are generally, but not exclusively, positively linked with adoption. In contrast, evidence on the impacts of fuel availability, prices, and household characteristics such as size and gender composition is unclear. Heltberg (2004) analyzes Living Standards Measurement Surveys from eight countries to examine the household-level determinants of fuel use and fuel switching. Both the size and direction of many factors vary across countries. Below I summarize more of the literature regarding different determinants of fuel choice and amount of fuel used. In many cases, the evidence is contradictory.

The relationship between income and fuel choice is clearly not as obvious as some of the hypotheses discussed above predict, but it is still an important factor. A significant body of evidence supports the concept of fuel stacking, or an increase in the adoption of fuels as income increases without abandonment of traditional fuels (Masera, Saatkamp & Kammen, 2000; Heltberg, 2005). Richer households are found to be more likely to use clean fuels (Alem et al., 2015; Farsi, Filippini, & Pachauri, 2007; Heltberg, 2005), but many studies have found little or no impact of income on the use of traditional fuels (Hiemstra-van der Horst & Hovorka, 2008; Arnold, Köhlin & Persson, 2005; Heltberg, 2005). In fact, the amount of wood use has been found to be increasing with income (Baland et al, 2010), suggesting that it remains a normal good throughout much of the income distribution.

Households cannot adopt modern fuels unless they have access to them. However, access does not necessarily ensure adoption or use. The impact of modern fuel availability on use depends both on the substitutability of the new fuel for old fuels (both in terms of purpose and ability to conform with traditional customs and practices) and how easy the new fuel is to use and maintain (Heltberg, 2005). This phenomenon has been particularly well documented in the context of adoption and use of improved cooking stoves (Barnes et al, 1993; Hanna, Duflo & Greenstone, 2016). In addition, there are often fixed costs associated with new fuels, such as new stove types or hookups, that act as barriers to adoption (Heltberg, 2005; Israel, 2002). Finally, even if increased access to modern fuels increases use of those fuels, this does not necessarily imply a reduction in consumption of traditional fuels (Hiemstra-van der Horst & Hovorka, 2008; Nepal, Nepal & Grimsrud, 2010). Increased access to biogas and LPG stoves have, however, been shown to both increase use of these fuels and reduce consumption of firewood (Meeks, Sims & Thompson, 2016; Somanathan & Bluffstone, 2015; Brooks et al, 2015).

A trend that emerges throughout the literature is that the cost of fuel plays a large role in household fuel choice and that households prioritize fuel economy over other desirable traits including convenience and health impacts (Hiemstra-van der Horst & Hovorka, 2008; Gundimeda & Köhlin, 2008; Heltberg, 2005; Mobarak et al, 2012). For instance, a 10% increase in wood price is found to increase the probability of using clean energy by 0.83% and reduce the probability of using biomass fuels by 0.84% (Alem et al, 2015). However, switching between fuels based on which is cheapest is only an option for households that can access and afford multiple fuels. In a meta-review, Arnold, Köhlin & Persson (2005) find wood and coal to be price-inelastic, despite the availability of alternatives. This finding is supported in many studies of rural areas (Cooke, Köhlin & Gunnar, 2008; Gundimeda & Köhlin, 2008). This makes sense, as rural household can often only access and afford traditional fuels, making them necessary consumption. In addition, many households that collect wood are underemployed, so an increase in the collection time of wood (often used as the price of wood) results in more time spent collecting rather than substitution to another fuel (Cooke, Köhlin & Gunnar, 2008).

Price subsidies for modern fuels have been found to encourage fuel switching to electricity in Zimbabwe (Hiemstra-van der Horst & Hovorka, 2008), fossil fuels in India, kerosene in Indonesia, and coal in China (Arnold, Köhlin & Persson, 2005). They have also been found ineffective in reducing consumption of traditional fuels due to weak cross-price elasticities (Gupta & Köhlin, 2005). As a policy tool, fuel subsidies are expensive and often encourage increased use among wealthier families rather than adoption by new users (Gangopadyay, Ramaswami & Wadhwa, 2003; Farsi, Filippini, & Pachauri, 2007; Heltberg, 2005).

Increasing barriers to traditional fuel use is another policy tool that should be considered with extreme caution. Evidence shows that per capita fuelwood consumption decreases as the proportion of land under forest cover decreases (Arnold, Köhlin & Persson, 2005). The 60% decrease in woodfuel use in Hyderabad over a 13-year period was partially attributed to a logging ban (ESMAP, 1999). However, raising barriers to forest access often disproportionately hurts women and the poor, as they are the ones who primarily bear the burden of increased collection time (Cooke, 1998). In addition, it is often the poor who collect and sell wood; so limiting access may harm them both in terms of fuel availability and income.

Community forest management is a strategy that has been widely applied to address the depletion of local forest resources, with the idea that instituting property rights and management over forest that was previously open or managed by the central government (often de-facto open access) would both provide environmental protection and increase local income from extracted products. Although there is variation in the goals and management of forest user groups (Arnold, Köhlin & Persson, 2005), in practice, they have often been found to disproportionately favor those in positions of management and the wealthier classes and further disadvantage the poor and women (Cooke, Köhlin & Gunnar, 2008; Agarwal, 2001).

Finally, there is evidence that several household factors influence fuel choice. Household size has been found to increase the likelihood of using multiple fuels (Heltberg, 2005), but the evidence is mixed on its association with adoption of modern fuels (Lewis & Pattanayak, 2012; Heltberg, 2004; Brooks et al, 2015). Caste and education are found to be strong predictors of fuel use (Gundimeda & Köhlin, 2006; Lewis & Pattanayak, 2012; Heltberg, 2004; Heltberg, 2005). There is also some evidence that female empowerment contributes to increased modern fuel use (Israel, 2002; Farsi, Filippini & Pachauri, 2007).

Nepal Context

Nepal is divided into three ecological belts: from north to south they are the Mountain, Hill, and Terai. These belts differ in many ways including climate, terrain, culture, and access to markets and infrastructure. In addition, although wood is the primary traditional fuel source throughout Nepal, many areas in the Terai use dried cow dung, whereas dung use in the Hill and Mountain region is almost non-existent. Following Baland et al. (2010), I group the Hill and Mountain regions together for analysis of cooking fuels, but analyze the Terai separately.

Traditional fuel use in Nepal remains high with one-third of households lacking access to electricity and 75% still relying on wood or dung for cooking (CBS, 2012). However, the government has been actively involved in the promotion of modern fuels including electricity (including micro-hydro projects and solar energy), LPG, and biogas, likely contributing to the increased adoption of these fuels in recent years.

Furthermore, Nepal has a highly developed system of Community Forest User Groups (CFUGs) that originated in the 1990s when the government began transferring management of forests to the local level (Agarwal, 2001). There are currently over 15,000 CFUGs involving 1.8 million households in the management of 1.35 million hectares of forest and shrub-land (Sharma et al, 2015).

Methods

Data sources

Household level data comes from the second and third rounds of the Nepal Living Standards Survey (2003/04 and 2010/11), conducted by Nepal's Central Bureau of Statistics and sponsored by the World Bank and the Government of Nepal. The surveys rounds, which include 3912 and 5988 households[2] from 326 and 500 primary sampling units, respectively, are nationally representative and provide a variety of demographic and socio-economic information.

The NLSS data are useful for considering fuel choice behavior because in addition to the primary fuel information collected by many household studies, they also provide more nuanced information on different fuels collected or purchased by the households. In the utilities section, households are asked about their primary fuel for both lighting (electricity, kerosene, solar, other)[3] and cooking (LPG, biogas, kerosene, wood, dung, leaves/rubbish, other)[4]. Further information on fuel use is scattered throughout the survey in the firewood collection, non-food expenditures, and household production sections. I count a household as using a given fuel if it reports it as their main fuel for either lighting or cooking, report spending any money on it or receiving it in kind (electricity, LPG, kerosene, wood), produce it (biogas), or collect it (wood). For these indicators, it is impossible to disentangle fuel use by application, except through the knowledge that in Nepal, electricity is almost never used as a cooking fuel and kerosene is the only fuel that is commonly used for both lighting and cooking. I then use information on the

[2] Total of 9900 households in sample reduced to 9787 for analysis due to missing income information.
[3] Solar was only included as an option in 2010. Biogas was also a lighting option in 2010, but as only 23 households reported biogas, this was grouped with other.
[4] For the analysis, dung and leaf/rubbish were grouped together as fuels being of lesser quality than wood.

value spent or received in kind and amount collected where available to look at quantity used by the household. Unfortunately, the actual amount (in fuel units) is not provided, nor are the prices.

Based on previous literature, I examine several household characteristics as potential determinants of fuel use. Household size is adjusted to represent adult equivalency units, with members under 16 counting as half an adult. This, along with per capita income in 2010 rupees, is included in logged form. I also include the average years of education for members older than 18, aggregated separately by women and men; head of household sex; and ethnicity grouped into three categories: Brahmin, Dalit, and other. Finally, I include the number of large livestock (cows or buffalo) owned by the household, as well as its square.

I also include VDC-level covariates that fall into two categories: forest access and management and market access. Forest variables include the logged average amount of time it takes households in the VDC to collect 1 kg of wood (a basic measurement of wood price), number of community forest user groups in the VDC (data from Oldekop et al., 2016), percent of VDC land that was forested in 2001, and an indicator for whether the VDC has any land under any level of national forest protection. Market access variables include an indicator for urban VDC and logged distance to Kathmandu, the nearest major road, and the nearest population center of at least 50,000 people.

Table I.1 reports the sample means for the covariates by year and region. In general, households are richer, smaller, and more educated in 2010 than in 2003, and in the Hill region compared to the Terai. Households in the Hill are also more likely to be of the Brahmin caste and own more livestock. In terms of VDC characteristics, the average time to collect a kilogram of firewood has increased over time. Community Forest User Groups are more numerous in the Hills, which is also more heavily forested. Sampled VDCs in the Hills also are more likely to be urban.

Empirical Strategy

The nuanced fuel use data allows the analysis of three different measures of fuel use: primary fuel, any use of each fuel, and amount of fuel used. In the NLSS survey, households can select one option for primary fuel from a mutually exclusive set, indicating the need for a multinomial response model to analyze choice. According to the energy ladder hypothesis, these choices should be ordered. Farsi, Filippini, & Pachauri (2007) take this approach, applying an ordered probit to their analysis of fuel choice. I compare three models: multinomial logit, ordered logit, and ordered probit, based on the percent of correctly predicted primary fuel and found that the multinomial logit[5] performed best both overall (81% vs. 78% and 78%, respectively) and especially when looking only at predictions for households whose primary fuel is not wood, since these events are much more rare (68% vs. 60% and 59%). These patterns hold when comparing models separately by region.

Firewood, being by far the most widely selected primary fuel, is designated as the base category. I therefore estimate the probability that household *i* chooses fuel *j* as opposed to wood conditional on a vector of household and VDC level covariates X_i according to the multinomial logit model:

[5] Other papers using MNL in the context of fuel choice: Gangopadyay, Ramaswami & Wadhwa (2003); Alem et al. (2015), Ouedraogo (2006), Heltberg (2005)

$$\Pr(Y = j|X) = \frac{e^{\left(\beta_j' X_i\right)}}{1 + \Sigma_{k=1}^{J} e^{\left(\beta_k' X_i\right)}} \quad for\ j = 1, 2, \dots, J \tag{1}$$

In order to examine the factors influencing whether a household uses each type of fuel, I use a logit model to predict the probability that household *i* uses each FUEL *j* conditional on the same vector of household and VDC level covariates.

$$\Pr\left(FUEL_j = 1\middle|X\right) = \frac{e^{\left(\Upsilon_j' X_i\right)}}{1 + e^{\left(\Upsilon_j' X_i\right)}} \quad for\ j = 1, 2, \dots, J \tag{2}$$

Finally, for the fuels for which information is available, I consider the amount of fuel consumed by the household using simple OLS with log-transformed dependent variables.

$$\ln\left(\text{Amount}_j\right) = \alpha_j + \Gamma_j' X_i + \varepsilon_j \quad for\ j = 1, 2, \dots, J \tag{3}$$

The same set of household and VDC level covariates is maintained throughout the analysis and standard errors are clustered at the VDC level.

Results

Descriptive results

The proportion of Nepali households using modern fuels has increased over time, although the transition is occurring faster for lighting fuels than for cooking fuels (Figures I.1a and I.1b). Across the country, electrification expanded rapidly, replacing the use of kerosene as main lighting fuel. While only 46% of households were electrified in 2003, 81% were by 2010. Although electrification is more difficult in the Hill region due to the terrain and remoteness of many VDCs, the regional electrification gap has been largely filled with solar energy. The shift in cooking fuels has been less pronounced – woodfuel remains the primary cooking fuel for the majority of households. However, the proportion of households relying primarily on LPG has doubled over the study period: from 13% to 27%.

There is also a clear relationship between modern energy use and wealth as each income group is more likely to use modern fuels than the groups below it (Figures I.2a and I.2b). It is worth noting, however, that while almost all of the top income decile is electrified, a large proportion of them are still using woodfuel as their primary cooking fuel, providing the first evidence from this analysis contradicting the idea that wood is the fuel of the poor.

Looking solely at how primary fuel changes across time and income groups, the evidence supporting the energy ladder hypothesis is strong. However, in order to really understand fuel choice and use, simply examining primary fuel is not sufficient. It is important to see if these trends represent fuel switching or stacking. As seen in Table I.2, almost all households use a portfolio of at least two fuels, and 47% use at least three fuels[6]. Furthermore, the wealthier a household is, the more likely it is to use more fuels. This suggests that households are not abandoning traditional fuels as they adopt new fuels, supporting the energy stacking model.

Figure I.3a illustrates how the proportion of households using each fuel changed over time. While there is a clear increase in the proportion of households using clean fuel and a reduction in those using kerosene, the proportions of households using wood and biomass remain fairly constant, with wood use even increasing slightly in the Terai region. Figure I.3b plots the same information across income quintiles. As expected from the primary fuel results, in both regions the proportion of households using clean fuels increases as income increases. The use of dung and other biomass, arguably the worst fuel, decreases steadily to almost no use as households get richer. However, the use of kerosene and wood remains remarkably high, although trends differ across regions. In the Terai, woodfuel use remains fairly constant across income categories until a slight decline among the richest households, while kerosene use faces a slow decline as household income increases. In the Hills, the trends are reversed and woodfuel use drops to only about half of richest households[7] while kerosene use remains fairly flat until the last quintile.

Fuel use, although more informative in some ways than primary cooking fuel, still fails to capture how much a household relies on each fuel. Figures I.4a and I.4b show the relative expenditures on each fuel used (and on wood collected) over time and across income categories[8]. Average amounts among users are reported in logged form in order to be able to directly

[6] Fuels: electricity, LPG, kerosene, biogas, wood, biomass (dung/leaves)
[7] Part of this large impact in the Hill region is driven by Kathmandu. When that district is removed, the use of woodfuel falls to only about 75% of households.
[8] Biogas is excluded as there is no accurate way of measuring amount used in the survey.

compare the trends in woodfuel collection (in kilograms) with the other amounts (in 2010 Nepali rupees). Interestingly, the average amounts of electricity and LPG expenditure have declined over time. This could be due to a decrease in price over time. Perhaps more likely, as poorer households adopt modern fuels, they drive the average amount spent on those fuels down. When looking across income categories, average amount spent on LPG and electricity increases with income. Among woodfuel users, households are increasingly relying on purchased wood rather than collected wood over time and across income categories.

Empirical results

I now turn to multivariate regression to examine the determinants of fuel use in terms of primary fuel, fuel use, and amount of fuel used. As the descriptive results demonstrated, fuel use trends vary by region. In addition, different factors are likely to have different effects across regions. Therefore all empirical results are estimated separately for the Terai and the Hills.

Table I.3 reports the log odds coefficients for the multinomial logit predicting the probability that households use primary cooking fuels other than wood. Income coefficients are of the expected signs and relative magnitudes – as households get wealthier, they are more likely to primarily rely on higher quality cooking fuels. The time trend from the descriptive analysis is also apparent, as households in 2010 are more likely to use LPG compared to wood and less likely to use kerosene than they were in 2003. Having more large livestock (a measure of wealth) decreases the likelihood of LPG being the primary cooking fuel and increases the likelihood of biogas (and dung in the Terai). However, the quadratic terms show that these effects decrease with the number of livestock. Ethnicity also correlates highly with modern primary cooking fuel, at least in the Terai, while household size and sex of household head do not except in the case of kerosene. Although male education does correlate with higher probabilities for modern fuels, it is dwarfed by the relationship women's education has with primary fuel choice. Forest access and policy measures do not have much effect on primary fuel, except that they decrease the likelihood of using dung relative to wood in the Terai. In general, distance from markets decreases the probability of using LPG and kerosene, the fuels that are not produced locally.

To better interpret the relationship between each factor and primary fuel choice, I present the marginal effects in Table I.4. Here, a 10% increase in per capita income can be read as increasing the probability of LPG as primary fuel by 0.005 in the Terai and 0.004 in the Hill and decreasing the probability of traditional fuel use (wood and dung/leaves) by 0.007 in the Terai and 0.004 in the Hill.

As is demonstrated in the descriptive analysis, choice of lighting fuel is between kerosene and electricity in the Terai. In the Hills, the use of other lighting fuel is not insignificant, but information on solar energy is only collected in 2010. Furthermore, all households that report any electricity use also report it as their main lighting fuel. Therefore, analysis of primary lighting fuel is generally equivalent to analyzing the use of electricity, which is explored in the logit results below.

Table I.5 reports the marginal effects of the logit regressions for any use of each fuel for either lighting or cooking. Table I.6 separates wood use into households who purchase and collect it[9]. The income effects are interesting in that although higher income is related to higher

[9] Approximately 22% of households both collect and purchase fuelwood.

probabilities of modern fuel use, it does not translate into a significant decrease in wood use in the Terai. Even in the Hills, where the negative effect is significant, it is still of smaller magnitude than the effects on modern fuels, once again contradicting the idea of fuel switching. Although income has little to no effect on the use of fuelwood, it does affect how the wood is obtained, increasing the likelihood of purchase while decreasing the likelihood of collection.

Comparisons between marginal effects of factors on primary fuel choice and indicators for any fuel use can be illuminating. For instance, although household size plays little role in choice of primary fuel, it significantly increases the probability that households use LPG at all. In fact, larger households are generally correlated with higher likelihoods of fuel use, suggesting that higher household occupancy encourages larger fuel portfolios. Having a male head of household is also insignificant in terms of primary cooking fuel (with the exception of a positive impact on kerosene), but it interesting that it is negatively correlated with any use of both electricity and LPG. Female-headed households are therefore more likely to employ modern fuels, even if they are unable to rely on them most of the time. The effects of education echo the results from primary cooking fuel. Once again, having more educated women in the household increases the probability of using modern fuels and decreases the probability of using traditional fuels much more than having more educated men.

Forest access and management have more of an influence on traditional and transition fuels than on modern fuel use. Higher wood collection time decreases the probability of any wood use. However, when comparing its relationship with purchased and collected wood, collection time has similar effects in the Hill but a much larger effect on collected wood than purchased wood in the Terai. This could be due to more insulated wood markets in the more remote Hill VDCs. Higher collection time not only reduces a household's willingness to collect, but also reduces supply if local people are unwilling to collect and sell it. CFUGs are associated with higher probabilities of wood use in the Terai, and wood purchases in the Hill. This may be because CFUGs streamline the use and sale of forest products. In terms of market access, proximity to markets is again correlated with higher use of modern fuels. Interestingly, market access is associated with a decrease in kerosene use among Terai households.

Table I.7 presents results for logged fuel expenditures and wood collection in kilograms. The expenditure results should be interpreted with caution as the values combine both price and quantity. It is therefore difficult to interpret coefficients for variables that may be correlated with higher or lower fuel prices such as market access. For instance, the increase in electricity and LPG expenditure with distance from Kathmandu is likely due to higher electricity and LPG prices in more remote areas. However, the coefficients on the household factors provide useful information. For instance, having more large livestock is correlated with less use among all fuels except collected wood[10], despite controlling for urban areas and other market access variables. Although women's education increases the amount of electricity use and decreases wood collected, the impact on amount of LPG used is not significant. Unsurprisingly, larger households consume more fuel across all fuel types.

The marginal effect of log income on log amount used is the income elasticity demand for fuel. Therefore, a 1% increase in per capita income is associated with a 0.4-0.5% increase in electricity expenditures across regions and a 0.2-0.3% increase in LPG expenditures. In terms of

[10] And supposedly dung in the Terai, although information on quantity of dung use is not available

wood use, the elasticities are positive for wood expenditures but negative for wood collection and are roughly similar in magnitude, suggesting only a small effect of income on overall wood use.

In Figure I.5, I plot the income elasticities across income quintiles derived from subgroup analysis, combining the Hill and Terai regions to increase sample size and including district fixed effects to attempt to control for geographic price variations[11]. With the exception of LPG, elasticities generally follow an inverse-U shape, increasing with income for the poorer households and decreasing for the richer households. The traditional income/environment hypotheses discussed above predict that as income increases, wood becomes an inferior good. However, in this sample, the point estimate for wood is positive for all except the highest income group, and even then it is not significantly different from zero (coefficient: -0.192; standard error: 0.290). In fact, the only significantly negative coefficient is that of kerosene in the highest income quintile, suggesting that in the context of Nepal, all fuels are normal goods for most households.

Discussion

Adoption of modern fuels is increasing over time in Nepal. This is a positive development in its own right as modern fuels provide benefits such as high quality, safe light and fast and easy cooking. There is also clear evidence that richer households are more likely to use modern fuels,

[11] When separated by region, the results for the Terai are qualitatively similar to the combined results. Elasticities in the Hills present a less clear story, possibly due to higher variation in expenditures among more remote VDCs.

which when taken on its own supports the energy ladder hypothesis. However, the energy ladder also predicts that households will switch away from traditional fuels as they become wealthier. Instead, I find evidence to support the energy stacking model: although some households do transition away from traditional fuels, especially in the higher income groups, woodfuel remains a large part of the household energy strategy throughout the income distribution. Therefore, if policy goals include the reduction or elimination of traditional fuel use, focusing solely on income and modern fuel availability will not be sufficient.

Overall, this evidence contributes to a growing body of literature suggesting that traditional fuel use in developing countries will remain prevalent for many years to come, especially in rural areas. One reason for this may be that the income distributions in these countries are not high enough to see full switching. Other likely reasons are institutional, economic, and cultural. As long as modern fuels remain unreliable either in availability or cost, households will continue to depend on lower quality fuels. In addition, cultural practices or customs that require traditional fuels will continue to keep these fuels in the household's energy portfolio.

Despite concerns over household health and the environment, continued reliance on traditional fuels may not necessarily be a bad thing. Some research points to an ambiguous impact of woodfuel dependency on the environment (Arnold, Köhlin & Persson, 2005) or stress that it is really only a problem in the immediate vicinity of major cities and roads (Heltberg, 2004). Foster and Rosenzweig (2003) even provide evidence that the demand for fuelwood improves forest quantity in India.

Instead of focusing exclusively on trying to reduce dependence on fuelwood, policymakers may consider shifting the priority to minimizing the damage caused by persistent fuelwood use. Possible options include expanding the use of technologies that both reduce negative impacts of wood use and are proven to be popular in a given context, such as mud stoves in Nepal (Nepal, Nepal & Grimsrud, 2010), or encouraging the use of sustainably obtained fuelwood to protect forests, especially in areas at high risk for forest degradation and loss.

The factors influencing household fuel decisions are many and complex. In this analysis, I find that in addition to expected income and time effects, female education, forest management policies, and market access are strong determinants of fuel choice. In addition, I find that the strength of these influences varies depending on whether the outcome variable of interest is primary fuel, any use of the fuel, or amount of the fuel used.

There are several limitations to this analysis. Results should be interpreted as associations rather than causal effects due to both omitted variable bias (primarily arising from the failure to account for fuel prices) and sources of endogeneity that affect both the controls and fuel use through unobserved channels. However, estimates contribute to an understanding of which households use each fuel and the degree to which they use them.

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Figure I.1a Main lighting fuel by region and year

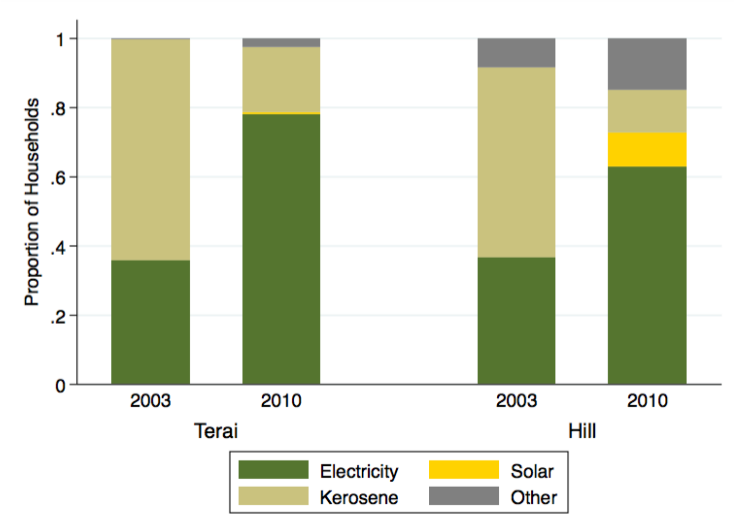

Figure I.1b Main cooking fuel by region and year

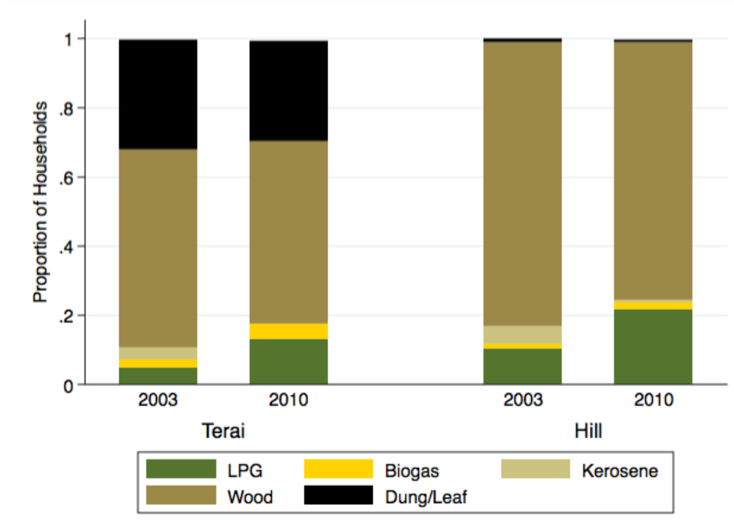

Figure I.2a Main lighting fuel by region and income quintile

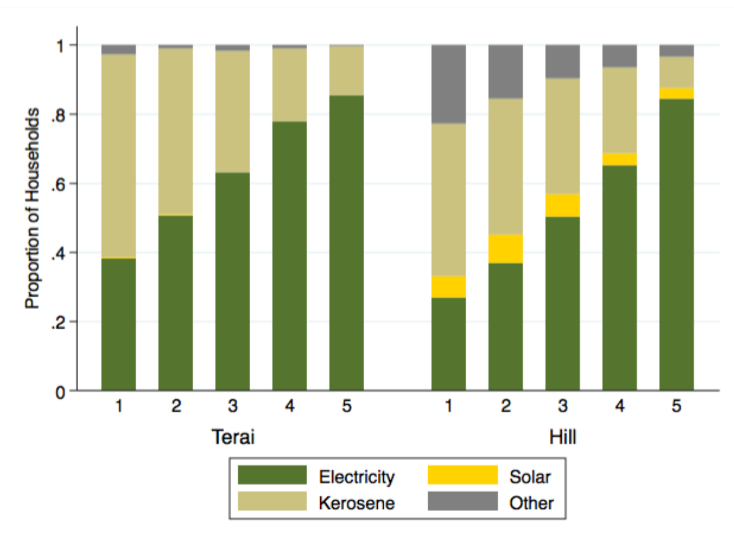

Figure I.2b Main cooking fuel by region and income quintile

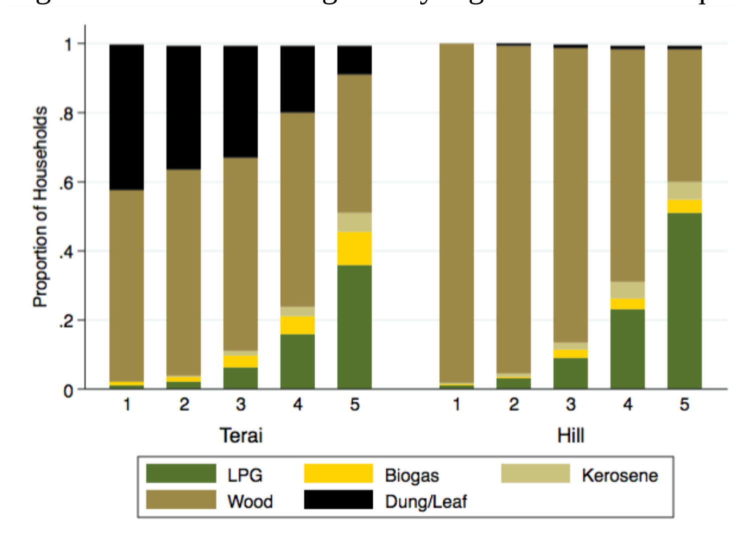

Figure I.3a Fuel use by region and year

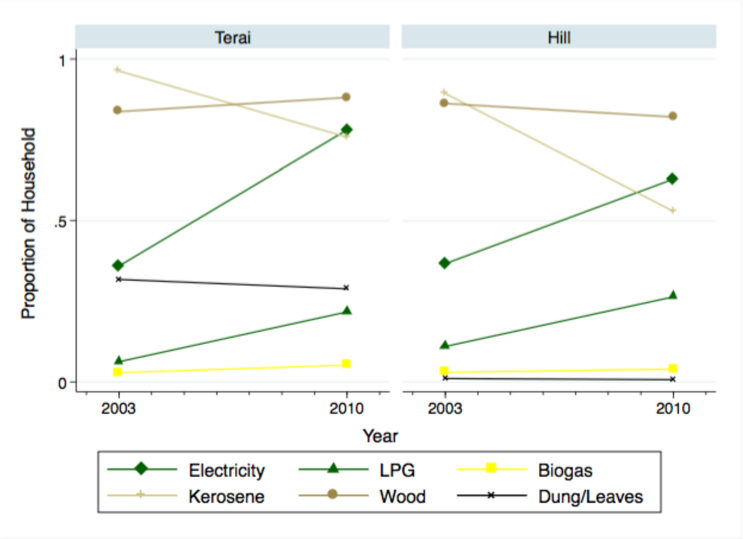

Figure I.3b Fuel use by region and income quintile

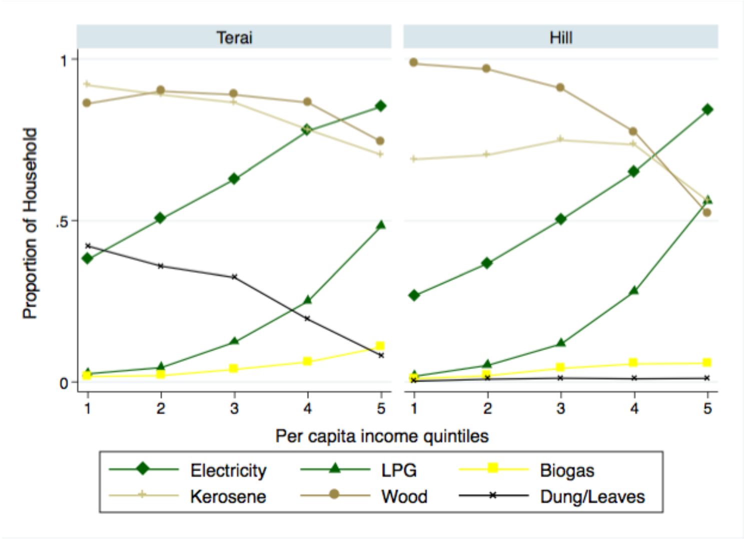

Figure I.4a Fuel amount used by region and year*

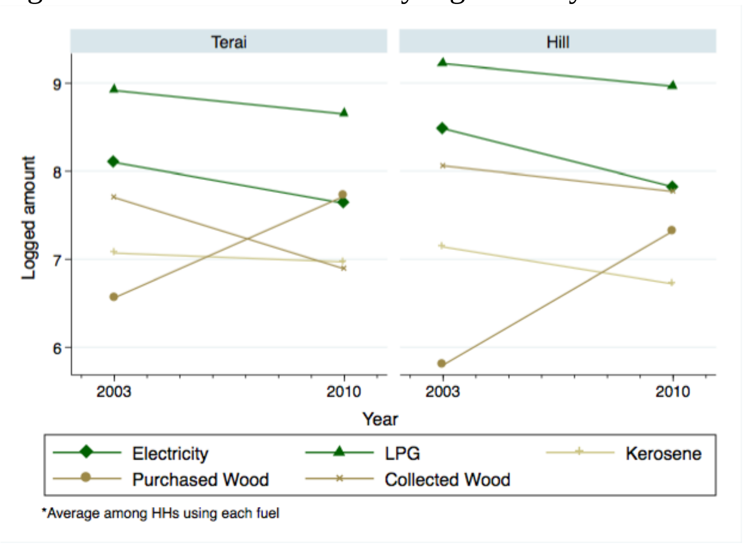

Figure I.4b Fuel amount used by region and income quintile*

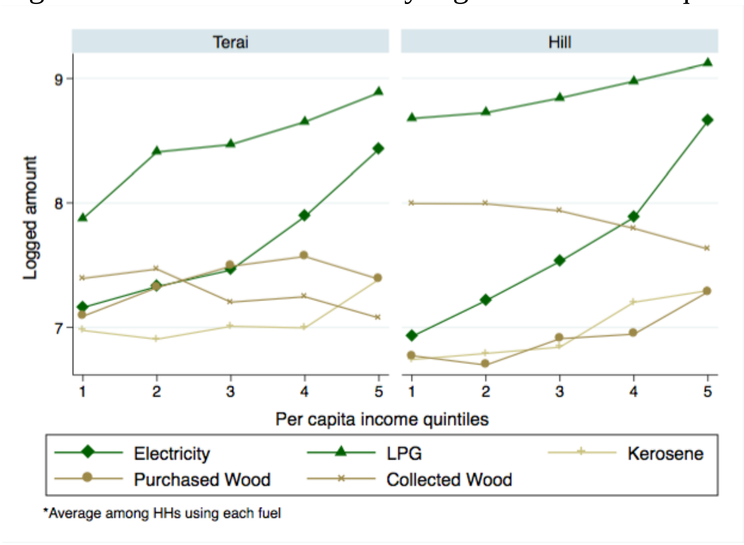

Figure I.5 Income elasticities by income quintile

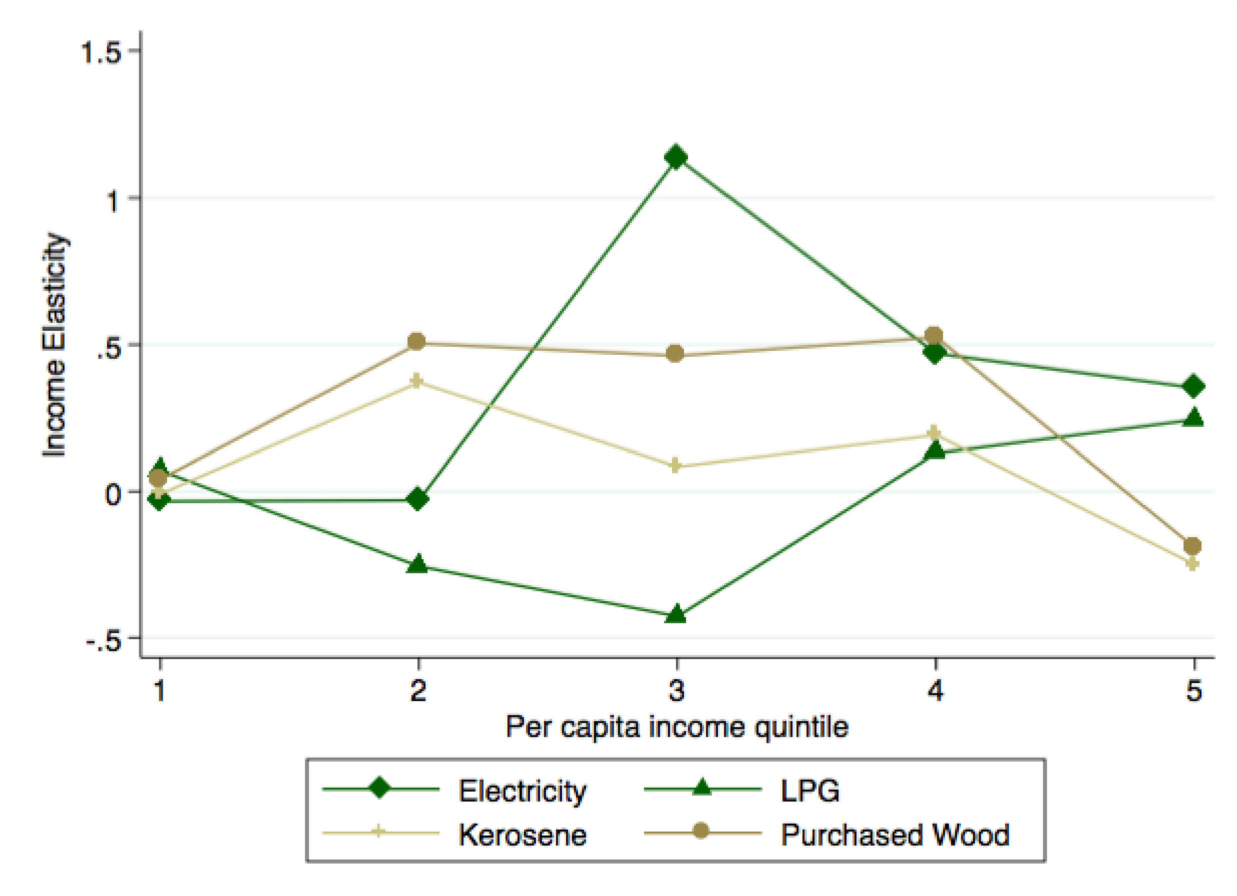

Table I.1 Descriptive Statistics

	2003		2010		
	Terai	Hill	Terai	Hill	Total
Household characteristics					
ln(per capita income)	7.42	7.66	7.84	8.02	7.79
	(0.81)	(0.94)	(0.92)	(1.08)	(0.99)
HH size (adult equivalent)	1.38	1.27	1.31	1.20	1.27
	(0.47)	(0.46)	(0.47)	(0.46)	(0.47)
Head: male	0.84	0.78	0.75	0.72	0.76
	(0.37)	(0.41)	(0.43)	(0.45)	(0.43)
Average male education	3.70	4.01	4.05	4.69	4.22
	(3.75)	(4.00)	(4.12)	(4.51)	(4.20)
Average female education	1.91	2.31	2.56	3.28	2.66
	(2.94)	(3.20)	(3.33)	(3.72)	(3.43)
Eth: Other	0.64	0.48	0.62	0.47	0.54
	(0.48)	(0.50)	(0.49)	(0.50)	(0.50)
Eth: Dalit	0.13	0.11	0.13	0.11	0.12
	(0.33)	(0.31)	(0.33)	(0.32)	(0.32)
Eth: Brahmin	0.23	0.41	0.26	0.42	0.35
	(0.42)	(0.49)	(0.44)	(0.49)	(0.48)
# large livestock	1.87	2.60	1.58	2.02	2.02
	(2.35)	(2.85)	(2.03)	(2.49)	(2.48)
# large livestock - squared	8.99	14.86	6.62	10.27	10.23
	(23.20)	(33.02)	(17.27)	(22.38)	(24.52)
VDC forest access and management					
ln(wood collection -min)	1.85	1.68	2.33	2.64	2.22
	(1.05)	(0.56)	(1.14)	(1.27)	(1.15)
ln(# CFUG)	0.70	1.78	0.83	1.75	1.36
	(0.95)	(1.06)	(1.03)	(1.04)	(1.14)
ln(% 2001 forest cover)	1.83	3.36	1.96	3.19	2.71
	(1.52)	(1.02)	(1.53)	(1.10)	(1.44)
Forest protection (any)	0.12	0.09	0.13	0.07	0.10
	(0.32)	(0.28)	(0.34)	(0.26)	(0.29)
VDC market access					
ln(Dist to Kathmandu)	5.16	4.02	5.23	3.75	4.40
	(0.58)	(1.96)	(0.56)	(2.18)	(1.79)
ln(Dist to nearest road)	1.52	1.65	1.35	1.51	1.51
	(0.83)	(1.23)	(0.81)	(1.19)	(1.07)
ln(Dist to pop center >50k)	2.81	2.84	2.70	2.64	2.73
	(1.33)	(1.60)	(1.38)	(1.72)	(1.56)
Urban	0.25	0.32	0.28	0.39	0.33
	(0.43)	(0.47)	(0.45)	(0.49)	(0.47)
N	1,618	2,236	2,354	3,579	9,787

Notes: Reports weighted means and standard deviations. Household size is adjusted so members <=16 are counted as 0.5. Education is in average years for members 18 and older by gender. Large livestock includes cows and buffalo. Wood collection time is the average reported for the VDC in minutes. Forest protection is a dummy for the VDC having any area under any level of forest protection (strict, conservation, or buffer zone). Standard errors are clustered at the VDC level.

Table I.2 Number of fuels used by households, by income categories

	Proportion of households					
	Income quintile (1 = lowest 20% of households)					
# of fuels	1	2	3	4	5	Total
4+	0.06	0.08	0.13	0.15	0.16	0.11
3	0.28	0.35	0.39	0.41	0.42	0.36
2	0.53	0.48	0.42	0.40	0.39	0.45
1	0.13	0.09	0.06	0.04	0.04	0.07
N	1,958	1,958	1,957	1,958	1,956	9,787

Notes: Maximum possible number of fuels is 6, although no households use more than 5. Results are weighted.

Table I.3 Factors influencing primary cooking fuel (compared to wood): log odds

	Terai				Hill			
	LPG	Biogas	Kerosene	Dung/ Leaves	LPG	Biogas	Kerosene	Dung/ Leaves
Household characteristics								
ln(per capita income)	1.344***	0.740***	0.559**	-0.208*	1.290***	0.817***	0.557***	0.487**
	(0.111)	(0.178)	(0.189)	(0.086)	(0.121)	(0.105)	(0.132)	(0.172)
HH size (adult equivalent)	-0.345	0.033	-1.493***	-0.090	0.140	0.106	-0.580*	0.468
	(0.200)	(0.288)	(0.398)	(0.144)	(0.239)	(0.269)	(0.280)	(0.469)
Head: male	0.323	0.396	0.956**	-0.003	-0.025	0.237	0.492	-0.413
	(0.240)	(0.255)	(0.347)	(0.142)	(0.213)	(0.313)	(0.271)	(0.315)
Average male education	0.022	0.008	0.030	-0.052**	0.089***	0.081**	0.051	-0.026
	(0.020)	(0.028)	(0.038)	(0.018)	(0.021)	(0.030)	(0.033)	(0.040)
Average female education	0.201***	0.212***	0.164***	-0.083***	0.191***	0.104**	0.0671	-0.169*
	(0.023)	(0.032)	(0.037)	(0.025)	(0.028)	(0.035)	(0.048)	(0.083)
Eth: Dalit (omit other)	-1.268***	-1.410	0.048	0.034	-0.620	-0.444	0.082	-1.064
	(0.374)	(0.907)	(0.371)	(0.180)	(0.349)	(0.680)	(0.430)	(0.644)
Eth: Brahmin (omit other)	0.802***	1.217***	-0.141	-1.519***	0.391	0.384	-0.079	-1.240*
	(0.206)	(0.308)	(0.348)	(0.249)	(0.213)	(0.277)	(0.242)	(0.512)
# large livestock	-0.609***	0.752***	-0.717	0.648***	-1.298***	0.460*	-1.283***	-0.298
	(0.099)	(0.109)	(0.537)	(0.078)	(0.131)	(0.182)	(0.271)	(0.159)
# large livestock - squared	0.036***	-0.052***	-0.093	-0.055***	0.052***	-0.049	0.055***	0.014*
	(0.006)	(0.011)	(0.142)	(0.011)	(0.011)	(0.025)	(0.010)	(0.007)
VDC forest access and management								
ln(wood collection -min)	0.010	-0.300*	0.153	0.091	0.363*	0.258	0.512**	-0.047
	(0.123)	(0.143)	(0.138)	(0.101)	(0.169)	(0.280)	(0.162)	(0.203)
ln(# CFUG)	-0.319*	0.085	0.385*	-0.536**	0.213	0.876**	0.010	-0.175
	(0.140)	(0.190)	(0.179)	(0.174)	(0.224)	(0.305)	(0.188)	(0.334)
ln(% 2001 forest cover)	0.020	-0.154	-0.297*	-0.654***	-0.425	-0.583*	-0.124	-0.714*
	(0.081)	(0.134)	(0.119)	(0.104)	(0.240)	(0.294)	(0.231)	(0.296)
Forest protection (any)	-0.105	-0.160	0.064	-1.629***	-0.862	-0.486	-0.942*	0.200
	(0.369)	(0.391)	(0.672)	(0.391)	(0.478)	(0.730)	(0.454)	(0.810)

	Terai				Hill			
	LPG	Biogas	Kerosene	Dung/ Leaves	LPG	Biogas	Kerosene	Dung/ Leaves
VDC market access								
ln(Dist to Kathmandu)	0.167	-0.007	0.417	0.036	-0.387**	-0.305**	-0.455***	-0.252
	(0.253)	(0.242)	(0.381)	(0.228)	(0.118)	(0.114)	(0.108)	(0.199)
ln(Dist to nearest road)	-0.423**	-0.262	-0.719**	-0.067	-0.774***	-0.427*	-0.584*	-0.973***
	(0.137)	(0.167)	(0.231)	(0.129)	(0.197)	(0.215)	(0.238)	(0.226)
ln(Dist to pop center >50k)	-0.299**	-0.124	-0.384**	0.020	-0.386	-0.201	-0.317	-0.054
	(0.092)	(0.117)	(0.123)	(0.139)	(0.204)	(0.164)	(0.209)	(0.265)
Urban	0.917**	-0.0248	0.749	-0.575	0.382	-0.270	0.811	-0.215
	(0.305)	(0.321)	(0.434)	(0.345)	(0.356)	(0.577)	(0.494)	(0.773)
Year: 2010	0.759***	0.593*	-3.047***	0.136	0.138	0.153	-2.923***	-0.447
	(0.207)	(0.285)	(0.440)	(0.217)	(0.288)	(0.411)	(0.398)	(0.471)
Constant	-13.37***	-10.39***	-6.713*	1.595	-8.834***	-9.437***	-2.980*	-1.329
	(1.891)	(2.208)	(2.659)	(1.345)	(1.335)	(1.667)	(1.285)	(2.022)
Pseudo R-squared	0.390	0.390	0.390	0.390	0.631	0.631	0.631	0.631
N	3939	3939	3939	3939	5789	5789	5789	5789

Notes: Results are from weighted multinomial logit regression. Effects for binary/categorical variables interpreted for a shift from omitted group. Excludes 58 households with primary cooking fuel = "other". Household size is adjusted so members <=16 are counted as 0.5. Education is in average years for members 18 and older by gender. Large livestock includes cows and buffalo. Wood collection time is the average reported for the VDC in minutes. Forest protection is a dummy for the VDC having any area under any level of forest protection (strict, conservation, or buffer zone). Standard errors are clustered at the VDC level. ***:p<0.01; **:p<0.05; *:p

Table I.4 Factors influencing primary cooking fuel choice: marginal effects

	Terai					Hill				
	LPG	Biogas	Kerosene	Firewood	Dung/ Leaves	LPG	Biogas	Kerosene	Firewood	Dung/ Leaves
Household characteristics										
ln(per capita income)	0.053***	0.015***	0.002	-0.032***	-0.037***	0.036***	0.010***	-0.005**	-0.043***	0.001
HH size (adult equivalent)	-0.009	0.003	-0.017***	0.031	-0.008	0.010	0.002	-0.013***	-0.003	0.004
Head: male	0.009	0.008	0.009***	-0.022	-0.004	-0.006	0.004	0.009**	-0.004	-0.004
Average male education	0.001	0.000	0.000	0.005**	-0.007***	0.002***	0.001**	0.000	-0.003***	0.000
Average female education	0.007***	0.005***	0.001***	-0.001	-0.013***	0.006***	0.001**	-0.001	-0.005***	-0.002**
Eth: Dalit (omit other)	-0.039***	-0.013**	0.005	0.034	0.013	-0.020**	-0.005	0.011	0.021*	-0.007
Eth: Brahmin (omit other)	0.043***	0.042***	-0.004	0.115***	-0.196***	0.016***	0.006	-0.005*	-0.008	-0.009**
# large livestock	-0.029***	0.020***	-0.008	-0.071***	0.087***	-0.032***	0.012***	-0.010*	0.029***	0.001
# large livestock - squared	0.002***	-0.001***	-0.001	0.007***	-0.007***	0.001***	-0.001**	0.000**	-0.001	0.000
VDC forest access and management										
ln(wood collection -min)	0.001	-0.008**	0.002	-0.007	0.013	0.006	0.003	0.006***	-0.014*	-0.002
ln(# CFUG)	-0.013**	0.005	0.007***	0.072***	-0.071***	0.006	0.015***	-0.002	-0.016**	-0.002
ln(% 2001forest cover)	0.006*	-0.002	-0.003**	0.085***	-0.086***	-0.011	-0.009*	0.003	0.021**	-0.005*
Forest protection (any)	0.001	0.001	0.003	0.185***	-0.189***	-0.019	-0.005	-0.008	0.026*	0.006
ln(Dist to Kathmandu)	0.005	-0.001	0.004	-0.012	0.003	-0.007**	-0.004**	-0.004***	0.016***	-0.001
ln(Dist to nearest road)	-0.014**	-0.005	-0.007***	0.031*	-0.005	-0.018***	-0.005	-0.001	0.030***	-0.005***
ln(Dist to pop center >50k)	-0.011***	-0.002	-0.004***	0.011	0.005	-0.010*	-0.002	-0.002	0.013*	0.001
Urban	0.039***	-0.002	0.006	0.039	-0.082*	0.005	-0.006	0.012	-0.008	-0.003
Year: 2010	0.043***	0.013*	-0.043***	-0.030	0.017	0.048***	0.003	-0.064***	0.014	-0.002
Predicted Probability	0.093	0.035	0.017	0.552	0.304	0.162	0.020	0.026	0.783	0.008
N	3939	3939	3939	3939	3939	5789	5789	5789	5789	5789

Notes: Results are from weighted multinomial logit regression. Effects for binary/categorical variables interpreted for a shift from omitted group. Excludes 58 households with primary cooking fuel = "other". Household size is adjusted so members <=16 are counted as 0.5. Education is in average years for members 18 and older by gender. Large livestock includes cows and buffalo. Wood collection time is the average reported for the VDC in minutes. Forest protection is a dummy for the VDC having any area under any level of forest protection (strict, conservation, or buffer zone). Standard errors are clustered at the VDC level. ***:p<0.01; **:p<0.05; *:p<0.1

Table I.5 Factors influencing household use of fuels: marginal effects

	Terai						Hill					
	Electricity	LPG	Biogas	Kerosene	Wood	Dung/ Leaves	Electricity	LPG	Biogas	Kerosene	Wood	Dung/ Leaves
Household characteristics												
ln(per capita income)	0.091***	0.074***	0.015***	-0.030***	-0.010	-0.039***	0.076***	0.044***	0.022***	-0.014	-0.018***	0.00
	(0.011)	(0.006)	(0.005)	(0.006)	(0.010)	(0.011)	(0.009)	(0.004)	(0.004)	(0.010)	(0.003)	(0.002)
HH size (adult equivalent)	0.063***	0.026**	0.009	-0.001	0.056***	-0.006	0.028	0.037***	0.019**	0.013	0.035***	0.003
	(0.019)	(0.011)	(0.009)	(0.013)	(0.014)	(0.019)	(0.017)	(0.007)	(0.008	(0.023)	(0.006)	(0.003)
Head: male	-0.041**	-0.034***	0.006	0.011	-0.037**	-0.006	-0.025*	-0.018**	0.010	0.019	-0.010*	-0.003
	(0.019)	(0.013)	(0.007)	(0.012)	(0.015)	(0.019)	(0.015)	(0.007)	(0.007)	(0.015)	(0.005)	(0.003)
Average male education	0.012***	0.005***	0.001	0.001	0.001	-0.007***	0.008***	0.003***	0.001*	-0.003**	-0.002***	-0.001
	(0.002)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.002)	(0.001)	(0.000)
Average female education	0.028***	0.012***	0.005***	-0.006***	-0.008***	-0.016***	0.010***	0.008***	0.002*	-0.002	-0.004***	-0.002***
	(0.003)	(0.001)	(0.001)	(0.002)	(0.002)	(0.003)	(0.003)	(0.001)	(0.001)	(0.004)	(0.001)	(0.001)
Eth: Dalit (omit other)	-0.105***	-0.042***	-0.012	0.023	0.041**	0.012	-0.023	-0.028***	0.001	-0.080***	0.014	-0.008*
	(0.024)	(0.013)	(0.007)	(0.014)	(0.020)	(0.026)	(0.026)	(0.010)	(0.016)	(0.028)	(0.010)	(0.004)
Eth: Brahmin (omit other)	0.093***	0.066***	0.053***	-0.044***	-0.001	-0.204***	0.016	0.012	0.008	-0.059***	-0.013	-0.008**
	(0.024)	(0.013)	(0.012)	(0.015)	(0.014)	(0.024)	(0.023)	(0.008)	(0.007)	(0.018)	(0.008)	(0.004)
# large livestock	-0.004	-0.035***	0.025***	0.013**	0.001	0.089***	-0.026***	-0.037***	0.023***	0.010	0.051***	-0.002
	(0.007)	(0.005)	(0.004)	(0.005)	(0.007)	(0.010)	(0.007)	(0.003)	(0.006)	(0.007)	(0.007)	(0.001)
# large livestock - squared	-0.001	0.002***	-0.002***	-0.001	0.001	-0.008***	0.001**	0.002***	-0.003***	-0.001*	-0.002***	0.000
	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)
VDC forest access and management												
ln(avg wood coll -min)	-0.006	-0.006	-0.008*	0.009	-0.020*	0.013	0.051	0.011*	-0.006	-0.005	-0.009**	-0.003**
	(0.010)	(0.005)	(0.005)	(0.007)	(0.012)	(0.013)	(0.049)	(0.006)	(0.005)	(0.028)	(0.003)	(0.001)
ln(# CFUG)	-0.003	-0.014**	0.006	-0.006	0.052**	-0.070***	-0.033	0.014	0.023***	0.041**	-0.001	0.000
	(0.018)	(0.007)	(0.005)	(0.009)	(0.021)	(0.023)	(0.020)	(0.009)	(0.008)	(0.017)	(0.005)	(0.003)
ln(% 2001 forest cover)	0.015	0.007*	-0.001	-0.024***	0.013	-0.086***	-0.014	-0.011	0.003	0.009	0.007	-0.004*
	(0.011)	(0.004)	(0.004)	(0.007)	(0.009)	(0.013)	(0.030)	(0.010)	(0.009)	(0.019)	(0.005)	(0.003)
Forest protection (any)	0.017	-0.006	0.001	-0.072**	0.043	-0.184***	-0.016	-0.029	0.003	-0.043	0.017	0.005
	(0.048)	(0.021)	(0.012)	(0.028)	(0.034)	(0.037)	(0.056)	(0.018)	(0.021)	(0.045)	(0.015)	(0.010)

	Terai						Hill					
	Electricity	LPG	Biogas	Kerosene	Wood	Dung/ Leaves	Electricity	LPG	Biogas	Kerosene	Wood	Dung/ Leaves
VDC market access												
ln(Dist to Kathmandu)	-0.052**	-0.025**	-0.003	-0.087***	-0.052***	0.005	-0.054***	-0.007	0.001	-0.036**	0.013***	-0.001
	(0.023)	(0.012)	(0.007)	(0.018)	(0.019)	(0.030)	(0.017)	(0.005)	(0.004)	(0.015)	(0.003)	(0.002)
ln(Dist to nearest road)	-0.039**	-0.019**	-0.004	0.024**	-0.003	-0.006	-0.079***	-0.027***	-0.013***	-0.033**	0.021***	-0.007***
	(0.016)	(0.007)	(0.005)	(0.011)	(0.012)	(0.017)	(0.016)	(0.007)	(0.005)	(0.015)	(0.007)	(0.002)
ln(Dist to pop center >50k)	-0.046***	-0.010**	0.001	0.014**	0.010	0.010	-0.045	-0.017**	-0.009*	0.026	0.008*	0.000
	(0.012)	(0.005)	(0.003)	(0.006)	(0.010)	(0.018)	(0.027)	(0.008)	(0.005)	(0.017)	(0.005)	(0.003)
Urban	0.108***	0.063***	-0.009	-0.037*	-0.087***	-0.104**	0.227***	0.006	-0.033*	-0.150***	-0.019**	-0.009
	(0.032)	(0.015)	(0.010)	(0.020)	(0.026)	(0.045)	(0.060)	(0.017)	(0.018)	(0.046)	(0.010)	(0.008)
Year: 2010	0.326***	0.096***	0.019**	-0.174***	0.070***	0.019	0.184***	0.069***	0.007	-0.348***	0.032***	-0.001
	(0.028)	(0.009)	(0.008)	(0.016)	(0.023)	(0.029)	(0.034)	(0.009)	(0.011)	(0.027)	(0.008)	(0.004)
Predicted Probability	0.595	0.148	0.041	0.849	0.864	0.302	0.513	0.193	0.036	0.690	0.843	0.008
N	3972	3972	3972	3972	3972	3972	5815	5815	5815	5815	5815	5815

Notes: Results are from weighted logit regression. Effects for binary/categorical variables interpreted for a shift from omitted group. Household size is adjusted so members <=16 are counted as 0.5. Education is in average years for members 18 and older, by gender. Large livestock includes cows and buffalo. Wood collection time is the average reported for the VDC in minutes. Forest protection is a dummy for the VDC having any area under any level of forest protection (strict, conservation, or buffer zone). Standard errors are clustered at the VDC level. ***:p<0.01; **:p<0.05; *:p<0.1

Table I.6 Factors influencing household purchase and collection of woodfuels: marginal effects

	Terai		Hill	
	Purchase	Collect	Purchase	Collect
Household characteristics				
ln(per capita income)	0.048***	-0.062***	0.016*	-0.029***
	(0.011)	(0.013)	(0.009)	(0.005)
HH size (adult equivalent)	0.104***	0.007	0.044**	0.028***
	(0.022)	(0.020)	(0.019)	(0.009)
Head: male	-0.026	-0.031	-0.016	-0.013
	(0.023)	(0.022)	(0.014)	(0.008)
Average male education	0.005**	-0.009***	0.000	-0.004***
	(0.002)	(0.003)	(0.002)	(0.001)
Average female education	-0.003	-0.012***	0.001	-0.004***
	(0.004)	(0.003)	(0.002)	(0.001)
Eth: Dalit (omit other)	-0.044*	0.103***	0.001	0.003
	(0.026)	(0.028)	(0.026)	(0.011)
Eth: Brahmin (omit other)	0.056**	-0.044*	-0.002	-0.025***
	(0.027)	(0.025)	(0.018)	(0.008)
# large livestock	-0.052***	0.025***	-0.032***	0.045***
	(0.009)	(0.010)	(0.006)	(0.005)
# large livestock - squared	0.002*	0.000	0.001***	-0.002***
	(0.001)	(0.001)	(0.000)	(0.000)
VDC forest access and management				
ln(wood collection -min)	-0.009	-0.039**	-0.031**	-0.032***
	(0.014)	(0.017)	(0.014)	(0.007)
ln(# CFUG)	-0.006	0.052***	0.034**	-0.001
	(0.019)	(0.019)	(0.016)	(0.005)
ln(% 2001 forest cover)	-0.025**	0.069***	-0.017	0.019***
	(0.012)	(0.010)	(0.017)	(0.006)
Forest protection (any)	-0.020	0.114***	0.032	-0.019
	(0.048)	(0.040)	(0.053)	(0.020)

	Terai		Hill	
	Purchase	Collect	Purchase	Collect
VDC market access				
ln(Dist to Kathmandu)	-0.020	0.002	0.016	0.017***
	(0.026)	(0.028)	(0.012)	(0.004)
ln(Dist to nearest road)	0.004	0.034**	-0.011	0.024***
	(0.018)	(0.016)	(0.013)	(0.005)
ln(Dist to pop center >50k)	0.011	0.044***	0.016	0.002
	(0.014)	(0.014)	(0.016)	(0.005)
Urban	0.040	-0.096**	-0.112***	-0.051***
	(0.041)	(0.041)	(0.038)	(0.013)
Year: 2010	0.207***	-0.069**	0.233***	0.022**
	(0.029)	(0.029)	(0.024)	(0.010)
Predicted Probability	0.383	0.587	0.234	0.779
N	3972	3972	5815	5815

Notes: Results are from weighted logit regression. Effects for binary/categorical variables interpreted for a shift from omitted group. Household size is adjusted so members <=16 are counted as 0.5. Education is in average years for members 18 and older by gender. Large livestock includes cows and buffalo. Wood collection time is the average reported for the VDC in minutes. Forest protection is a dummy for the VDC having any area under any level of forest protection (strict, conservation, or buffer zone). Standard errors are clustered at the VDC level. ***:p<0.01; **:p<0.05; *:p<0.1

Table I.7 Factors influencing amount of annual fuel use

	Terai					Hill				
	Expenditures				Wood	Expenditures				Wood
	Electricity (NR 2010)	LPG (NR 2010)	Kerosene (NR 2010)	Wood (NR 2010)	Collection (KG)	Electricity (NR 2010)	LPG (NR 2010)	Kerosene (NR 2010)	Wood (NR 2010)	Collection (KG)
Household characteristics										
ln(per capita income)	0.492***	0.328***	0.0516*	0.512***	-0.471***	0.405***	0.178***	0.0347	0.243**	-0.209***
	(0.077)	(0.055)	(0.024)	(0.084)	(0.088)	(0.083)	(0.034)	(0.027)	(0.084)	(0.047)
HH size (adult equivalent)	1.233***	0.462***	0.228***	0.836***	0.121	1.159***	0.658***	0.328***	0.184	0.457***
	(0.147)	(0.118)	(0.047)	(0.189)	(0.160)	(0.232)	(0.070)	(0.058)	(0.168)	(0.101)
Head: male	-0.218	0.137	0.144**	0.034	-0.0784	-0.244	-0.0248	0.0569	-0.0599	-0.083
	(0.189)	(0.096)	(0.052)	(0.194)	(0.161)	(0.125)	(0.058)	(0.049)	(0.125)	(0.077)
Average male education	0.0474**	0.00457	0.00047	0.0538**	-0.0955***	0.0334***	0.0160**	-0.00031	0.0362*	-0.0305**
	(0.018)	(0.010)	(0.005)	(0.021)	(0.019)	(0.010)	(0.005)	(0.006)	(0.017)	(0.010)
Average female education	0.0783***	0.0135	-0.00296	0.0366	-0.0695**	0.0798***	0.0031	0.0165	0.0504*	-0.0431**
	(0.019)	(0.012)	(0.009)	(0.026)	(0.025)	(0.018)	(0.008)	(0.009)	(0.025)	(0.015)
Eth: Dalit (omit other)	-0.694**	0.0592	-0.0347	-0.488*	0.606**	0.247	-0.394	0.0496	0.0131	0.0616
	(0.253)	(0.142)	(0.058)	(0.228)	(0.187)	(0.180)	(0.260)	(0.071)	(0.211)	(0.093)
Eth: Brahmin (omit other)	0.539**	0.289**	-0.194**	0.612**	-0.272	-0.0798	0.0114	-0.0321	-0.0126	-0.142
	(0.166)	(0.092)	(0.064)	(0.222)	(0.186)	(0.145)	(0.051)	(0.049)	(0.150)	(0.078)
# large livestock	-0.146*	-0.329***	0.00499	-0.575***	0.243***	0.025	-0.243***	-0.0411*	-0.362***	0.281***
	(0.068)	(0.083)	(0.016)	(0.072)	(0.061)	(0.063)	(0.072)	(0.018)	(0.055)	(0.045)
# large livestock - squared	0.00949	0.0280*	0.00141	0.0269***	-0.0130**	-0.00456	0.0144	0.00327**	0.0195***	-0.0162***
	(0.007)	(0.011)	(0.001)	(0.005)	(0.005)	(0.006)	(0.018)	(0.001)	(0.003)	(0.004)
VDC forest access and management										
ln(wood collection -min)	0.00276	-0.00175	0.0617*	0.0657	-0.286*	0.0348	0.0332	-0.0506	0.349*	-0.781***
	(0.103)	(0.038)	(0.026)	(0.148)	(0.145)	(0.076)	(0.043)	(0.067)	(0.175)	(0.106)
ln(# CFUG)	-0.278*	-0.136**	0.0119	-0.311*	0.0737	0.0126	0.00432	0.0790*	0.0282	-0.00739
	(0.126)	(0.049)	(0.035)	(0.153)	(0.110)	(0.087)	(0.051)	(0.035)	(0.119)	(0.048)
ln(% 2001 forest cover)	0.155	0.0478	-0.0799***	-0.229*	0.579***	-0.124	-0.104	-0.217***	-0.306	0.311**
	(0.086)	(0.036)	(0.020)	(0.095)	(0.063)	(0.103)	(0.094)	(0.058)	(0.177)	(0.099)
Forest protection (any)	0.386	-0.0225	-0.217*	-0.329	0.733**	0.512*	0.127	-0.0397	0.121	-0.137
	(0.232)	(0.123)	(0.101)	(0.381)	(0.265)	(0.204)	(0.213)	(0.127)	(0.379)	(0.226)

	Terai					Hill				
	Expenditures				Wood	Expenditures				Wood
	Electricity (NR 2010)	LPG (NR 2010)	Kerosene (NR 2010)	Wood (NR 2010)	Collection (KG)	Electricity (NR 2010)	LPG (NR 2010)	Kerosene (NR 2010)	Wood (NR 2010)	Collection (KG)
VDC market access										
ln(Dist to Kathmandu)	0.965***	0.255**	-0.125*	-0.0515	0.322	0.0381	-0.0103	-0.0728	0.0264	0.150*
	(0.170)	(0.089)	(0.051)	(0.220)	(0.178)	(0.061)	(0.033)	(0.040)	(0.104)	(0.062)
ln(Dist to nearest road)	-0.423**	-0.124	0.0708*	0.0164	0.322*	-0.0501	-0.0277	0.0753*	-0.112	0.195***
	(0.143)	(0.071)	(0.031)	(0.158)	(0.124)	(0.083)	(0.093)	(0.029)	(0.111)	(0.042)
ln(Dist to pop center >50k)	-0.122	-0.0690*	0.0325	-0.0626	0.346***	0.0566	-0.0253	0.0245	-0.134	0.15
	(0.078)	(0.028)	(0.029)	(0.119)	(0.100)	(0.076)	(0.051)	(0.052)	(0.158)	(0.099)
Urban	0.332	0.098	0.195*	1.070**	-0.468	0.278	0.0888	-0.0146	0.0103	-1.237***
	(0.225)	(0.122)	(0.080)	(0.366)	(0.323)	(0.215)	(0.127)	(0.126)	(0.336)	(0.229)
Year: 2010	-0.457*	-0.0926	-0.147**	1.581***	-1.318***	-0.165	-0.151	-0.419***	1.725***	-0.107
	(0.207)	(0.072)	(0.057)	(0.255)	(0.206)	(0.188)	(0.112)	(0.068)	(0.201)	(0.085)
Constant	-3.455*	3.784***	6.314***	-1.202	5.494***	1.886	6.607***	6.747***	0.651	6.685***
	(1.349)	(0.657)	(0.359)	(1.450)	(1.329)	(1.150)	(0.421)	(0.463)	(1.145)	(0.732)
Mean (dependent variable)	6.25	8.35	6.62	3.38	4.95	6.77	8.73	6.41	2.00	7.19
Adjusted R-squared	0.221	0.274	0.077	0.182	0.277	0.128	0.202	0.087	0.157	0.333
N	2544	739	3212	3376	3376	3507	1760	3737	4301	4301

Notes: Results are from weighted OLS regression. Dependent variables are logged and limited to households who use the fuel. Household size is adjusted so members <=16 are counted as 0.5. Education is in average years for members 18 and older, by gender. Large livestock includes cows and buffalo. Wood collection time is the average reported for the VDC in minutes. Forest protection is a dummy for the VDC having any area under any level of forest protection (strict, conservation, or buffer zone). Standard errors are clustered at the VDC level. ***:p<0.01; **:p<0.05; *:p<0.1

CHAPTER II

Waste Not: Can Biogas Deliver Sustainable Development?

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Abstract

Household biogas systems are a renewable energy technology with the potential to provide sustainable development benefits by reducing dependence on traditional fuels and by shifting household time budgets towards higher value activities. We estimate the environmental and socioeconomic impacts of biogas expansion in Nepal using an instrumental variables approach that exploits variation in access to biogas installation companies. We confirm prior evidence that biogas use significantly reduces both collected and purchased fuelwood. We find new evidence that biogas substantially changes labor allocations and increases time spent on education. We do not detect robust impacts of biogas on increased local forest cover overall, but we find evidence of positive impacts when biogas is paired with forest protection policies. Together the results suggest that biogas can improve environmental and socioeconomic conditions, particularly in combination with complimentary opportunities or policies.

Introduction

Access to energy services such as electricity, natural gas, and other modern cooking fuels contributes to development by improving both living standards and productivity (World Bank 2006, Barnes et al. 2010). Indeed, electrification has been shown to increase hours devoted to work outside the home (Dinkelman 2011), to raise education, income, and formal employment levels (Lipscomb et al. 2013), and to enhance agricultural productivity through irrigation and mechanization (Assuncao et al. 2015). However, the relationship between increased access to energy and local environmental quality remains understudied. There is evidence that other pro-poor development increases resource use, by encouraging consumption of goods that are forest-intensive (Baland et al. 2010), energy-intensive (Wolfram et al. 2012) or land-intensive (Alix-Garcia et al. 2013). Similarly, with increased wealth, households may increase fuel consumption and could switch to more polluting fuels, rather than moving up a clean "energy ladder" (Arnold et al. 2006, Hanna and Oliva 2015).

In this paper, we evaluate household use of biogas in Nepal with the goal of understanding its socioeconomic and environmental impacts. Household renewable energy technologies, such as biogas, promise to increase energy access while also improving environmental quality (e.g. Bond and Templeton 2011, Surendra et al. 2014, Christiaensen and Heltberg 2014, Somanathan and Bluffstone 2015). Biogas systems produce clean cooking fuel by capturing methane and other combustible gases emitted during the breakdown of animal manure and human waste. Their potential environmental benefits include reduced greenhouse gas emissions due to displaced fossil fuel use and direct capture of methane.[12] They also include reduced forest degradation in areas where wood is a primary cooking fuel. Biogas may thus provide a greener energy option, particularly for the 3 billion people who still rely on traditional biomass fuels such as wood and dung (United Nations, 2016). Recent analyses in Nepal (Somanathan and Bluffstone 2015) and China (Christiaensen and Heltberg 2014) both suggest that households with biogas use less fuelwood than non-biogas households, by magnitudes of 46% and 47%, respectively. Other studies also find biogas associated with less fuelwood use (Singh and Maharjan, 2003 ~60% in Nepal; Gosens et al. 2013 ~30-60% in China, depending on the province; Garfi et al. 2012 ~ 50-60% in Peru).

Biogas also has potential socioeconomic benefits, including time and money saved due to reduced use of biomass fuels and potential health benefits from cleaner-burning fuel. Surveys from Nepal for instance, suggest that households with biogas believe they spend less time and money on fuel, spend more time on schoolwork and other productive activities, and have better health and more empowered women (SETM 2014). When asked, 98% of biogas-using households in China said biogas had saved them time in cooking (Christiaensen and Heltberg, 2014). The same study found the time-savings from collecting other fuels to be 24 days per year for women, 10 days for men, and 4 days for children.[13] In general, time saving technologies have the potential to increase economic development by shifting time from home production to income generating activities. Time-saving technologies have increased labor force participation in both developed (Greenwood et al. 2016, Cavalcanti and Tavares 2008, Coen-Pirani et al.

[12] Dhingra et al (2011) find that biogas households have 23-55% lower global warming contribution than non-biogas households, taking into account the 3% of biogas systems that had methane leaks. Rajendran et al (2012) summarize the literature on biogas and greenhouse gas emissions.
[13] There is also evidence of household health benefits from studies in Nepal (Pant, 2008 and 2011) and China (Christiaensen and Heltberg, 2014) comparing households with and without biogas.

2010) and developing countries (Dinkelman 2011, Meeks 2015). Time-saving technologies can also increase time allocated to leisure activities which could be of high value to households (Devoto et al. 2012).

With these expected dual benefits for economic development and environmental quality, biogas potentially provides a "double dividend": achieving goals for both climate and livelihood improvement (Kohlin et al. 2015, Jeuland and Pattanayak 2012).[14] Indeed, institutions such as the United Nations Framework Convention on Climate Change (UNFCCC) and the Clean Development Mechanism (CDM) of the Kyoto Protocol have promoted the technology. With developing countries on track to consume more energy than OECD countries by 2040 (U.S. Energy Information Administration 2016), such win-win technologies are key to achieving sustainable development goals.

Yet there are reasons why this double dividend might not be realized in practice. Recent work has suggested that attempting to achieve both environment and human development goals with a single policy or technology is difficult (e.g. Alix-Garcia, Sims and Yanez-Pagans 2015, Jeuland and Pattanayak 2012, Kohlin et al. 2015).[15] Prior research on improved cookstoves (a related cooking technology) raises concerns that some improved cooking technologies may result in lower than expected benefits due to improper use, maintenance problems, and incompatibility with traditional food-preparation practices (e.g. Hanna et al. 2014, Levine et al 2012 Miller and

[14] The original use of the double dividend terminology in environmental economics referred to the potential for reduced deadweight loss due to raising more revenue from pollution taxes and less from taxes on labor or capital (e.g. Goulder 1995, Bovenberg and de Mooij 1997, Pezzey and Park 1998). More recently, it has been used to refer to the possibility of achieving both environmental and social goals using new policies or technologies, which is how we use the term in this paper.
[15] In addition, Kohlin et al. (2015) argue that there is a large "know-do gap" between research on sustainable development technologies and what is actually implemented globally.

Mobarak 2014). Biogas may not be as susceptible to these issues both because it shifts the fuel type itself and because it has the potential for larger and more noticeable impacts on indoor air pollution, health benefits, and time and labor outcomes. However, since biogas does require time to collect dung and water to feed the system, the net impact on home production may be small. Even if biogas reduces time spent in home production, household members may find it challenging to reallocate time to activities that are economically productive, particularly in regions lacking high-return labor opportunities.[16] Thus, time-savings might not be used in ways that could actually increase economic development.

Similarly, biogas may not necessarily reduce resource use overall. Improved cooking technologies and access to modern fuels have been shown in some cases to have little or no effect on the amount of fuelwood used (Hiemstra-van der Horst and Hovorka, 2008; Nepal, Nepal and Grimsrud, 2010). Even if individual households do reduce their fuelwood consumption following biogas adoption, these impacts may not accrue locally or they may be smaller than expected. For example, if there are well-connected markets for firewood, families may sell surplus wood or may purchase less from other locations, making it hard to detect local impacts. Other households could also respond by increasing their own collection due to increased wood availability. Furthermore, if biogas use increases time available for agriculture, deforestation could actually increase due to additional land clearing. In short, careful empirical analysis of the potential socioeconomic and environmental impacts is needed to better understand whether they can exist following the introduction of biogas.

[16] Unlike other energy sources, such as household electrification, which may provide households with small business opportunities, biogas does not likely provide households with new business options.

To date, the empirical literature on the impacts of biogas is based either on comparisons of households with and without biogas or small samples that are likely non-representative. Estimating the causal impact of biogas installation is complicated by the endogeneity of adoption; households that install biogas systems are likely to differ systematically from those that do not. Thus comparisons based on households with and without biogas may not capture impacts accurately, and the direction of the potential bias is unclear.[17] Recent papers by Somanathan and Bluffstone (2015) and Christiaensen and Heltberg (2014) do use local fixed effects along with a detailed set of controls to account for selection on observables as much as possible given data limitations.

We seek to improve on prior literature by providing the first instrumental variables-based evidence on the impacts of biogas and by estimating impacts on additional outcomes using comprehensive, national data. Our instrument, which was informed by conversations with biogas experts in Nepal, uses the spatial variation in installations resulting from government programs. These programs differentially encouraged biogas adoption in particular districts between 2001 and 2011 by providing a combination of subsidies and requirements for biogas installation companies to expand their operations. We rely on two important assumptions. First, households with greater access to installation opportunities—i.e. those located closer to a biogas company branch—are more likely to adopt biogas than households with less access. Second, the locations of biogas company branches, conditional on our included controls, are driven by factors

[17] If households that make more educated investments or are more entrepreneurial are more likely to install biogas and use it optimally, we would expect to find inflated impacts of biogas. If, on the other hand, households that install biogas are more likely to be locked in to agricultural production (have more livestock) or are less entrepreneurial, the impact of biogas may be underestimated.

uncorrelated with household demand for biogas, providing a source of variation in biogas adoption that is exogenous to household characteristics.

We combine national datasets with government administrative data to determine whether the expected labor and fuelwood savings from biogas translate into actual improvements for households and the local environment. Specifically, we employ census micro-data from 2011, nationally representative household survey data collected between 2003 and 2010, remote sensing data on changes in forest cover from 2000-2012 (Hansen et al. 2013), and administrative data on the expansion of biogas across the country over time. Following Baland et al.'s study of firewood use in Nepal (2010), we estimate different impacts for the Terai and Hill regions, which are substantially different in terms of land ownership, education levels and climate.

Results indicate that biogas significantly affects households, although not always in ways consistent with promotional literature. First, we confirm that biogas reduces reliance on traditional fuels such as wood, in terms of both the amount collected and purchased. We then show that biogas leads to significant reallocation of time amongst both male and female household members. Biogas leads to increased time allocated to education, suggesting the potential for long-lasting impacts on human capital and the potential for increases in income if higher wage opportunities accompany more education. Biogas decreases time spent on home production for women and increases it slightly for men, possibly reflecting men's increased willingness to contribute to cooking and chores after biogas is introduced. Within the Terai region, biogas also leads to a substantial shift from time spent in wage labor and self-employment to time spent in agriculture. This suggests that biogas adoption may complement other investments in agricultural productivity including the use of biogas fertilizer byproduct and again could improve incomes if agriculture is a high value activity. Finally, we do not find consistent evidence that biogas installations result in higher local net forest cover overall. However, higher rates of biogas installation may reduce local deforestation when interacted with forest protection policies (protected areas and community forest user groups). Overall, our results indicate that biogas could improve time-allocation and fuel choices, but that positive outcomes for incomes and environmental quality may require complementary opportunities for economic development or environmental protection policies. This highlights the importance of a context-specific, integrated approach to promoting renewable energy technologies.

The rest of the paper is organized as follows. In section 2, we provide details on the Nepal context and the biogas expansion program. Section 3 describes each of the datasets used in the analysis. We present the empirical strategy in Section 4. Section 5 documents the results and Section 6 concludes.

Background

Nepal Context

Nepal provides an ideal context in which to study both the economic and environmental impacts of renewable energy technologies due to the large number of energy-poor households and recent promotion of such technologies within the country. One-third of households in Nepal lack access to electricity and 75% still rely on wood or dung for cooking (Nepal Census 2011). One of Asia's least developed countries, much of Nepal is remote and characterized by high poverty rates and a lack of economic opportunity.[18] In addition, the environment has been considerably strained in recent decades, with forest cover in Nepal falling from 38.1% in 1978/79 to 29% in 2001 (CBS 2014).

Nepal has developed a portfolio of renewable energy technologies, such as biogas, wind, solar, and micro-hydro, to provide energy to its underserved and remote areas. Although biogas has been promoted in Nepal for more than 20 years, the largest increase has come in the past decade. As of 2015, more than 300,000 household biogas systems have been installed (~4% of households; data from AEPC, Barnhart 2012, Bajgain and Shakya 2005). Along with international partners, the government of Nepal has heavily invested in biogas by providing large subsidies, overseeing product quality, and facilitating credit access for biogas construction. A key partner in developing and maintaining this portfolio is the Alternative Energy Promotion Centre (AEPC),[19] a government institution within the Ministry of Science, Technology, and Environment. Important for this study, AEPC tracks household biogas installations, making possible an empirical analysis of impacts.

A prominent feature of the biogas program in Nepal is its partnership with the private sector. Although biogas is subsidized and promoted by the government, system installations ultimately depend on household purchases through private companies, which operate out of company branches throughout the country and serve nearby communities. To receive subsidies from the government, biogas operators must register and meet criteria established by the government. Currently, there are approximately 100 biogas companies that are approved to receive subsidies.

[18] 25.2% of the population lives below the national poverty line (World Bank, 2016).
[19] AEPC works together with the Biogas Promotion Program (BSP) to support biogas expansion.

Figure II.1 maps the percent of households that have installed biogas in each Village Development Committee (VDC) in both 2001 and 2011.[20]

Nepal is divided into three ecological belts: from north to south they are the Mountain, Hill, and Terai. These belts differ in many ways that are of importance to our study, including their climate, terrain, culture, and access to markets and infrastructure. With its diverse landscape ranging from mountain to savannah, Nepal also serves as a convenient testing ground for technologies and policies that may be transferred to other settings. For example, although wood is the primary traditional fuel source throughout Nepal, many areas in the Terai use dried cow dung. As biogas requires a certain minimum temperature in order to operate, it is generally only appropriate for the Hill and Terai regions. For these reasons, we run analyses separately by ecological belt. Most of the mountain area is excluded because it is too cold for biogas.[21]

What is Biogas?

Home biogas systems use anaerobic digestion to convert human and animal waste into a clean, odorless gas that can be used for cooking, heating, and lighting, although it is mainly used for cooking in Nepal (Winrock International, 2003). In addition to the production of the gas itself, biogas systems produce fertilizer (bioslurry) as a byproduct, which lab studies have shown to be just as, if not more, effective than the traditional dung fertilizer (Karki, 2006).[22] Finally, although large livestock (cows, buffalo, oxen) are required to adequately fuel the digester, biogas systems

[20] VDCs should be thought of as sub-districts – there are 3973 VDCs within the 75 districts of Nepal.

[21] We included 190 mountain VDCs that had biogas systems installed by 2011, maintaining a mountain control, but grouping them as hill for regional comparisons. We exclude the Kathmandu District from analysis because most of the households are not suitable for biogas and there are no good counterfactuals given its unique status as the capital and major international hub of the country. Robustness checks including the district yield similar results.

[22] Indeed, some households in Nepal cite the bio-slurry as the main reason they chose to invest in a biogas system.

can also be connected to a latrine and used as a septic tank. Figures II.2a and II.2b provide a stylized diagram and a photo of a typical biogas system, which are 6 cubic meters on average and constructed mostly underground on the household's property. Each day, the digester must be fed with a mixture of dung and water, a chore that is typically the responsibility of women. The system can connect to a kitchen stove via a long pipe so that, once the gas has accumulated in the system, one can begin cooking simply by flipping a switch in the kitchen.

Biogas systems are a costly investment for the household, averaging 47,000 NRs but ranging from 25,000-70,000 NRs (SETM, 2013) even after subsidies are included.[23] The same study found that 80% of biogas users surveyed had a monthly income of 20,000 NRs or less. The total installation process for one system takes approximately one month (Karki, Shrestha, and Bajgain 2005) and must be completed during the dry season (October-May). Biogas systems are built to last for over 20 years and biogas companies provide 3 years of free maintenance and service as part of the accreditation and subsidy program.

Data and Variable Construction

Our analysis combines data from multiple sources: micro-data from the country's census in 2001 and 2011, the 2003 and 2010 Nepal Living Standards Survey (NLSS), the 2008 Nepal Labor Force Survey (NLFS), official AEPC records and documents, and interpreted satellite data on

[23] Costs vary depending both on location and whether the household must purchase the required construction materials (brick, stone, cement, etc.) and unskilled labor or whether they can obtain them in kind.

forest cover from Hansen et al. (2013). Census, NLSS, and NLFS data are at the household level, while installations and forest cover data are calculated at the VDC level.

Household Data – Census

The 2001 and 2011 census micro-data are from the Central Bureau of Statistics in Nepal and contain information on demographics, assets, basic household characteristics, education, and employment for 841,567 (15.5%) and 520,624 (12.2%) households, respectively.[24] We use the 2011 micro-data for our economic outcome variables as well as household and VDC level covariates. We used the 2001 data to construct baseline covariates.[25]

The census data reports limited information on the economic and non-economic activities of each family member over age 10. Our primary labor outcome variable is the percent of months devoted to each of five activities: home production (combining household chores and extended economic work), agriculture, wage or salaried work, small business activities, and studies. Home production includes cooking, cleaning, and caring for household members, as well as any production of goods or services for home consumption including fuel and water collection, preparation of foodstuff and livestock feed, etc. Because men and women are often engaged in different activities and biogas is expected to primarily affect the time allocation of women, we present results for household labor allocation by gender of the household member.

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[24] Due to political turmoil, 2001 census enumeration was disturbed in 83 VDCs (across 12 districts); these VDCs are thus excluded.

[25] The 2001 time allocation information was collected differently and so we could not construct the same outcome variables for this year and cannot use the data as a panel at the VDC level.

Household-level covariates that likely influence biogas adoption or labor decisions are also created from the census micro-data. Household covariates include number of household members under 10, aged 10-17, and older than 18; head of household education; ownership of home, TV, toilet, radio, and tap water; electricity as main lighting fuel; and ethnicity. Covariates were also aggregated to VDC averages or proportions as appropriate for VDC-level analysis using the 2001 data. These include population, the average number of livestock owned by VDC households, and the respective percentages of households owning land and livestock, with female members owning land, engaged in agriculture, or engaged in any non-agricultural business. Household ownership of land and livestock variables were only collected in 2001.

Household Data – NLSS and NLFS

The Nepal Living Standards Survey is a nationally representative household survey also managed by the Central Bureau of Statistics. We use the most recent two rounds: NLSS-II and NLSS-III, which were conducted in 2003/04 and 2010/11 and sample 3912 and 5988 households, respectively. We also use the Nepal Labor Force Survey 2008 (NLFS), which is managed by CBS and interviews 15,976 households.

Both NLSS survey rounds collect detailed information on household fuelwood collection and expenditures. NLSS-III and the NLFS include detailed information on time allocation for home production in the past week for household members older than 5 years of age. All surveys include the data necessary to create the previously described household-level covariates, as well as the amount of land owned by the households. In addition, the NLSS survey rounds report the number of livestock owned by the household, the location of firewood collection, and per capita consumption.

Biogas installations and primary cooking fuel

We collected programmatic data from AEPC on the history of subsidized biogas installations in Nepal (the vast majority of household systems). These system-level data provide the exact date of system completion, the location (VDC)[26], basic system characteristics, and the company branch that sold the system and oversaw construction. We used these data for VDC-level analysis as well as identifying when biogas company branches were in operation.

Information on biogas use is also available in survey data; both the census and the NLSS/NLFS report primary cooking fuel. The NLSS also reports whether the household produces any biogas for home consumption. In that dataset, we consider households as biogas users if they either report biogas as their main cooking fuel or report producing any biogas. Because we want to compare households with biogas to those using traditional fuels, we limit our analysis sample to households who use dung, wood, or biogas as their main cooking fuel.[27]

Forest Cover

To study changes in forest cover at the VDC level, we use recent global data available from Hansen et al. (2013). This data is the only source of comprehensive data on forest cover over this time period. It includes estimates of baseline forest cover in 2000 and forest cover change from 2000-2012 based on interpretation of images from the US Landsat satellites (30 m resolution).

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[26] 5,000 of 293,000 installations (1.7%) up through 2011 could not be matched to census VDC codes

[27] We exclude households using electricity, LPG, kerosene, or "other" main cooking fuels.

We construct a value for the net change in forest cover in each VDC by combining Hansen's forest gain and loss values.[28] We calculate forest loss both as a percent of total area in the VDC and as a percent of initial VDC forest cover in 2000.

We also incorporate data on two types of forest protection policies: community forest management and government protected areas. Community Forest User Groups (CFUGs) are at the forefront of Nepal's forest management program (e.g. Ojha, Persha and Chhatre 2009, Bluffstone et al. 2014, Paudel 2016). There are over 15,000 CFUGs involving 1.8 million households in the management of 1.35 million hectares of forest and shrub-land (Sharma et al, 2015). Data comes from the Nepali Department of Forests database on community forest user groups.[29] Information on protected areas is from the IUCN-UNEP WCMC World Database of Protected Areas (accessed in 2015).[30] Prior work on these two types of forest protection find contrasting impacts for livelihoods, with CFUGs increasing food consumption for nearby households (Paudel, 2016) and protected areas reducing consumption of forest-goods without increasing reliance on market purchases (Howlader and Ando, 2016).

We limit the analysis of forest cover data to VDCs with at least some forest cover at the start of the period, defined as having 10 hectares or more of forest cover and at least 1% of area forested in 2000[31]. This reduces measurement error due to potentially large percentage changes measured where there is no substantial forest cover at baseline. Because we are interested in the potential

[28] Similar use of the Hansen et al. (2013) dataset to evaluate conservation initiatives is growing, e.g. Brandt et al. (2016), Wiesse and Naughton-Treves (2016), Sims and Alix-Garcia (2016) and Alix-Garcia, Sims and Yanez-Pagans (2015).

[29] We gratefully thank Johan Oldekop for sharing this data as well as the forest cover data. Both are also used and described in more detail in Oldekop et al. 2016.

[30] This includes land under strict protection, conservation zones, and buffer zones and covers approximately 20% of Nepal's land area.

[31] About 20% of VDCs, mostly located in the Terai region

for biogas to achieve a double-dividend, we also limit the census analysis to the same set of VDCs, although using the full household sample yields similar results (available upon request). We use all available NLSS households due to the survey's smaller sample size.

Empirical Strategy

Instrument: Access to Biogas Company Branches

Following a strategy similar to that of Burgess and Pande (2005) in their paper on rural bank expansion in India, our empirical analysis exploits policy-generated differences in the locations of biogas company branches. Specifically, we instrument for biogas adoption at the household and VDC level with a measure of access to company branches, conditional on controls for overall market access or possible determinants of company location that could be correlated with household demand. Access to biogas company branches is a determinant of installations because trained technical experts from these branches must transport biogas-specific materials (e.g.; gas valves, stoves, pipes, and fittings) to each biogas construction site. They are thus more likely to serve consumers that are closer to the branch.

To create a measure of access to biogas companies, we used programmatic data from AEPC on the history of subsidized biogas installations in Nepal. Although there are lists of current biogas companies and their branch locations, we could not find a complete source of all historical company branches. We therefore used the AEPC biogas installation data to compile a list of all companies and their respective branches that installed subsidized biogas systems between 2001 and 2011. We then used several sources (Winrock International, 2003; AEPC Biogas User' Surveys (2001-2008); and AEPC internal documents) to match the branches to VDC addresses and those addresses to census VDC codes.[32] We used mapping software to calculate Euclidean distance from the VDC to the nearest biogas branch in each year. Our instrument is the average distance from the VDC to the nearest biogas branch for the years between 2002 and the year of the outcome data.

Our instrumental variables approach assumes that access to biogas installation was quasi-random, conditional on controls for market access. We argue that this is due to the structure of government policies promoting biogas adoption across Nepal during the 2000s. Although biogas expansion occurred through the private sector, AEPC was highly involved in the technology's expansion, providing large subsidies (up to 40% of cost) to pre-approved biogas companies as well as quality enforcement for installations and maintenance. An AEPC policy goal was to expand biogas into underserved and remote areas, and they enacted a portfolio of policies starting in the early 2000's to encourage biogas company expansion into these areas. In 2006, AEPC introduced an additional subsidy for biogas systems constructed in an official set of "less penetrated districts (LPDs)" (Figure II.3). Also, companies wishing to maintain their pre-approved status were required to install systems and open company branches in LPDs.

These policies provide a source of variation in the supply of biogas that is arguably exogenous to household demand for biogas, because the government promoted biogas even where demand might not have been strong otherwise. Figure II.4 displays the location of all branches operating

[32] Of the 215,668 systems installed between 2001 and 2011, we matched the company branch to a location for all but 5,951 installations (~3%). The remaining 73 unmatched branches either existed very briefly and thus were never included on any official list, or were incorrectly coded in the administrative data.

in alternate years between 2001 and 2011 in relation to measures of market access. The figure shows that in 2001, branches tended to be located in population centers. However, between 2002 and 2011 there is clear improved access to biogas companies across the country, particularly in more remote areas. Over time, branch locations became less concentrated as companies responded to government policy and expanded into these new markets. The maps also show that there is some apparent randomness in the locations of branches over time—e.g. branches that pop up (and sometimes disappear) but are not correlated with obvious connectivity to markets or locational advantages. Most likely, this is due to imperfect information and experimentation on the part of biogas companies, and provides a further good source of plausibly random variation in access during this period.

To separate the variation in location due to government policies or other random factors from the endogenous variation in location due to overall market access or household demand, our first stage includes controls for the distance to the nearest branch at baseline (2001) and multiple measures of market access such as distance to the nearest population centers and distance to the nearest road. We also include multiple baseline controls for other locality or household characteristics that might attract biogas branches and be endogenous to household demand, such as asset ownership, involvement in agriculture, etc. Thus our instrument uses the remaining variation in biogas company branch location, which is partly due to government incentives to establish new branches and partly due to other factors we assume to be random. Although there is no direct way to test these assumptions, we do check the conditional exogeneity assumption using a placebo test for uptake of LPG fuel use, an alternative cooking fuel that is often correlated with wealth and market access.

Household Analysis: Wood collection and time allocation

We first examine the impact of biogas on both household firewood collection and time allocation. We apply the three-stage IV approach discussed in Wooldridge (2002) that takes into account the binary nature of our endogenous variable and provides valid standard errors for our estimates. In each stage, we use robust standard errors, clustered at the VDC level. We include interactions with Hill to allow the impacts of biogas to vary by region.

The first stage uses a logit regression, where $F(.)$ is the cumulative logistic distribution function, to predict the probability that household *i* in village *v* uses biogas as a function of our branch access instrument and sets of both household (X_{iv}) and VDC-level (V_v) time-consistent and aggregated baseline controls from 2001:

$$\Pr(BG_{iv} = 1) = \mathrm{F}(\vartheta + \sigma_1 BRANCH_v + \sigma_1 BRANCH_v x Hill_v + \Delta_1' X_{iv} + \Gamma_1' V_v) \qquad \textbf{(1)}$$

We then use predicted biogas and the interaction between predicted biogas and Hill as instruments in a standard two stage least squares estimation of the impact of biogas in both regions on household outcomes (equations 2-4). We include a dummy variable for dung use[33] and the same set of household and VDC controls. This means the omitted category is households who use wood, so the estimates should be interpreted as the impact of changing from wood to biogas.

[33] Robustness checks excluding the dung covariates yield similar results. Dung covariates are not included in the first stage as dung and wood together are perfectly collinear with biogas.

$$BG_{iv} = \pi_1 + \theta_{11}\widehat{\Pr(BG)}_{iv} + \theta_{12}\widehat{\Pr(BG)}_{iv}\text{x}Hill_v + \Delta'_{21}X_{iv} + \Gamma'_{21}V_v + \omega_{1iv} \quad \textbf{(2)}$$

$$BG_{iv}\text{x}Hill_v = \pi_2 + \theta_{21}\widehat{\Pr(BG)}_{iv} + \theta_{22}\widehat{\Pr(BG)}_{iv}\text{x}Hill_v + \Delta'_{22}X_{iv} + \Gamma'_{22}V_v + \omega_{2iv} \quad \textbf{(3)}$$

$$Y_{iv} = \alpha + \beta_1\widehat{BG}_{iv} + \beta_2\widehat{BG}_{iv}\text{x}Hill_v + \Phi'_1 Dung_{iv} + \Phi'_2 Dung_{iv}\text{x}Hill_v + \Delta'_3X_{iv} + \Gamma'_3V_v + \varepsilon_{iv} \quad \textbf{(4)}$$

Because we use both the NLSS and Census data to conduct these analyses, the details of the covariates included in each stage vary slightly because of the questions asked in each type of survey. The details of included covariates are provided in Tables 2-5.

Forest Cover Analysis

In addition to looking at the impact of biogas on household fuelwood use, we also estimate the environmental impacts on a larger scale: the change in VDC forest cover relative to VDC area. This analysis, conducted at the VDC level, uses the change in rate of VDC biogas use as the key independent variable.

As with household biogas use, the rate of VDC biogas uptake is not random and is correlated with both observed and unobserved factors. We therefore apply our biogas company branch-access IV strategy once again. However, instead of predicting household biogas in the survey year, we use two-stage least squares with our branch instrument predicting the change in biogas rate between 2001 and 2011. Again, we use the instrument interacted with the Hill region to obtain differential impacts by region. The household-level controls (Agg_v) and cooking fuel use ($Fuel_v$) are aggregated to the VDC level, differenced, and included to account for changes in household characteristics occurring over the study period that may influence the outcome variable. $\boldsymbol{V}_v$ once again represents the time-invariant and 2001 baseline VDC controls included in equations (5) and (6). $\Delta Forest_v$ is the inverse hyperbolic sine of the percent change in net forest cover from 2000-2012.

$$\Delta\%BG_{\square} = \kappa_1 + \rho_{11}BRANCH_v + \rho_{12}BRANCH_v\text{x}Hill_v + \Omega'_{11}\Delta Fuel_v + \Omega'_{12}\Delta Fuel_v\text{x}Hill_v + \Phi'_1\Delta Agg_v + \Psi'_1\boldsymbol{V}_v + \nu_{1v} \qquad \textbf{(5)}$$

$$\Delta\%BG_v\text{x}Hill_v = \kappa_2 + \rho_{21}BRANCH_v + \rho_{22}BRANCH_v\text{x}Hill_v + \Omega'_{21}\Delta Fuel_v + \Omega'_{22}\Delta Fuel_v\text{x}Hill_v + \Phi'_1\Delta Agg_v + \Psi'_1\boldsymbol{V}_v + \nu_{2v} \qquad \textbf{(6)}$$

$$\Delta Forest_v = \alpha + \beta_1\Delta\widehat{\%BG}_v + \beta_2\Delta\widehat{\%BG}_v\text{x}Hill_v + \Omega'_{31}\Delta Fuel_v + \Omega'_{32}\Delta F\square el_v\text{x}Hill_v + \Phi'_3\Delta Agg_v + \Psi'_3\boldsymbol{V}_v + \varepsilon_v \qquad \textbf{(7)}$$

If there are markets for fuelwood, biogas take-up may not affect forest cover. In the absence of constraints on collection or sales, fuelwood saved by biogas users may be collected and sold for consumption elsewhere. For this reason, we also look for differential effects of biogas in areas with forest protection policies. We examine the impact of two policy types: the presence of protected areas (PAs) and community forest user groups (CFUGs) by interacting the measures of these forest protection policies with biogas.

Results

Household level: fuelwood and time-allocation

Table II.1 shows Chi-squared test statistics for the joint significance of instruments *BRANCH* and *BRANCH*Hill* in each of the household-level first stage logit regressions described in equation (1). Columns 1 and 2 show the first stages for census households used in the analysis of male and female time-use (these are slightly different as some households have only one gender). Column 3 shows the first stage for the NLSS data used to analyze firewood collection. The regression coefficients are reported in detail in the Appendix. With values of 33.21 and 29.62 (p-value = 0.00 in both cases), the test statistics indicate that the instruments are jointly relevant and are reasonable predictors for the large census sample.[34] However, the instruments are not as strong when applied to the NLSS data due to its smaller sample size.[35]

Placebo test results are also reported in the table. Our placebo test is whether our instrument strongly predicts the use of LPG, the other high-quality cooking fuel available to households. The dependent variable for these regressions thus becomes a binary variable for the choice of primarily LPG as a cooking fuel vs. wood or dung, instead of biogas vs. wood or dung. In every instance, the Chi-squared statistics are of small magnitude and insignificant, meaning that our instrument fails to predict LPG use. This suggests that our instrument successfully captures the expansion of biogas supply due to factors not correlated with LPG use, such as market access or household wealth.

[34] Other papers that use this methodology and provide similar evidence for instrument relevance in this first stage include Adams et al. (2009), Nguyen et al. (2008), Guash et al. (2007), and Durrance (2010).
[35] Running the first stage using the census data limited to the NLSS 03/10 VDCs produce a Chi-squared statistic more similar to columns 1 and 2, suggesting it is an issue of sample size, not VDC selection.

We also use the Kleibergen-Paap rank Wald F-statistic as a test for weak instruments for the first stage of the two-stage least squares (reported in Tables II.2 and II.3 with each set of results). This is similar to the Cragg-Donald F-statistic (which is equivalent to the normal F-statistic in the case of one endogenous regressor), but is robust to violations of conditional homoscedasticity. Although critical values for the Kleibergen-Paap have not been generated, it is standard to use the Stock-Yogo values (Stock and Yogo, 2005), which were developed for the Cragg-Donald statistic (see for example Bentzen, 2012 or Fishback et al, 2010). We indicate whether the test statistic is above the critical value for two-stage least squares maximal size distortions of 20%, 15% and 10%. All of our test statistics are above these critical values. In other words, if one is willing to accept a maximal weak instrument bias of 10%, the null hypothesis of weak instruments is rejected.

Table II.2 presents both OLS and IV results for household fuelwood collection based on the NLSS data from 2003 and 2010. Since households can either collect or purchase wood, we include both variables (as well as time spent collecting wood) in our analysis. How households get firewood varies considerably by region. In the Hill region, 94% of households collect wood and only 27% purchase wood; in the Terai, those numbers are 65% and 41%, respectively. Our preferred results (Panel B: OLS with VDC fixed effects) suggest that across regions, biogas reduces the amount of fuelwood collected by 800-950 kg per year, saves households 65-70 hours per year, and reduces expenditure by approximately 800-1100 NP per year.[36] Comparing the biogas effect to the mean values among households using firewood as their main fuel (83% of

[36] Many households do not both collect and purchase fuelwood. Households that report no collection amount or no expenditure are coded as having a value of 0 for that variable.

households in our sample), when a Terai household switches from wood to biogas, they can expect to collect 50% less wood, spend 40% less time doing it, and spend about 55% less money on it. For a household in the Hill region, those figures are approximately 30%, 25%, and 85%. The impacts on wood collection (amount and time) in the colder Hill region are likely lower because biogas displaces a smaller share of total firewood, which is used for both cooking and heating. Also, it appears Hill households (almost all of whom collect some wood) use biogas to replace purchased wood before replacing collected wood. Although not significantly different from the OLS[37], the IV results generally yield even larger impacts, suggesting that our preferred results may be conservative. However, our preferred point estimates are comparable to Somanathan and Bluffstone (2015), who find biogas reduces firewood collection by 1100 kg/year.

We use the much larger sample of census data to examine whether adopting biogas affects time use for different members of the household in Table II.3. We do find substantial changes, with the results differing by both sex and region. In general, the IV results are typically of much larger magnitude than the OLS results.[38] As expected, women spend less time on home production as a result of biogas, although only in the Terai region. In fact, the use of biogas in the Terai region reduces women's time burden for home production by 11 percentage points from a mean of 43%, or to almost the same level as that in the Hill region (~30% of time). Interestingly, biogas leads men in the Terai to spend more time (2.8 percentage points or 45% more time) on home

[37] We tested for the endogeneity of regressors using the *endog* option of *ivreg2*, which tests the difference between the two Sargan-Hansen statistics. Unlike the Durbin-Wu-Hausman test, this test is robust to violations of conditional homoscedasticity. We fail to reject the null in all three of the firewood analyses, suggesting that for these outcomes, OLS and IV analyses give similar answers

[38] Testing for endogeneity using the same method as above, we find that 8/10 of the census outcomes reject the null at the 5% level and the other 2/10 reject at the 10% level.

production, possibly reflecting an increase in time spent on food processing observed in the more detailed data below or a willingness among men to help with cooking when it is easier. The impacts on home production for both genders are insignificant in the Hill region, possibly because water, a main input to biogas, is more difficult to collect there, and thus the net impact on home production may be smaller.

In addition, a strong and consistent result using our IV strategy, across gender and regions, is that biogas causes households to increase the time spent on education by 4-11 percentage points (25-40% from the means of 20% among women and 27% among men). Although these household aggregates include all members 10 and older, those under 18 already spend most of their time in school, and a test looking separately at this group did not find a significant increase in study time. Therefore this result reflects an increase in educational time for non-school aged adults. It is interesting that the result does not come from increased studies by children, given that in the past children did play a large role in collecting firewood according to data from the 1990's (Baland et al. 2010). This may be due to stronger educational opportunities and policies in Nepal in the most recent decade. Overall, the apparent investment in education due to biogas adoption has the potential to have real long-term welfare benefits for households.

Households with biogas also appear to shift away from wage labor (in both regions), and to a lesser degree, self-employment (in the Hill region). One explanation for this result is that for households purchasing wood, a shift to biogas likely reduces their liquidity needs. This could also explain why households in the Terai shift away from wage labor much more than those in the Hill region: among wood-using households, 44% of Terai households purchase at least some wood while only 27% of Hill households do. Biogas may thus allow households to reallocate their time from activities that generate quick cash to activities that yield higher returns. In the Terai, households reallocate substantial time towards agriculture (12-13 percentage points or an approximate doubling of time) in addition to education, indicating that may be where their extra time is most valuable. This larger return to agriculture in the Terai compared to the Hill could be due to a higher focus on commercial crops rather than subsistence agriculture, and a general increase in agricultural productivity driven by increased access to irrigation and more effective fertilizer practices (Marquardt, Khatri and Pain, 2016).

Using more detailed NLSS and NLFS time use data, we also sought to understand the channels through which biogas may affect home production (Table II.4). These results use OLS with VDC fixed effects rather than our IV strategy[39], so these results should be taken as suggestive but not conclusive. Columns 1-5 and 7-11 are all components of "home production" in the census, while livestock care (columns 6, 12) is considered "agriculture". When we examine this more detailed data, which reports number of hours spent on each activity in the past week, we find that in both regions, biogas is associated with a decrease in time spent collecting fuelwood, supporting the conclusions drawn from the firewood section of the survey. However, there is no statistically significant evidence that biogas households spend less time in cooking or cleaning, a benefit often expected of biogas. Although impacts are not significant, there are positive coefficients on water collection, cooking, and cleaning time in the Hills, suggesting this may explain why time spent in home production does not decrease. Although not significant, men also spend more time

[39] The IV strategy had a first stage that was too weak due to the smaller number of VDCs in the sample. Although the NLSS/NLFS sample includes more households than the NLSS II/III sample, there is more overlap among sampled VDCs, so the number of VDCs is lower.

in food processing, particularly in the Terai, which may partially account for the increase in home production for men in the Terai observed in the census analysis.

VDC level: forest cover

The substantial reduction in fuelwood use among biogas households suggests that forest cover could increase over time in areas with higher rates of biogas use. This is not necessarily the case, as short term firewood collection tends to impact forest quality, not overall forest cover. Yet Hansen's dataset spans more than 10 years, a period over which repeated pressure from firewood collection could affect forest regeneration or susceptibility to disease, pests or fire, and thus affect overall forest cover.

Interestingly, the OLS and IV estimates give somewhat different results for impacts on forest cover, yet generally not significantly so (Table II.5).[40] As shown in Columns 1 and 2, OLS results suggest more biogas is associated with significantly positive forest change in the Terai but no significant impacts in the Hill region. The IV analysis suggests more biogas is associated with possible forest loss in the Terai and no impacts in the Hill region. In columns 3-6, we test whether biogas can improve forest cover when complemented by forest management policies.[41] The IV results allowing for an interaction between biogas and protected areas show that if a VDC fully overlapped with a protected area in the Hill region, a one percentage point increase in biogas use generates a 0.035 percent increase in forest cover relative to VDC area and a 0.11 percent increase relative to 2000 forest cover. OLS estimates are also positive and significant,

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[40] Once again, we use the *endog* option for the *ivreg2* command, which is robust to violations of conditional homoscedasticity. We fail to reject the null in all analyses except for the Protected Areas regressions (Columns 3-4).
[41] Stock-Yogo critical values have not been tabulated for cases with more than two endogenous variables. Therefore, we also include the first stage Sanderson-Windmeijer F statistics testing for weak identification of each endogenous regressor, all of which exceed the critical values.

although of somewhat smaller magnitude. The IV estimates for biogas combined with protected areas in the Terai are not statistically significantly different from zero; however, OLS estimates are positive and significant. The CFUG IV results also suggest that biogas may have a larger impact when paired with forest protection policy than alone, as the interaction between biogas and CFUG is positive and significant in Column 5. However, the forest policy effect is insignificant in both regions. Together these results, although noisy, give some indication that biogas may improve forest cover when paired with other policies; however, the results also highlight challenges in causally linking biogas and improved forest outcomes.

Well-connected firewood markets provide a reason as to why the impacts are difficult to detect. Work by Chakravorty et al. (2015) suggests an important role of fuelwood markets on collection times in neighboring India. In Nepal, wood is more likely to be purchased in the Terai than in the Hills, potentially explaining why biogas has a larger impact on forest cover in the Hills. Even purchased wood is likely to be from more local sources in the Hills, as transportation is much more difficult in that region. An alternative reason for small estimates is that neighboring households respond by collecting additional wood. For this reason, we tested for spillovers to other households without biogas in VDCs with high uptake of biogas; however, we did not find increases in wood collection for those households. Finally, it may be the case that biogas will have an impact on forest cover, but that not enough time has passed to observe it in the data.

Conclusion

Renewable energy technologies are a tool available in the global effort to improve energy access and standards of living while minimizing environmental harm worldwide. This study represents one of the first attempts to rigorously measure the sustainable development potential of renewable energy technologies.

Biogas in particular is an important renewable energy technology. To date there have been more than four million installations in India and 27 million in China. Yet there remains significant potential for additional future installations; estimates indicate potential for up to 17 million household systems in India and a doubling of China's household systems (Chen et al. 2010, Bond and Templeton 2011). In Nepal, the 300,000 systems installed by 2015 are estimated to be only 29% of households that are well-suited for biogas[42] (BSP, 2012). Yet before continuing major investments in this technology, or other renewable energy technologies, it is important to understand their impacts and the other policies or conditions that may interact with the technology.

Previous literature found a significant decrease in fuelwood use among biogas households, but did not answer whether these savings translated to measurable improvements in the household's time allocation or the local environment. Our findings support these results, and suggest that they may even underestimate the true impact of biogas on fuelwood use. Additionally, we find that the impact of biogas on labor outcomes is substantial, but varies between the Terai and Hill

[42] A study of technical potential of biogas in Nepal suggests 1.03 million suitable households who have not yet installed biogas (SETM, 2013).

regions of Nepal, likely reflecting the differences in biogas efficiency, availability of inputs, and access to high-return labor opportunities in these regions.

We find that households generally switch away from home production and wage work and into agriculture. If increased time in agriculture generates higher returns, these changes may improve household welfare. Yet this is not clearly a given; it will depend on the economic opportunities available to households, both locally and on a national or global scale. The fact that many people in Nepal often lack good economic opportunities, especially in rural areas, may explain why adult household members reallocate time to education and learning new skills rather than directly to income-generating activities. Again, for these investments to pay off, there must be higher wage opportunities available for more skilled workers. Similarly, despite the clear decrease in fuelwood collection resulting from biogas, we find that that it has consistent positive impacts on local forest cover only in the presence of protected areas. Thus in summary, we find that biogas can achieve a double dividend in terms of socio-economic and environmental outcomes, but that these results may require other factors, such as high-return labor options and forest protection policies, to facilitate true sustainable development achievements.

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Figure 1I.1 Percent of households with biogas installed per VDC

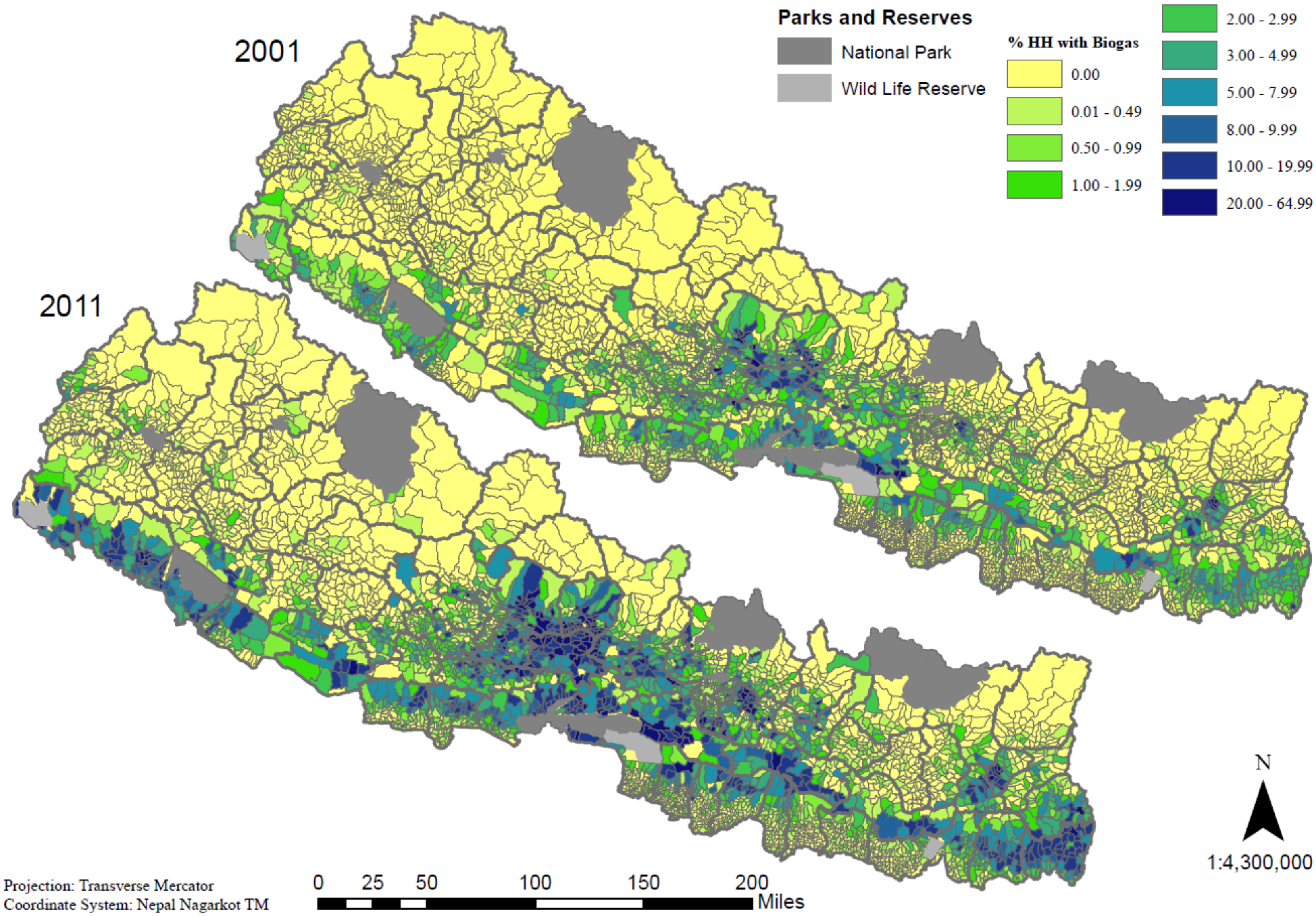
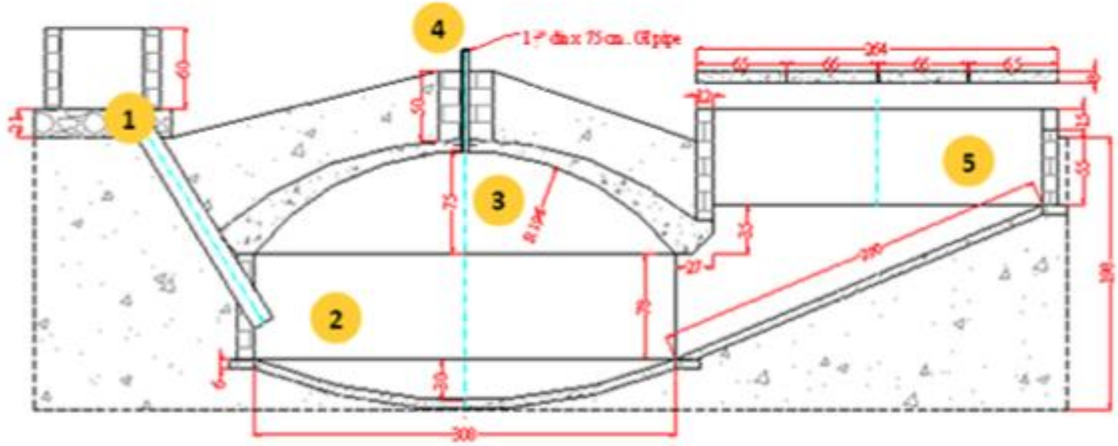


Figure II.2a Blueprint of a $10m^3$ biogas digester model GGC2047.



Key: (1) Inlet chamber with inlet pipe; (2) Digester; (3) Dome (gas storage); (4) Gas outlet; (5) Bioslurry overflow (Lohri et al., 2010)

Figure II.2b Finished biogas system (Bajgain et al., 2005)

Photo 1.2: Biogas system

Figure II.3 Less penetrated districts

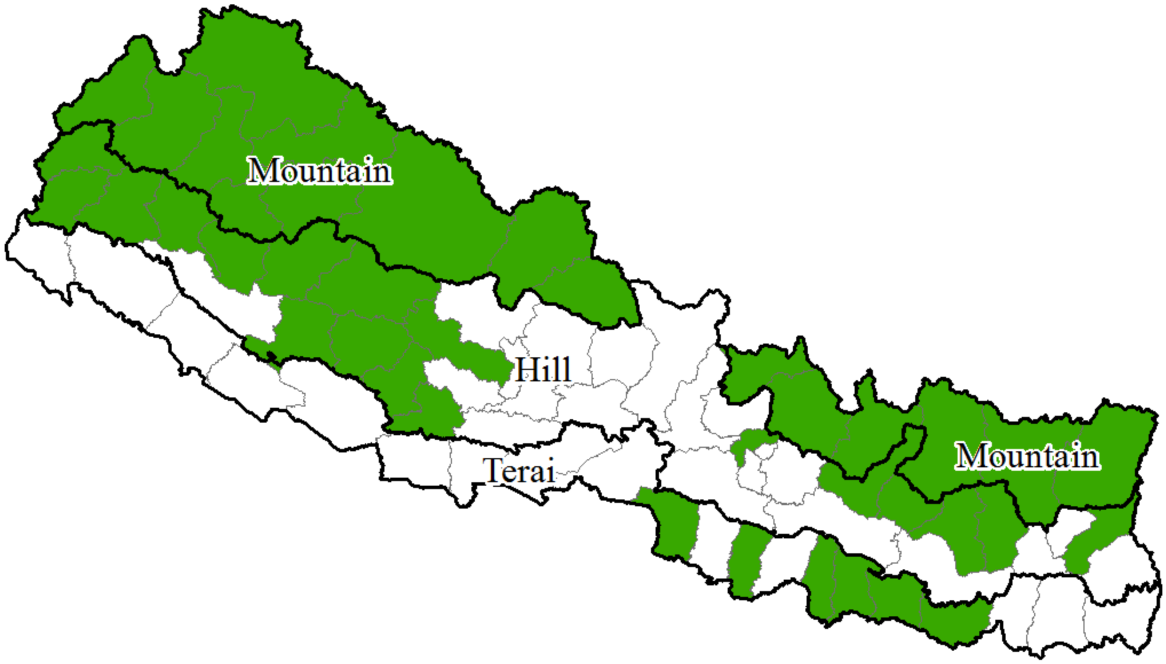


Figure II.4 Biogas Branches and Market Access

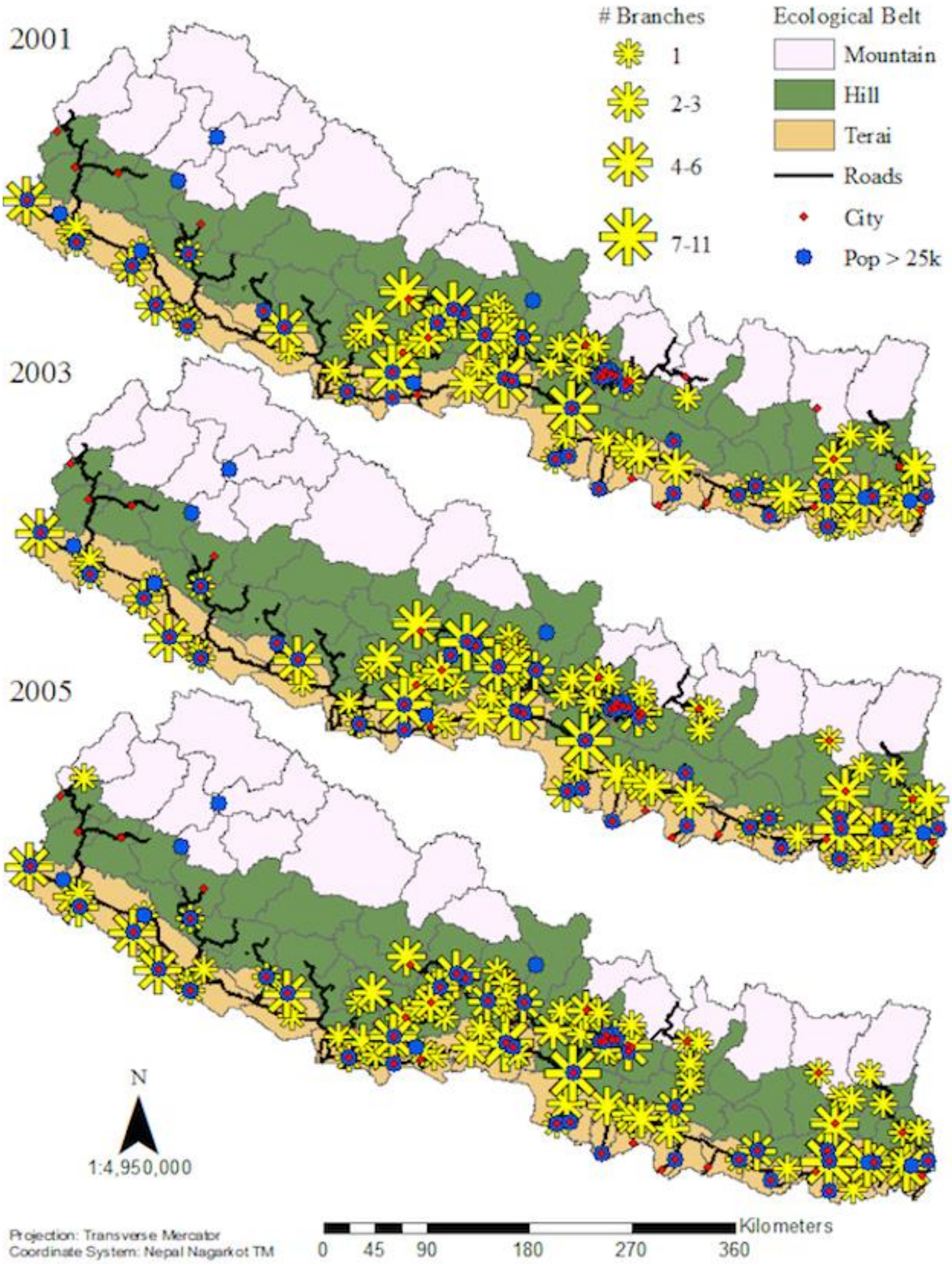


Figure II.4 (continued) Biogas Branches and Market Access

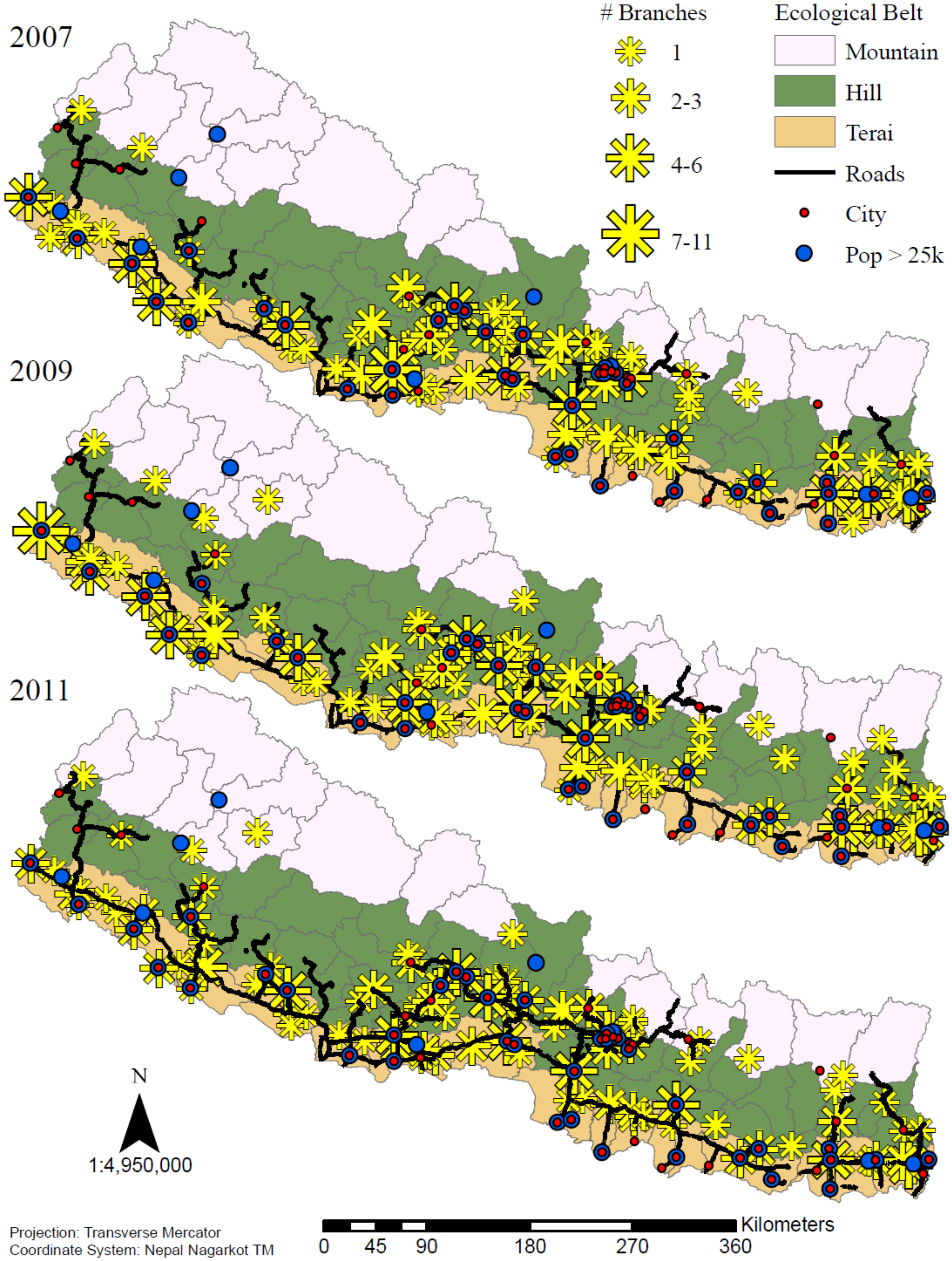


Table II.1 First stages and placebo tests: tests of joint significance for instruments

First Stage - Predicting Biogas Use	Census (2011)		NLSS II/III (2003, 2010)
	Male	Female	
	(1)	(2)	(3)
Chi-Squared	33.21	29.62	9.50
P-value	0.00	0.00	0.01
VDC clusters	2736	2,736	530
Observations	392,786	435,297	6,649

Placebo Test using LPG	Census (2011)		NLSS II/III (2003, 2010)
	Male	Female	
Chi-Squared	2.20	1.43	3.83
P-value	0.33	0.49	0.15
VDC clusters	2736	2736	527
Observations	481,795	530,732	7,507

Notes: Household samples report chi-squared test of joint significance of instruments (branch and branch*hill). Census households considered biogas if main cooking fuel is biogas. NLSS/NLFS households are considered biogas households if it is their main cooking fuel OR they produce any biogas at home. LPG refers to main cooking fuel. Branch distance is the logged average Euclidean distance to nearest branch between 2002 and 2011. Household samples include households using biogas, dung, or wood as cooking fuel. Placebo test replaces biogas households with LPG households. The omitted group is wood. Includes all VDCs from Terai and Hill region and 190 mountain VDCs with any biogas installations by 2011. Census analysis limited to VDCs with >10 hectares forest cover and >1% forest cover in 2001. Each sample includes the covariates listed in the results table for that sample.

Table II.2 Impacts of biogas on household firewood collection and purchase

	Annual Wood Collection		Expenditure
	Kilograms	Minutes	2010 NR
	(1)	(2)	(3)
Panel A: OLS			
Biogas in Terai	-1105.0***	-4758.5***	-963.9***
	(135.70)	(810.70)	(205.50)
Biogas in Hill	-946.9***	-5000.3***	-793.9***
(Biogas + Biogas*Hill)	(150.93)	(719.05)	(213.96)
Panel B: OLS with VDC Fixed Effects			
Biogas in Terai	-943.2***	-4405.3***	-1106.5***
	(146.40)	(928.40)	(210.70)
Biogas in Hill	-794.6***	-3917.1***	-818.8***
(Biogas + Biogas*Hill)	(124.76)	(691.18)	(232.54)
Panel C: IV			
Biogas in Terai	-1965.2***	-5301.0*	-923.3
	(435.10)	(2347.10)	(608.50)
Biogas in Hill	-1354.4***	-7692.1***	-1415.9**
(Biogas + Biogas*Hill)	(388.68)	(2277.67)	(569.79)
First Stage Kleibergen-Paap F	178.3 †††	178.3 †††	178.3 †††
Mean dep. var. - Terai	1,853	11,317	2,024
Mean dep. var. - Hill	2,787	16,802	946
VDC clusters	530	530	530
Observations	6,649	6,649	6,649

Notes: Outcome variables are from the Nepal Living Standards Survey 2003 and 2010. Top 1% of outcome measures Windsorized. Households are considered biogas households if it is their main cooking fuel OR they produce any biogas at home. Dung refers to main cooking fuel. Omitted group is wood. Households using other fuel types are excluded. Includes all VDCs from Terai and Hill region and 31 mountain VDCs with any biogas plants installed by 2011. All columns control for VDC and year fixed effects as well as household and VDC controls. Household controls: asset ownership (home, piped water, electricity, toilet, radio, TV), ethnicity, household head education, household size separated by age (0-9, 10-17, 18+), land and livestock ownership, per capita consumption, dung as main fuel source, location of firewood collection, and month of interview. VDC controls: proportion of 2001 households in VDC with electricity, piped water, tv female land ownership, migrant in the household, involvement in agriculture, own business, head with high school education, household size in each age category, ethnicity, owning land, owning livestock, average number of livestock, and main fuel being dung, wood, and LPG/kerosene; VDC area, elevation, slope, annual precipitation, 2001 population, change in population 2001-2011, and region; having at least 25k and 50k inhabitants; distance to Kathmandu, the nearest road, the nearest municipality, and the nearest pop centers of 25k and 50k; proportion of forest cover under CFUG management in pre-2001 and post-2001; and the proportion of protected forest cover. Standard errors clustered at VDC level. *, **, *** indicate significance at the 10%, 5%, and 1% level, respectively. †, ††, ††† indicate TSLS size distortions of a maximum of 20%, 15%, and 10%, respectively.

Table II.3 Impacts of biogas on percent of months household members spent on each activity in last year

	Men					Women				
	Home Production	Studies	Agriculture	Wage	Self-Employ-ment	Home Production	Studies	Agriculture	Wage	Self-Employ-ment
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A: OLS										
Biogas in Terai	0.493*	1.847***	6.027***	-8.042***	-0.263	-2.460***	1.154***	4.353***	-2.617***	-1.154***
	(0.225)	(0.371)	(0.580)	(0.590)	(0.286)	(0.470)	(0.281)	(0.500)	(0.267)	(0.161)
Biogas in Hill	-0.272	2.077***	-0.796	-0.167	-0.516*	0.916	0.755***	-0.265	-0.294	-0.681***
(Biogas + Biogas*Hill)	(0.266)	(0.455)	(0.579)	(0.527)	(0.299)	(0.593)	(0.268)	(0.583)	(0.260)	(0.207)
Panel B: IV										
Biogas in Terai	2.753**	10.96***	13.29***	-31.84***	0.722	-11.20***	5.435***	12.05***	-11.32***	-0.509
	(1.024)	(1.445)	(2.557)	(2.711)	(1.085)	(1.961)	(1.044)	(2.242)	(1.200)	(0.698)
Biogas in Hill	1.036	5.734***	1.250	-7.359**	-2.928*	-1.584	4.795***	0.222	-2.806*	-1.869*
(Biogas + Biogas*Hill)	(1.165)	(2.061)	(3.306)	(3.363)	(1.643)	(3.178)	(1.664)	(3.419)	(1.437)	(1.001)
First Stage Kleibergen-Paap F	345.5 †††	345.5 †††	345.5 †††	345.5 †††	345.5 †††	344.2 †††	344.2 †††	344.2 †††	344.2 †††	344.2 †††
Mean dep. var. - Terai	6.22	26.38	27.17	23.42	7.43	42.70	19.80	20.55	6.51	3.63
Mean dep. var. - Hill	8.82	26.98	31.97	16.09	6.19	29.97	20.04	35.14	4.19	3.82
VDC clusters	2,736	2,736	2,736	2,736	2,736	2,736	2,736	2,736	2,736	2,736
Observations	392,786	392,786	392,786	392,786	392,786	435,297	435,297	435,297	435,297	435,297

Notes: Outcome variables are from the 2011 census microdata and are aggregated across all male/female members of the household 10 and older. Includes households using biogas, dung, and wood as their main fuel type. Omitted group is wood. Includes all VDCs from Terai and Hill region as well as 190 VDCs from the mountain region that had at least one biogas plant installed by 2011. Sample limited to VDCs with >10 hectares forest cover and >1% forest cover in 2001. All columns control for household and VDC controls. Household controls: asset ownership (home, piped water, electricity, toilet, radio, TV), ethnicity, household head education, household size separated by age (0-9, 10-17, 18+), and dung as main fuel source. VDC controls: proportion of 2001 households in VDC with electricity, piped water, TV female land ownership, migrant in the household, involvement in agriculture, own business, head with high school education, household size in each age category, ethnicity, owning land, owning livestock, average number of livestock, and main fuel being dung, wood, and LPG/kerosene; VDC area, elevation, slope, annual precipitation, 2001 population, change in population 2001-2011, and region; having at least 25k and 50k inhabitants; distance to Kathmandu, the nearest road, the nearest municipality, and the nearest pop centers of 25k and 50k; proportion of forest cover under CFUG management in pre-2001 and post-2001; the proportion of protected forest cover, and distance to the nearest biogas branch in 2001. Standard errors clustered at VDC level. *, **, *** indicate significance at the 10%, 5%, and 1% level, respectively. †, ††, ††† indicate TSLS size distortions of a maximum of 20%, 15%, and 10%, respectively.

Table II.4 Impacts of biogas on hours household spent in past 7 days on home production

	Men						Women					
	Wood/ Dung Collection	Water Collection	Cooking	Cleaning	Food Processing	Livestock Care	Wood/ Dung Collection	Water Collection	Cooking	Cleaning	Food Processing	Livestock Care
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Panel A: OLS												
Biogas in Terai	-0.0909	-0.137	-0.278	0.0275	0.291	2.051	-1.441***	-0.315	-0.164	1.044*	0.66	-0.234
	(0.272)	(0.084)	(0.219)	(0.187)	(0.157)	(1.781)	(0.405)	(0.245)	(0.538)	(0.442)	(0.337)	(1.821)
Biogas in Hill (Biogas + Biogas*Hill)	-0.513**	-0.012	0.135	-0.205	-0.030	-0.760	-0.940**	0.422	0.609	0.374	0.146	-0.499
	(0.244)	(0.207)	(0.325)	(0.197)	(0.072)	(1.591)	(0.392)	(0.463)	(0.651)	(0.502)	(0.313)	(1.751)
Panel B: OLS with VDC FE												
Biogas in Terai	-0.235	-0.129	-0.287	-0.0522	0.278	1.413	-1.500***	-0.214	-0.0794	0.825*	0.56	0.268
	(0.235)	(0.073)	(0.247)	(0.190)	(0.166)	(1.721)	(0.420)	(0.215)	(0.545)	(0.377)	(0.324)	(1.995)
Biogas in Hill (Biogas + Biogas*Hill)	-0.390**	-0.134	-0.165	-0.298	0.064	0.862	-0.937**	0.427	0.131	-0.011	0.380	-0.085
	(0.191)	(0.169)	(0.345)	(0.217)	(0.064)	(1.781)	(0.364)	(0.396)	(0.650)	(0.520)	(0.315)	(1.990)
Mean dep. var. - Terai	1.27	0.30	1.26	1.16	0.33	10.65	3.44	1.08	17.41	12.17	1.44	17.53
Mean dep. var. - Hill	2.35	1.62	2.09	1.65	0.60	17.46	4.56	3.79	16.69	12.29	3.32	25.81
VDC clusters	421	421	421	421	421	340	421	421	421	421	421	340
Observations	13,086	13,086	13,086	13,086	13,086	3,555	13,625	13,625	13,625	13,625	13,625	3,749

Notes: Outcome variables are from the Nepal Living Standards Survey 2010 and Nepal Labour Force Survey 2008 and aggregated across all male/female members 10 and older. Households are considered biogas households if it is their main cooking fuel OR they produce any biogas at home. Dung refers to main cooking fuel. Omitted group is wood. Households using other fuel types are excluded. Omitted group is wood. Includes all VDCs from Terai and Hill region and 14 mountain VDCs with any biogas installations by 2011. All columns control for VDC and year fixed effects as well as household and VDC controls. Household controls: asset ownership (home, piped water, electricity, toilet, radio, TV), ethnicity, household head education, household size separated by age (0-9, 10-17, 18+), dung as main fuel source, land ownership, location of fuel collection, per capita consumption, and month of interview. Livestock regression includes number of large livestock. VDC controls: proportion of 2001 households in VDC with electricity, piped water, TV female land ownership, migrant in the household, involvement in agriculture, own business, head with high school education, household size in each age category, ethnicity, owning land, owning livestock, average number of livestock, and main fuel being dung, wood, and LPG/kerosene; VDC area, elevation, slope, annual precipitation, 2001 population, change in population 2001-2011, and region; having at least 25k and 50k inhabitants; distance to Kathmandu, the nearest road, the nearest municipality, and the nearest pop centers of 25k and 50k; proportion of forest cover under CFUG management in pre-2001 and post-2001; and the proportion of protected forest cover. Standard errors clustered at VDC level. *, **, *** indicate significance at the 10%, 5%, and 1% level, respectively.

Table II.5 Impacts of biogas on change in percent of VDC forest cover relative to VDC area

			Policy: Protected Areas		Policy: CFUG pre 2001	
	Relative to VDC area	Relative to 2000 Forest Cover	Relative to VDC area	Relative to 2000 Forest Cover	Relative to VDC area	Relative to 2000 Forest Cover
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: OLS						
Change in % biogas	0.0112**	0.0270**	0.0105**	0.0249*	0.0107**	0.0263*
	(0.004)	(0.010)	(0.004)	(0.010)	(0.004)	(0.010)
Change in % biogas*Hill	-0.0121***	-0.0260**	-0.0122***	-0.0262**	-0.0125***	-0.0265**
	(0.004)	(0.010)	(0.004)	(0.010)	(0.003)	(0.010)
Hill effect (%biogas + %biogas*Hill)	-0.0009	0.0011	-0.0017*	-0.0013	-0.0018	-0.0002
	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)	(0.004)
Biogas*Forest Policy			0.00800*	0.0253*	0.002	0.002
			(0.004)	(0.011)	(0.002)	(0.005)
Forest Policy Effect - Terai			0.019***	0.050***	0.012***	0.029***
(biogas + biogas*policy)			(0.005)	(0.014)	(0.003)	(0.010)
Forest Policy Effect - Hill			0.0063*	0.0240**	-0.0002	0.0021
(biogas + biogas*hill + biogas*policy)			(0.0038)	(0.0105)	(0.0012)	(0.0031)
Panel B: IV						
Change in % biogas	-0.010	-0.053	-0.010	-0.053	-0.016	-0.065
	(0.017)	(0.052)	(0.017)	(0.051)	(0.019)	(0.056)
Change in % biogas*Hill	0.012	0.064	0.013	0.066	0.009	0.057
	(0.015)	(0.045)	(0.015)	(0.044)	(0.014)	(0.043)
Hill effect (%biogas + %biogas*Hill)	0.0017	0.0116	0.0021	0.0128	-0.0067	-0.0084
	(0.008)	(0.021)	(0.008)	(0.021)	(0.009)	(0.025)
Biogas*Forest Policy			0.0325**	0.0974**	0.0131*	0.031
			(0.011)	(0.031)	(0.006)	(0.018)
Forest Policy Effect - Terai			0.0221	0.0446	-0.0024	-0.0338
(biogas + biogas*policy)			(0.018)	(0.054)	(0.016)	(0.049)
Forest Policy Effect - Hill			0.0346***	0.1102***	0.0064	0.0228
(biogas + biogas*hill + biogas*policy)			(0.0129)	(0.0350)	(0.0077)	(0.0210)

			Policy: Protected Areas		Policy: CFUG pre 2001	
	Relative to VDC area	Relative to 2000 Forest Cover	Relative to VDC area	Relative to 2000 Forest Cover	Relative to VDC area	Relative to 2000 Forest Cover
	(1)	(2)	(3)	(4)	(5)	(6)
First stage Sanderson-Windmeijer F						
Δbiogas	27.41 †††	27.41 †††	27.91 †††	27.91 †††	27.33 †††	27.33 †††
Δbiogas*hill	55.94 †††	55.94 †††	55.92 †††	55.92 †††	55.32 †††	55.32 †††
Δbiogas*policy			78.22 †††	78.22 †††	336.54 †††	336.54 †††
First stage Kleibergen-Paap F	14.83 †††	14.83 †††	10.02^	10.02^	9.69^	9.69^
Mean proportion forest change - in Terai	-0.005	-0.037	-0.005	-0.037	-0.005	-0.037
- in Hill	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Observations	2736	2736	2736	2736	2736	2736

Notes: Outcome variables are from Hansen (2012) and represent the inverse hyperbolic sine of the percent of forest cover change between 2001 and 2011 (positive values = increase in forest cover). Percent change is relative to either VDC area or original forest cover. The top and bottom 1% of values have been Windsorized and values have been transformed by hyperbolic sine. Includes all VDCs from Terai and Hill region as well as 190 VDCs from the mountain region that had at least one biogas plant installed by 2011. Sample limited to VDCs with >10 hectares forest cover and >1% forest cover in 2000. Controls: proportion of 2001 households in VDC with electricity, piped water, TV, female land ownership, migrant in the household, involvement in agriculture, own business, head with high school education, household size in each age category, ethnicity, owning land, owning livestock, average number of livestock, and main fuel being dung, wood, and LPG/kerosene; VDC area, elevation, slope, annual precipitation, 2001 population, change in population 2001-2011, and region; having at least 25k and 50k inhabitants; distance to Kathmandu, the nearest road, the nearest municipality, and the nearest pop centers of 25k and 50k; proportion of forest cover under CFUG management in pre-2001 and post-2001; the proportion of protected forest cover, and distance to the nearest biogas branch in 2001. Standard errors clustered at VDC level. Standard errors clustered at VDC level. *, **, *** indicate significance at the 10%, 5%, and 1% level, respectively. †,††, ††† indicate TSLS size distortions of a maximum of 20%, 15%, and 10%, respectively (for single endogenous or multiple endogenous regressors as appropriate). ^ indicates Stock-Yogo values not tabulated.

CHAPTER III

The Economic Impacts of Grid versus Off-grid Electrification: Evidence from Nepal

Co-authored by Robyn Meeks

Abstract

In an effort to increase electrification rates in developing countries, policymakers and donors rely on both grid and off-grid electricity sources. Yet, to date, little evidence exists as to how the benefits from these sources compare. In this paper, we implement a quasi-experimental analysis exploiting eligibility requirements for government subsidies in Nepal to quantify the impacts of two rural electrification programs: one electrifying via off-grid micro-hydro plants and the other through the expansion of the centralized electrical grid. We find that the electrification source matters for labor allocation among both women and men; the effects from grid electrification are generally concentrated in different activities and are of larger magnitudes than those from micro-hydro.

Introduction

Universal access to clean and modern energy (electricity, natural gas, biogas, etc.) is a key component of both meeting basic needs and achieving economic growth (World Bank, 2006). This sentiment was reiterated in the Sustainable Development Goals, and will thus continue to be a priority through 2030 (UN, 2016). Recent papers have documented positive benefits of electrification across many outcomes including labor force participation (Dinkelman, 2011); economic development (Rud, 2012; Lipscomb, Mobarak & Barham, 2013; Van de Walle et al., 2013); agricultural productivity and land use (Chakravorty, Emerick & Ravago, 2016); and health (Barron & Torero, 2016). These papers suggest that electrification directly contributes to improving household economic outcomes in addition to quality of life.

Providing electrification to rural and remote places is challenging for many reasons, including: the expense of expanding infrastructure to scattered settlements across what is often difficult terrain; low demand and ability to pay among potential consumers; and lack of well-functioning political and institutional structures that oversee and fund large infrastructure projects. In addition, many countries with low electrification rates already face energy supply shortages with existing customers, so expansion of the national grid places further strain on an already scarce resource.

Renewable energy technologies (RETs) emerged and gained popularity as a way to bypass many of the barriers to grid expansion and provide clean, modern energy to rural communities. These off-grid and micro-grid solutions include solar, micro-hydro, wind, and geothermal power.[43] Although the average cost per MWh provided through the grid is cheaper than through off-grid technologies, studies have found that RETs can often be less costly than grid expansion in remote and rural areas, where the main cost is extending the grid to the settlement (Mainali & Silveira, 2013; IEG, 2008). RETs are therefore likely to serve an important role in achieving universal modern energy access by 2030; of the estimated $477 billion required between 2016 and 2030 to reach this target, policymakers expect to invest approximately two-thirds in RETs (IEA, UNDP & UNIDO, 2010).

There is concern, however, that although these technologies may meet basic energy needs such as lighting, they have neither the potential to support large-scale development nor to provide households with the lifestyles they truly want. (Lee, Miguel & Wolfram, 2016; UNDP, 2011). Although electrification is generally measured in binary terms (electrified or not), there is no official consensus on how much electricity should be considered enough when targeting the energy poor. The International Energy Agency (IEA) has proposed 100 kWh of electricity per person per year as a minimum threshold (IEA, UNDP & UNIDO, 2010). To put this in perspective, the average American consumes over 40 times that amount per year (4,191 kWh).[44] Exactly how much energy is required to go beyond meeting basic needs and support a household in a path out of poverty is an unanswered question.

[43] For the remainder of the paper, we refer to all electrification that is not through the national grid as "off-grid," even if it incorporates a community-level micro-grid.

[44] According to the US Energy Information Administration (2016), the average residential customer (household) consumes 10,812 kWh per year. According to the US Census (Lofquist et al, 2012), the average household size in the US is 2.58 people.

A related question that has received little attention despite the growing literature on the benefits of electrification is how the quality or reliability of electricity influences the impacts of electrification. An exception is a recent study by Chakravorty, Pelli, and Marchand (2014); they find that while simply connecting rural Indian households to the grid increases income of those households by 9%, a higher quality connection (in terms of fewer outages and more hours per day of service) triples the impact. Grid electrification in developing countries, including Nepal, is often characterized by long periods of load-shedding and frequent outages (Mainali & Silveira, 2012; Sarangi et al, 2014). How off-grid service provision compares to that of the grid likely varies based on type of technology, load, and management, among other factors. However, the electricity being sourced and managed locally could facilitate coordination among consumers, possibly leading to more reliable service.

Differences in both quantity and quality of electricity provided by off-grid technologies could lead to impacts that diverge from those found for grid expansion. In this paper, we provide the first causal estimates of the impacts of off-grid community electrification. We then compare these estimates to causal impacts of grid electrification within the same geographic and cultural context. Measuring causal effects of electrification is difficult due to both reverse causality and other sources of endogeneity that may lead to the electrification of one area over another. For instance, governments may target wealthy or rapidly growing areas for electrification, which would bias results towards finding positive economic impacts. The reverse may also be true if electrification is targeted towards underprivileged communities as part of a pro-poor policy initiative.

To identify the causal impacts of electrification, we employ two instrumental variables to predict the placement of off-grid micro-hydro plants and community-driven, grid-based electrification in previously un- or under-electrified areas in Nepal. To predict micro-hydro placement, we rely on a GIS-based study of locations in Nepal that identified potential sites for micro-hydro based on a variety of geophysical factors. To predict grid expansion, we take advantage of a government-subsidized program to extend the grid to communities that were initially bypassed during grid construction, but are within a certain distance of the grid. We then look at the causal impact of electrification by micro-hydro and by grid expansion on individual labor outcomes measured in terms of the amount of time in a year spent on six activities: household chores, extended economic work (other home production), studies, agriculture, wage labor, and self-employment.

We find that when compared to having no electrification, micro-hydro and grid electrification both result in labor reallocation among men and women, but that the effects differ in terms of both the types and magnitudes of time use adjustments. Micro-hydro electrification results in a modest increase in time allocated to studies for men and women, and a reallocation of time from agriculture to own business activities for men. Grid electrification results in a large labor shift for women, from being primarily occupied with household work to involvement in both wage employment and own business activities. Men also increase time allocated to wage work in response to grid electrification, decreasing time spent on own business activities. However, we find that when we compare the causal impacts grid and off-grid electrification directly, they both result in a shift from household work to employment activities for women, although the significance and magnitudes are larger for grid electrification.

The remainder of the paper is organized as follows: Section 2 describes Nepal's energy situation and the differences between grid and off-grid electrification. In Section 3 we provide details on our instrumental variables. Section 4 discusses data sources. We present the empirical strategy in Section 5. Section 6 reports the results and Section 7 concludes.

Background

Nepal is one of Southeast Asia's poorest countries, with 25.2% of the population living below the national poverty line (World Bank, 2016). One of many reasons much of Nepal has remained poor is the difficulty of transporting people and goods throughout the country. As of 2010, 9 of the 75 district headquarters remained unconnected to the national highway network despite it being a major policy goal (Shrethsa, 2015), giving some idea of the challenge construction poses in the mountainous, remote areas. The country is divided into 3 ecological belts from south to north (Terai, Hill, Mountain) that differ in terms of climate, terrain, culture, and access to markets and infrastructure. In general, the farther north and more mountainous an area is, the more difficult it is to access.

Nepal experienced a period of rapid growth in electrification during the last decade. In 2001, 40% of the population used electricity as their main light source. By 2011, that number had increased to 67% (CBS, 2003; CBS, 2012).[45] Figures III.1a and III.1b show the expansion in terms electrification rates for each Village Development Committee (VDC), which should be thought of as a sub-district containing multiple settlements. This expansion is due to a combined

[45] Among rural areas, the electrification rate increased from 32% to 61%.

effort between the National Electric Authority (NEA), which oversees the national grid; the Alternative Energy Promotion Centre under the Ministry of Science, Technology, and Environment (AEPC), which manages all RETs; and several international donors and partners.

Policymakers have pursued a multifaceted approach in the electrification of Nepal. The vast majority (87%) of Nepal's electricity is sourced from large hydropower plants located across the country (Mainali & Silveira, 2013). The electricity is then transmitted through high-voltage cables that run across the Terai and into the Kathmandu Valley and other population centers in the Hill and Mountain regions (i.e., the grid). In an effort to electrify the district headquarters, the government also constructed several mini-hydro (100 – 1000 kWh) plants in the 1980s that electrify the headquarters and some of the surrounding area. For the remaining communities living away from the grid, connection is prohibitively expensive in the foreseeable future given the difficult terrain and scattered settlements (Sarangi et al., 2014). Furthermore, rural communities are often subsistence economies that generate very little cash income and thus have low demand for electricity. This combination of high supply cost and low demand provides little incentive for private companies to provide large-scale electrification to these communities. However, the steep slopes and abundance of rivers makes Nepal extremely suitable for smaller hydropower schemes in these underserved areas. These micro-hydro plants produce between 5 and 100 kW, serving roughly 10 households per kW.[46]

Concurrently with efforts to expand the grid, donors and policymakers have developed a strategy where alternative electrification methods are promoted and subsidized in different regions according to the highest quality technology (grid, then micro-hydro, then solar) that is feasible.

[46] There are also pico-hydro plants (>5 kW), 1480 of which had been installed by 2011, generating 3.18 MW.

These efforts led to significant growth in the use of RETs. Through mid 2011, AEPC reports 999 micro-hydro installations providing 18.65 MW and 284,097 home solar installations providing 7.44 MW (AEPC, 2011). We illustrate this multifaceted approach to electrification in Figure III.2, which shows the main electrification source for each VDC in 2011.

Grid versus Micro-hydro

Paramount to predicting impacts from grid versus off-grid electrification is to understand the differences in service characteristics; to what extent should we think of each method as better or worse than the other? The main characteristics to consider are quantity and quality of electrification service, which could differ between grid and off-grid electricity sources. In terms of service quantity, households that are connected to the grid are able to consume more than households using micro-hydro. In 2010/2011, the average NEA customer consumed 77.5 kW per month,[47] yet 90% of rural customers consume only 20 kWh per month (Mainali & Silveira, 2012). The average micro-hydro consumer uses approximately 22 kWh per month, or roughly enough to power three 60 W light bulbs for four hours per day (Banerjee, Singh & Samad, 2010). So in terms of amount of energy, rural consumers are receiving similar services regardless of whether their electricity comes from the grid or from micro-hydro, and in both cases, the level of service is incredibly low compared to that of developed countries.

The second dimension is service quality. Nepal faces extreme electricity shortages, to the point that it has been in an almost perpetual state of energy crisis since 2008 (Mainali & Silveira, 2012; Sarangi et al, 2014). The underlying causes of these shortages are both the

[47] According to the Ministry of Finance (2011), the NEA produced 3,858.37 GW of power and served 1,854,275 customers, of which 42.54% and 95.18%, respectively, are residential.

underdevelopment of Nepal's hydropower potential and the unfortunate imbalance between the time of year when electricity is plentiful (monsoon season/summer) and when energy demand is highest (winter). The typical grid consumer experiences 12-14 hours per day of outages (Sarangi et al, 2014). Micro-hydro customers must also endure severe quality shortcomings. Like their larger counterparts, the loads of micro-hydro plants are subject to low water flow in the dry season, which results in approximately 21 days per year of scheduled outages. There are also unplanned outages due to overuse and technical issues that cause an average of 9 hours of outages per day. All electricity users must also worry about voltage fluctuations, which affect 62% of micro-hydro consumers and result in an average of 15.5 NRs per month of damage to electricity-using bulbs and appliances (Banerjee, Singh & Samad, 2010).

Regardless of electricity source, the overwhelming majority (97.5% for micro-hydro) of residential electricity in Nepal is used for lighting (Banerjee, Singh & Samad, 2010). This is likely due to the low level of energy most households are consuming, but could also be due to the uncertainty surrounding electricity provision. Households may hesitate to invest in appliances that are either going to go unused for half or the day or may be harmed through surges. Although 67% of the population has electricity (94% in urban areas), only 7% own refrigerators (23% in urban areas). Mobile phones are widely owned (84% of the total population and 60% of rural population), but with the prevalence of charging locations do not require home electrification to own. The most common appliances other than mobile phones are televisions, which are owned by 36% of the population (61% urban and 31% rural). As most of Nepal is so poor, it is likely that income constraints, in addition to energy constraints, limit asset ownership.

There has been substantial evaluation of micro-hydro projects and their impacts in Nepal, although almost none of these incorporate rigorous strategies to deal with the endogeneity resulting from communities self-selecting into micro-hydro construction.[48] However, these impact evaluations often conduct their own detailed household surveys and are thus able to examine possible benefits of micro-hydro that are unobservable with the census or many other large, national datasets. For instance, Banerjee, Singh & Samad (2010) evaluate gains to consumer surplus and find that micro-hydro households spend 154 NRs per month on electricity and kerosene combined compared to the 200 NRs per month spent by non-micro-hydro households. The evaluations have also found that micro-hydro households have improved health, education outcomes, and higher levels of female empowerment (Banerjee, Singh & Samad, 2010; Abhiyan, 2011; Dutta, Singh & Thakali, 2007, UNDP, 2011).

When it comes to economic outcomes, the impact evaluations find little evidence of micro-hydro benefits. Some find positive impacts on certain categories of non-farm income, but fail to find increases in overall income (Abhiyan, 2011; Banerjee, Singh & Samad, 2010). These findings are likely disappointments to the donors, who encouraged the creation of productive end-uses for the plants such as mills and hotels, and invested in skills training and the promotion of income-generating activities for households. Dutta, Singh & Thakali (2007) note that although community members found the training useful in terms of “exposure to basic income livelihood options” and did modestly increase output, almost no products were being sold in markets on a regular basis. This suggests that even with some accompanying pro-poor development, rural

[48] One exception is Abhiyan (2011), who uses an approach comparing micro-hydro-electified VDCs to VDCs that will be installing micro-hydro in the future.

areas still struggle to convert benefits from improved energy access into successful income-generating activities.

Instruments

To identify the effect of electrification, we take advantage of strategies by the Government of Nepal and donors to increase the pace of rural electrification beginning in the early 2000s. In the cases of micro-hydro and grid expansion, potential new sites were identified based on characteristics specific to the VDC's location.

Micro-hydro and the Carpet Approach

Whether or not an area has a micro-hydro plant can be attributed to many observable and unobservable community characteristics. Despite being heavily promoted and subsidized by the government, being approved for and constructing a micro-hydro plant is both bureaucratically complicated and time consuming. Therefore, communities that are able to start and successfully navigate this process are likely more entrepreneurial, community-focused, and have better leadership than otherwise similar communities that are not, despite NGO involvement in trying to encourage and streamline the process.

To instrument the placement of micro-hydro plants, we exploit the fact that some areas are suitable for micro-hydro construction based on geophysical conditions while others are not.[49] In

[49] This is similar to the approach used by Duflo and Pande (2007), who exploit land gradient to predict the location of dams in India.

the early 2000s, one of the NGOs engaged in micro-hydro promotion realized that their ground teams were not able to identify potential sites for micro-hydro fast enough to reach their construction goals. In 2002, they commissioned the "carpet study", a GIS-based method that used geophysical conditions[50] to identify sites with potential for micro-hydro suitability. Next they considered the proximity of the sites to settlements and roads, the location of the existing grid, where the grid was likely to expand, and whether there was already a micro-hydro constructed. Finally, they sent teams to the sites to determine feasibility based on community interest and commitment. Our instrument ignores the feasibility ratings, as these are endogenous. Results of the study were available in 2005. Because the ultimate result of the carpet study excluded sites that already had a micro-hydro plant, we consider all locations with micro-hydro existing by 2005 as carpet-identified. Figure III.3 shows the VDCs containing at least one site identified by the carpet approach and those electrified by micro-hydro. 882 VDCs contain carpet-identified sites, of which 348 have at least one micro-hydro plant installed by 2011.

Community Rural Electrification Programme (CREP)

Whether or not a community is connected to the central grid is not random. Within a country, connected areas are likely to differ from unconnected areas on factors such as geography, political connectedness, population size, income and the associated potential demand and ability to pay for connections, etc. Therefore, any analysis that simply compares connected areas to non-connected areas is almost certain to produce biased results. Furthermore, since the timing of when locations are connected is also correlated with those characteristics, comparisons between connected places and those about to be connected are also likely biased.

[50] The initial analysis considered land cover and land use, topography, hydrography, and meteorology.

The Community Rural Electrification Programme (CREP) was officially launched in 2003/2004 as a joint effort between the government and the NEA to expand grid connections to areas without electricity access. Community-formed Community Rural Electrification Entities (CREEs) apply for grid-extension, and are evaluated based on a survey and cost estimate. CREEs are responsible for paying 10% of the connection cost, while the government subsidizes the remaining amount.[51] Once the connection has been established, the CREE buys electricity in bulk from the NEA and operates as a community utility, collecting payments based on metered consumption and covering all management, maintenance, and repair costs.[52] Otherwise, CREEs experience the same level of service (load shedding, outages, etc.) as other grid consumers. CREEs can generally be financially viable with a minimum of 200 households and depending on size, can employ up to 6 people. As of 2015, there are more than 250 CREEs throughout the country.

Due to cost considerations, CREEs must be close to the existing grid in order to be approved. In practice, this separates VDCs into those that are CREE-eligible and those that are not based on electrification status and distance from the grid. Our instrument considers a VDC to be CREE-eligible if it had an electrification rate below 30% in 2001 and is within 15 km of the grid.[53] Figure III.4 shows the placement of CREE VDCs in relation to the grid and the buffer.

[51] At the beginning of the program, the CREE paid 20%.

[52] CREEs are prohibited from charging higher rates than the NEA; many actually provide additional subsidies for the poorest households.

[53] The actual rule of thumb is 5-10 km, but since our knowledge of grid location is limited to transmission lines that are 33 kV or higher (and thus not including 11 kV lines), we use a 15 km buffer to incorporate the unobserved presence of lower-voltage lines.

Data sources

Main lighting source

Determining the main lighting source of each VDC (grid, CREE, micro-hydro, solar, kerosene/other) is not straightforward. The census asks households about main lighting source, but groups CREE, micro-hydro, and grid electrification all under "electricity".[54] We complement the census data with administrative data from AEPC and NEA that indicate the VDCs where micro-hydro plants and CREEs are located. After assigning each VDC its main lighting source based on the census data (electrification, solar, kerosene/other), and considering a VDC electrified if at least 30% of its households report electricity, we then recoded VDCs as either micro-hydro or CREE based on the administrative data.

Micro-hydro plants and CREEs

According to AEPC (2011), there were 999 micro-hydro plants installed in Nepal from 1962 – July 2011, although the rate of installation increased over time. The detailed lists of plants we collected include location, date, capacity, and households served. We combined several lists provided by AEPC to ultimately identify the VDC locations of 857 micro-hydro plants.[55] A VDC from the micro-hydro list was considered to be micro-hydro-electrified if it had any capacity installed between 1990 and 2010. This takes into account the expected 20-year lifespan of the plants. We also excluded any VDC with an electrification rate of <5%, as these VDCs can hardly be considered electrified. Unfortunately, service area of the plant does not necessarily correspond with VDC boundaries. We thus used the map to determine which VDCs were likely electrified

[54] The census also includes electrification from diesel generators in this group, but residential use of these generators is not widespread (Mainali & Silveira, 2012)

[55] The ones that are missing appear to have mainly been ones constructed in the earlier decades.

by a plant in a neighboring VDC based on the available micro-hydro capacity, the populations of both VDCs, and whether there was another likely source of electrification nearby. We created the map of the grid and the locations of minigrids based on the 2011 NEA Annual Report.

We obtained data on the location of all CREEs established through 2015 from the NEA. However, the data did not include the year of establishment. Therefore, we assume that if the VDC electrification rate is below 30% in the 2011 census, that the CREE had not yet been established. We define a VDC as CREE-electrified if contains any part of a CREE that was established as of 2011.

Census Outcomes

The 2001 and 2011 census micro-data are from the Central Bureau of Statistics in Nepal and contain information on demographics, assets, basic household characteristics, education, and employment for 841,567 (15.5%) and 520,624 (12.2%) households, respectively.[56] We use the 2011 micro-data for our economic outcome variables as well as individual and household covariates. We used the 2001 data to construct baseline VDC-level covariates.[57]

The census data reports limited information on the economic and non-economic activities of each family member over age 10. Our primary labor outcome variable is the percent of months devoted to each of six activities: household chores (cooking, cleaning, child care, etc.), extended economic work (collecting fuel and water, preparing goods for consumption at home), studies,

[56] Due to political turmoil, 2001 census enumeration was disturbed in 83 VDCs in 12 districts; these VDCs are thus excluded.

[57] The 2001 time allocation information was collected differently and so we could not construct the same outcome variables for this year and cannot use the data as a panel at the VDC level.

agriculture, wage or salaried work, and small business activities. Because men and women are often engaged in different activities, which may be differentially affected by electrification, we present results for household labor allocation by gender.

Table III.1 presents the average percent of months women and men spend on each activity by the main type of lighting in their VDC. Predictably, women spend much more time on household chores (20-35%) than men (3-6%) whereas men spend more time in wage labor and on their own businesses. Time spent on the other activities is fairly similar between women and men. Also unsurprisingly, people who live in grid-electrified VDCs are less likely to be involved in agriculture and more likely to be wage laborers, reflecting the higher rate of grid connection among cities and towns than in rural areas. Interestingly, women with grid electrification report spending more time on household chores than women with other lighting sources do. Because of the way the data were collected, this could occur if women living with the grid have fewer other responsibilities (such as agriculture) to divide their time, even if they spend equal, or even less time on chores. Finally, when comparing micro-hydro and CREE-electrified VDCs: wage labor is slightly more, and own business activities slightly less prevalent in CREE VDCs for both women and men; and women spend more time on agriculture and less time on household chores in micro-hydro VDCs.

Empirical Strategy

Whether a VDC is electrified in 2011 and by which source depends on many observable factors (e.g.; geography, baseline population, proximity to roads, etc) as well as many unobservable factors (e.g.; political connectedness, community characteristics). Therefore, any simple comparison of outcomes between these VDCs will suffer from selection bias. The direction of the bias is also unknown. On the one hand, richer, more entrepreneurial VDCs are both more likely to be seen as good partners for construction and to successfully navigate the installation or connection process. On the other hand, much of rural electrification expansion is spearheaded by NGOs, who may be more likely to focus their attention on the poorer VDCs.

Our identification relies on the assumption that our instruments are uncorrelated with labor allocation, conditional on our controls. This argument is fairly straightforward for our micro-hydro instrument, as it is based on the specific geophysical factors of the VDC and factors that may be relevant for labor allocation (e.g.; slope) are included as controls. Given that CREE-eligibility is based on distance to the grid, which is highly correlated with several factors that may impact labor decisions, we specifically control for measures of market access (distance to nearest road, nearest city, and nearest population centers of 25 and 50 thousand people). We argue that within a zone[58] and conditional on these and other controls, whether a household's VDC is within 15 km of the grid or not is orthogonal to our outcomes.

[58] Nepal is divided into 14 administrative zones, each of which consists of 4-6 districts. Using district fixed effects resulted in weaker first stages.

We estimate the impact of electrification on outcomes using instrumental variables. The first stage predicts electrification source, E_{zv}, (micro-hydro or CREE) for VDC *v* in administrative zone *z* using our instruments, Z_{zv},[59]; main VDC lighting source, $Light_{vz}$ (with kerosene/other as the omitted group); individual characteristics, $\boldsymbol{X}_{ivz}$; a set of VDC-level controls including aggregates of 2001 household characteristics, VDC characteristics such as area and slope, and measures of market access, $\boldsymbol{V}_{vz}$; and zone fixed effects.[60] All standard errors are clustered at the VDC level.

$$E_{vz} = \alpha + \lambda Z_{vz} + \Delta_1' Light_{vz} + \Upsilon_1' \boldsymbol{X}_{ivz}\, \Gamma_1' \boldsymbol{V}_{vz} + \rho_z + \varepsilon_{vz} \qquad (1)$$

The second stage includes predicted micro-hydro or CREE electrification (or both) in our estimation of individual labor allocation, $Activity_{ivz}$. We analyze impact of electrification on labor allocation separately for men and women.

$$Activity_{ivz} = \kappa + \beta \hat{E}_{vz} + \Delta_2' Light_{vz} + \Upsilon_2' \boldsymbol{X}_{ivz} + \Gamma_2' \boldsymbol{V}_{vz} + \rho_z + \varepsilon_{ivz} \qquad (2)$$

Ideally, we would like to be able to directly compare causal impacts from all different methods of electrification, with instruments for grid, CREE, micro-hydro, and solar. For now, we estimate a model where both CREE and micro-hydro are causally identified through the two instruments. Although for the most part, grid expansion and micro-hydro are promoted in different areas of the country, there are zones in which both are utilized in very close proximity and VDCs could

[59] We include specifications using the instruments separately and combined, but just show the case using one instrument in the equations.
[60] While our main specification includes main VDC lighting source, we also present results excluding these controls in Tables 3 and 4.

have been electrified by either micro-hydro or CREE. Which method was ultimately applied depends on several factors including timing, grid location at the time and predictions of where it would expand[61], the community's knowledge of their options, and involvement of NGOs. This element adds some additional randomness to electrification method, although the overlap between micro-hydro and CREE potential is much higher in some zones than in others.

Results

First-stage results

Table III.2 shows the predictive power of our instruments for both the individual (columns 1, 2, 5, 6) and combined instrument (columns 3, 4, 7, 8) models. VDCs containing at least one carpet-identified site are 15-17% more likely to have a micro-hydro plant installed by 2011 than VDCs within the same zone that contain none. The CREE instrument is weaker: being within 15km of the grid only increases the likelihood of the VDC containing a CREE by 5-6%, even when the instrument is limited to VDCs that were not electrified in 2001. However, there were only 142 CREEs in operation as of 2011; the predictive power of the instrument will grow as the program continues. The F-statistic for the carpet variable is 67 for the female sample and 65 for the male sample. Although the CREE first stage is weaker, the F-statistics for the female and male samples are still robust at 46 and 44, respectively. When we run the combined model, with both instruments included in each first stage, the F-statistics for the joint significance of both instruments decrease compared to the individual models.

[61] No one, not even the NEA, knows exactly where the grid will expand in the medium or long run, so different groups may come to different conclusions about where grid expansion is likely to occur.

Labor results

In Tables III.3 – III.5, we present IV estimates for the impact of electrification via micro-hydro and the grid on labor allocation among both female and male household members. Due to the way it was collected in the census, labor allocation is measured in terms of percent of months the individual was primarily engaged in each activity. Therefore, impacts should be thought of as representing shifts in overall occupations rather than incremental changes in daily time use.[62] For example, an individual could spend a few more hours a day on an activity due to electrification, but it would not show up in the census data unless that increase changed the individual's perception of their general activity for the month. On the other hand, if an individual was primarily a homemaker but starts their own small business due to electrification, they may start referring to themselves as being primarily engaged in their business, even if the actual hours spent on chores only changes slightly. For this reason, coefficient magnitudes should be interpreted with caution and used mainly to indicate relative changes in primary occupations.

Table III.3 reports the impacts of micro-hydro electrification on labor outcomes for women (Panel A) and men (Panel B), with and without controlling for main VDC lighting source. We present the results without controlling for lighting source as a first estimate of the impacts of micro-hydro electrification, where the comparison group is all other VDCs. We then present results controlling for other sources of electrification, where the omitted group relies on non-electric sources of light (kerosene, flashlights, fire, etc.). Interestingly, both in the case of micro-hydro and CREE electrification, the impacts are very similar regardless of whether these controls

[62] 63% of women in our sample report 1 activity for all months; 86% report 2 or 1. 71% of men report 1 activity for all months; 89% report 2 or 1.

are included or not (although the magnitudes for the impacts of CREE electrification are generally larger when the controls are excluded). This could occur if labor allocation in the omitted group is similar to the overall average labor allocation, which is shown in the descriptive statistics to be the case for several activities. Because micro-hydro and CREE electrification were designed to electrify previously non-electrified areas, we prefer the estimates that control for other sources of electrification and use non-electrified VDCs as the comparison group.

For women and men, being in a VDC electrified by micro-hydro results in a 4-percentage point increase in months spent studying. With the additional hours and better quality lighting at night, there is more time for available for reading. Anecdotal evidence supports this interpretation: with micro-hydro electrification, women are able to participate in literacy classes for which they previously had no time (Abhiyan, 2011). Our results suggest men may also be participating in literacy classes or learning more skills. Micro-hydro has an additional impact on time allocation among men, as they decrease months spent on agriculture by 7.7 percentage points and increase time spent on own business activities by 7.2 percentage points. Again, this may not represent an actual decrease in hours spent on agriculture. For example, a man whose only employment was working on his own land, but who had little to do in the winter months, may, with electrification, be encouraged to start a small business, and thus now report his time as split between the two. However, it is likely that men actually do spend more time on own business activities with micro-hydro electrification.

The impacts from CREE electrification are very different from those of micro-hydro in terms of trends and much larger in terms of magnitudes (Table III.4). CREE electrification results in a huge decrease in women reporting household chores as their main monthly occupation (48 percentage points). This time is reallocated to extended economic work (8.6 percentage points), wage work (17.4 percentage points), and own business activities (7.8 percentage points), all three of which are very rare activities for women in non-electrified VDCs. For household work, it is likely that the observed decrease is not entirely (or even mostly) due to an actual reduction in hours spent on chores, but to an increase in time spent on other activities thanks to the extended hours of light. For men, the impact of CREE electrification appears to be a shift from own business activities to wage work.

Table III.5 reports coefficients from running a combined specification where both micro-hydro and CREE are instrumented. In this specification, we can directly compare the causal impacts of grid and off-grid electrification. For women, both electrification sources result in a large and significant reduction in chores, but the effect from CREE electrification is almost three times as large. In addition, women who receive electrification through CREEs reallocate that time to extended economic work, wage labor, and their own businesses to a much larger extent than women receiving micro-hydro electrification. For men, the only impact is a marginally significant increase in wage labor when receiving electrification through a CREE.

Evidence in support of instrumental variables

Table III.6 presents results supporting the claim that our instruments are orthogonal to labor outcomes, conditional on our controls. Ultimately, concerns about the instrument derive from two channels. The first is that households may relocate in response to electrification and that our results would then capture the impacts of these population shifts, rather than changes in labor decisions of households that had always lived there. The second is that our instruments may predict VDC or household characteristics that cannot be controlled for in our data, but that influence labor allocation. This is more of a concern for the CREE instrument as households closer to the grid may be more advantaged than those who are farther away. If our instruments are correlated with either population shifts or unobserved indicators of wealth or privilege that may impact labor outcomes, they would fail the exclusion criteria and would lead to biased estimates.

First, we address the concern that households may migrate to areas that are being electrified using the difference between the 2011 and 2001 VDC household population from the census. This type of systematic relocation would alter both the number and the composition of households in VDCs that receive micro-hydro or grid electrification, and could thus influence our results. If migration into an electrified VDC increases labor supply to a large extent, the surplus could cause a decrease in overall percent of time spent in formal employment. Also, it is unclear whether the migration would be driven mostly by wealthy households, who have the means to relocate, or by poorer households, who have fewer large investments like a home or land to leave behind. In column (1) we find no evidence of any significant population shifts in carpet-identified or CREE-eligible VDCs compared to other VDCs in the zone, conditional on our controls.

Next, we use supplementary data from the Nepal Living Standards Survey (NLSS) Rounds II and III, collected in 2003/04 and 2010/11, to test whether our instruments are correlated with per capita income.[63] Since neither the carpet study nor the CREP were in use as of 2003, the Round I sample provides a reasonable baseline estimate for comparing carpet-identified and CREE-eligible VDCs to other VDCs within a zone. In column (2), we find that neither being in a carpet-identified VDC nor being in a CREE-eligible VDC is associated with a statistically significantly different per capita income in 2003. However, it may be the case that the 2003 sample of 270 VDCs is too small to detect a significant difference. We thus analyze the association between our instruments and income in 2010 (column 3) and in both years (column 4). Although there is still no significant association between income and being carpet-identified, being CREE-eligible is associated with a marginally significant, higher income of 370-505 NRs per person (7.5-9%) more than in non-eligible VDCs. That the 2003 and 2010 estimates differ not only in terms of significance, but also by a large difference in point estimates suggests that the association only exists in the 2010 sample, and may thus be due to the expanded electrification in these VDCs.

Conclusion

As the international community continues to promote both grid expansion and off-grid technologies to achieve universal energy access by 2030, it is important to understand how these methods compare with each other in terms of both service and benefits. This paper provides the first rigorous comparison of the impacts of grid and off-grid electrification using two natural experiments to predict micro-hydro installations and grid expansion into previously non-electrified areas.

[63] We cannot use the NLSS to estimate outcomes because there are not enough VDCs in the sample that are electrified by either micro-hydro or CREEs. However, there are sufficient VDCs that are carpet-identified (15% of sample) and CREE-eligible (48% of sample).

We find that electrification via micro-hydro plants results in some shifts in labor allocation: towards studies for everyone, and self-owned business activities for men. The impacts from CREE electrification are different and much larger. Women shift from being primarily occupied with household chores to participating in both formal and informal employment. There is also an increase in wage labor for men. When micro-hydro and CREE electrification are directly compared, they both result in a shift from household chores to formal employment for women, although the impacts are much larger for CREE electrification. These larger shifts into cash-generating employment likely represent real improvements in income and livelihoods, but more detailed data is required to confirm this.

It is not surprising that the impacts on labor allocation for micro-hydro are small – most of the very modest amount of electricity provided by micro-hydro is used for lighting. However, according to the NEA, most rural grid customers consume similar levels of electricity (Mainali & Silveira, 2012). Also, both micro-hydro and grid electrification is unreliable in Nepal, with multiple hours of outages every day. So if both service quality and quantity are similar, what could account for the large difference in impacts? It is possible that the CREEs facilitate more employment opportunities, or that they are on average closer to more services and opportunities that interact with electrification, boosting its impact. CREEs are also more likely to be surrounded by other electrified VDCs, which may generate spillovers. Both of these channels should be tested in future studies.

The arguments for grid expansion versus off-grid promotion vary by context. In a country like Nepal, where grid expansion is prohibitively expensive for many communities, off-grid technologies offer an alternative option for providing lighting and basic electric services. However, in countries where grid expansion is less challenging, service via the grid is plentiful and more reliable, or where populations are rich enough to afford more electricity and the more expensive appliances to go along with it, the argument for grid expansion over off-grid electricity provision may differ.

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Figure III.1a Nepal VDC Electrification 2001

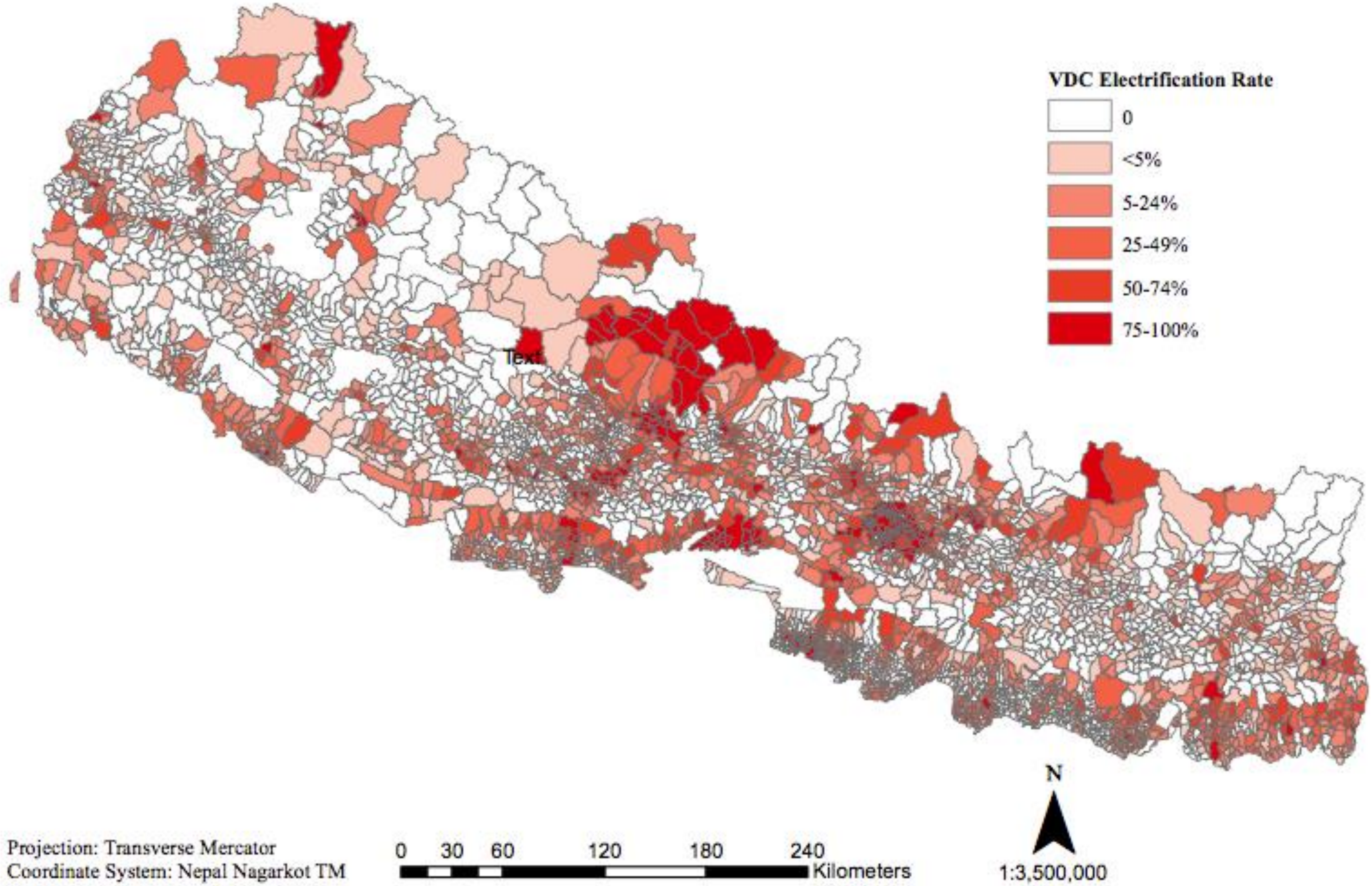

Figure III.1b Nepal VDC Electrification 2011

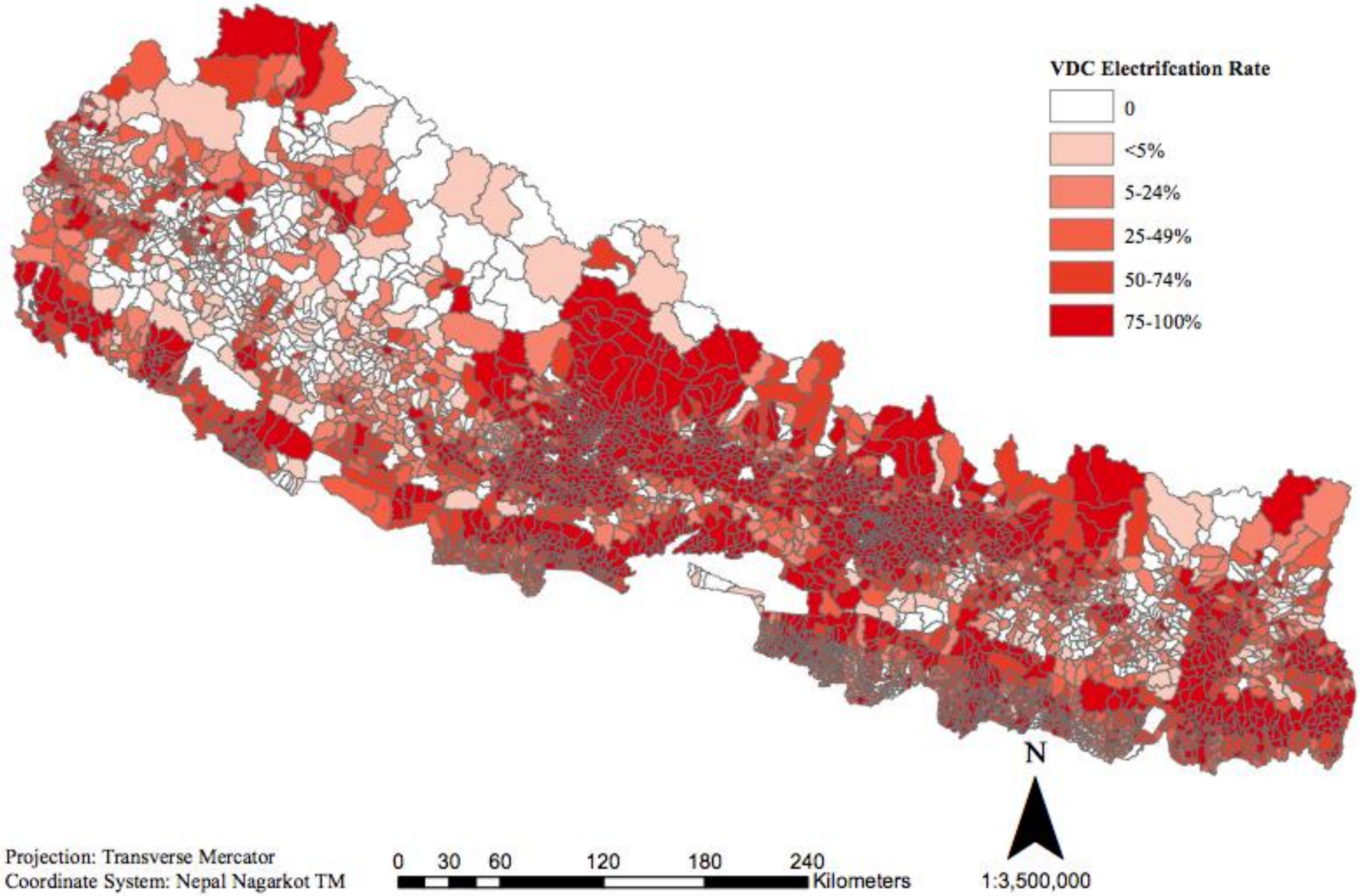

Figure III.2 VDC Electrification Source (2011)

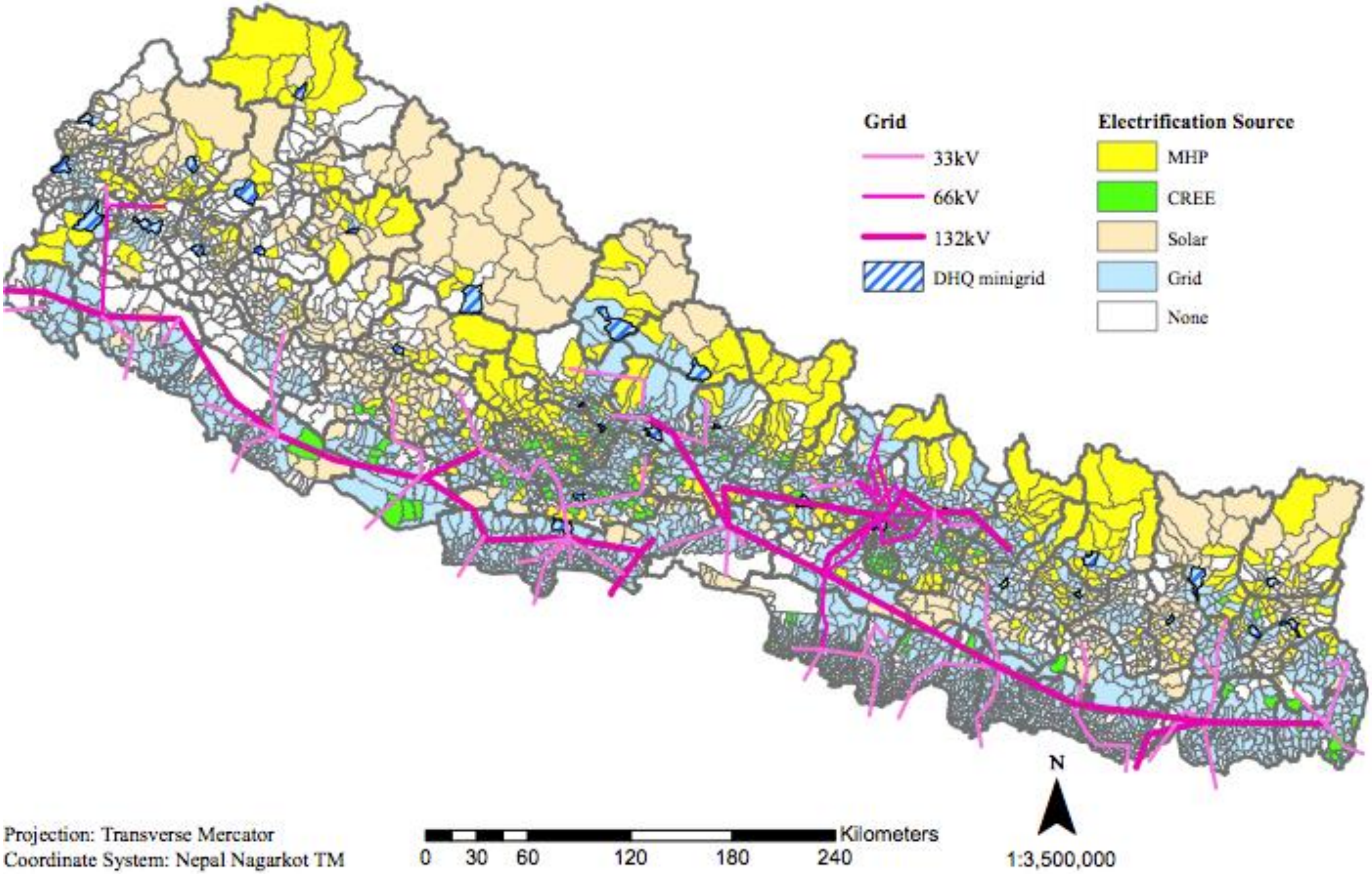

Figure III.3 Carpet-identified and MH Electrified VDCs (2011)

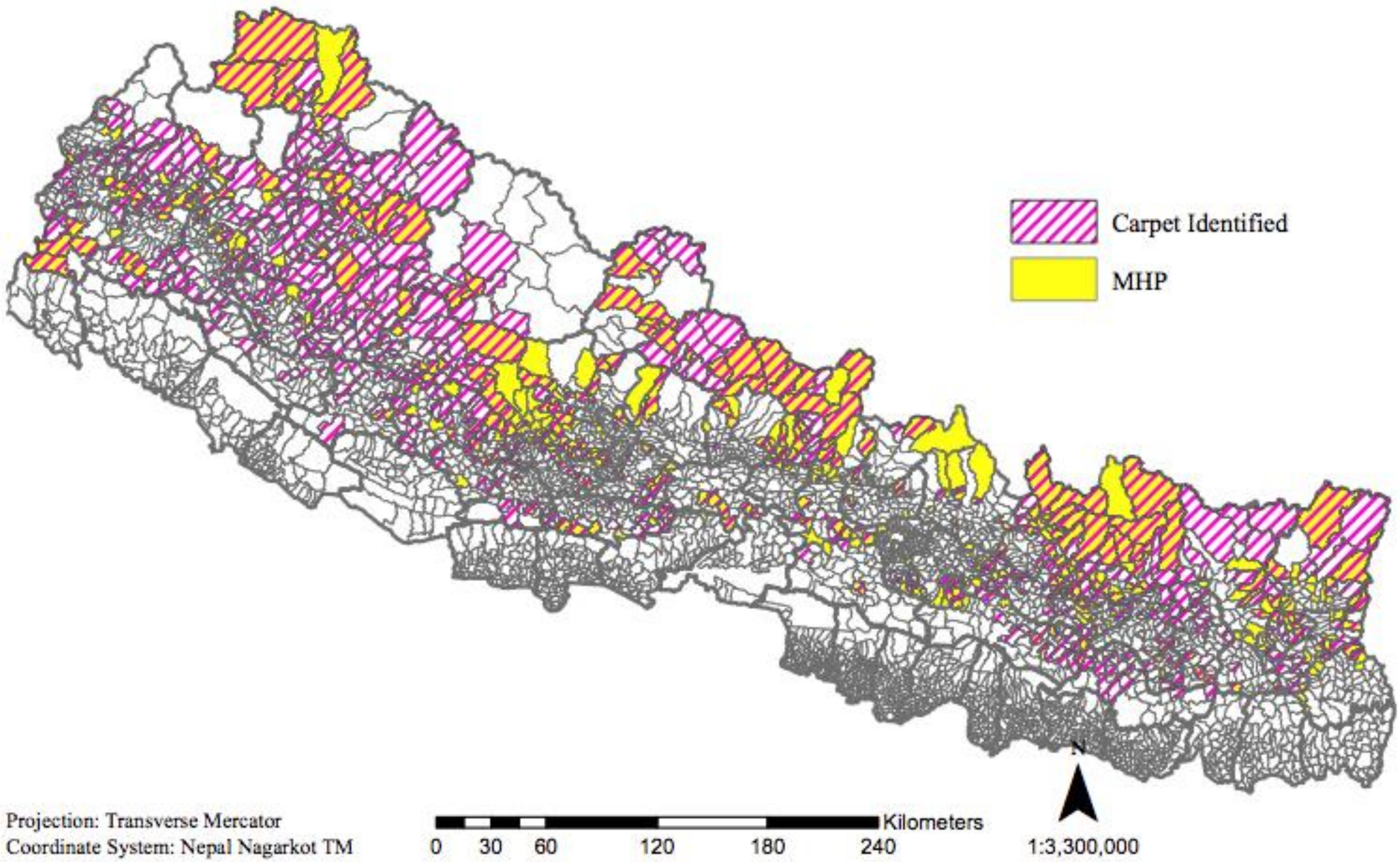

Figure III.4 CREE VDCs (2011) and NEA Grid Buffer

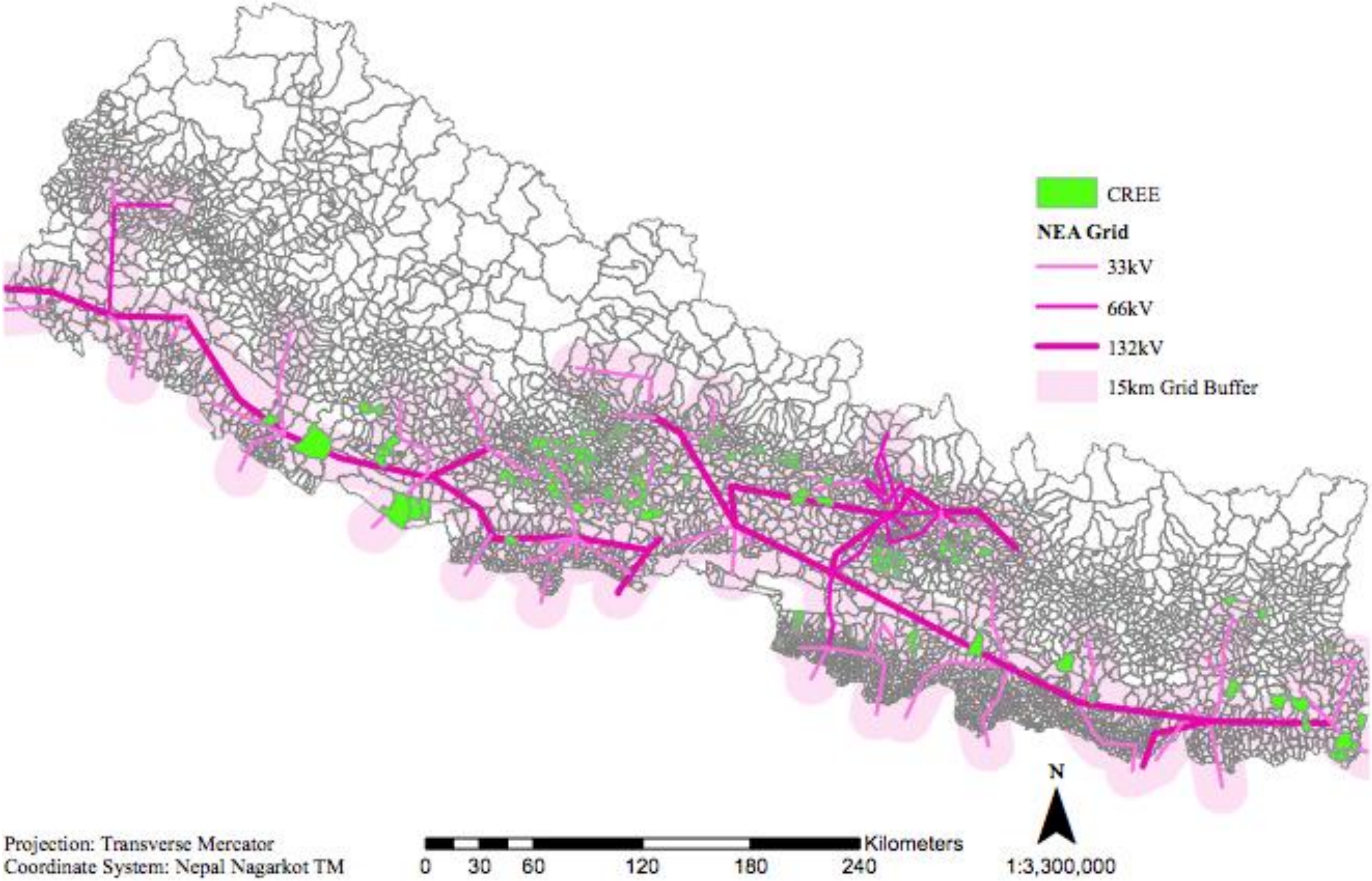

Table III.1 Average percent of months spent on each activity by VDC main lighting source

	Females					Males				
	Micro-hydro	CREE	Grid	Solar	Other	Micro-hydro	CREE	Grid	Solar	Other
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Chores	20.13	25.9	35.36	22.42	30.15	5.2	4.65	3.41	6.14	5.83
	(26.22)	(32.72)	(41.99)	(27.33)	(35.79)	(12.88)	(14.15)	(13.91)	(13.98)	(15.36)
Extended Economic	4.8	4.66	2.65	4.79	4.35	4.39	3.15	1.86	4.33	3.78
	(11.07)	(11.96)	(10.18)	(11.52)	(11.60)	(11.31)	(10.28)	(9.66)	(11.17)	(11.29)
Studies	25.74	25.77	26.41	26.26	24.68	30.5	31.03	31.35	31.82	30.96
	(42.13)	(42.43)	(43.27)	(42.29)	(41.84)	(44.40)	(45.10)	(45.69)	(44.76)	(44.98)
Agriculture	35.01	28.31	16.83	33.95	27.75	31.47	30	19.83	32.48	31.77
	(34.83)	(34.22)	(30.64)	(33.83)	(33.42)	(36.25)	(38.20)	(35.46)	(36.18)	(37.86)
Wage	3.58	4.88	6.77	2.7	3.25	13.39	15.73	23.75	11.39	13.93
	(15.83)	(19.05)	(23.49)	(13.87)	(14.90)	(29.55)	(32.94)	(40.64)	(27.58)	(30.45)
Own business	4.09	3.17	4.38	3.19	2.52	6.34	5.66	10.19	5.56	4.74
	(14.15)	(13.42)	(18.27)	(11.99)	(10.55)	(18.70)	(19.75)	(28.81)	(17.27)	(16.39)
Observations (individual)	85,450	37,583	1,236,449	91,935	162,177	72,265	29,972	1,125,233	78,734	147,620

Notes: Sandard deviation in parentheses. Activity variables from 2011 Nepal census microdata, collected for household members 10 and older. Percentages do not add up to 100 because we do not include seeking work or no work in our analysis. Power source variables are the most prevalent source of lighting for the VDC in 2011.

Table III.2 First Stage: Using the instrument to predict electrification via MH and CREE

	Females				Males			
	MH	CREE	MH	CREE	MH	CREE	MH	CREE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Carpet-identified	0.155***		0.174***	-0.061***	0.159***		0.175***	-0.055***
	(0.019)		(0.020)	(0.011)	(0.020)		(0.021)	(0.010)
CREE-eligible		0.057***	-0.013	0.056***		0.053***	-0.013	0.052***
		(0.008)	(0.011)	(0.009)		(0.008)	(0.011)	(0.008)
Zone Fixed Effects	yes	yes	yes	yes	yes	yes	yes	yes
F-stat	66.97	45.79	42.45	29.88	64.50	44.31	39.63	28.11
# VDC clusters	3878	3878	3878	3878	3,878	3,878	3,878	3878
Observations (individual)	1,613,594	1,613,594	1,613,594	1,613,594	1,453,824	1,453,824	1,453,824	1,453,824

Notes: VDC-level controls include: power source (most prevalent source of lighting for the VDC in 201 - omitted group is kerosene/other), Hill and Mountain region indicators, VDC area, elevation, slope, distance to measures of market access (road, city, population centers of 25 and 50 thousand), and VDC aggregates of 2001 household characteristics (number of households, electrification rate, and percent of households with a toilet and piped water). Individual-level controls include: age, age-squared, education level, household size (for ages 0-9, 10-17, and 18 and older), ethnicity, piped water, and toilet. Standard errors clustered at VDC level. *, **, *** indicate significance at the 10%, 5%, and 1% level, respectively.

Table III.3 Impact of MH on percent of months in past year spent on each activity

	Chores	Extended Economic	Studies	Agriculture	Wage	Own business
	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: Females			
MH hat	4.845	0.119	2.360**	-4.653	-1.738*	-0.22
	(2.820)	(1.377)	(0.842)	(2.384)	(0.691)	(0.736)
First stage F-stat	109.0	109.0	109.0	109.0	109.0	109.0
MH hat	1.292	0.279	3.803**	-2.464	-1.611	-0.155
	(4.299)	(2.220)	(1.320)	(3.601)	(0.960)	(1.143)
Grid	-2.567	0.0216	1.304**	1.607	-0.0236	0.0239
	(1.503)	(0.755)	(0.463)	(1.248)	(0.314)	(0.387)
Solar	0.0843	-0.374	1.883***	0.006	-0.832*	-0.344
	(1.640)	(0.851)	(0.521)	(1.424)	(0.377)	(0.421)
CREE	(3.588)	0.891	1.161*	1.944	0.295	(0.242)
	(1.842)	(0.902)	(0.574)	(1.581)	(0.460)	(0.455)
First stage F-stat	66.97	66.97	66.97	66.97	66.97	66.97
Zone Fixed Effects	yes	yes	yes	yes	yes	yes
Mean (non-electrified VDCs)	29.7	4.4	24.9	28.1	3.2	2.5
# VDC clusters	3878	3878	3878	3878	3878	3878
Observations (individual)	1,613,594	1,613,594	1,613,594	1,613,594	1,613,594	1,613,594

	Chores	Extended Economic	Studies	Agriculture	Wage	Own business
	(1)	(2)	(3)	(4)	(5)	(6)
			Panel B: Males			
MH hat	0.44	1.248	3.021*	-6.637**	-2.962	5.790***
	(0.917)	(0.646)	(1.190)	(2.077)	(1.703)	(1.098)
First stage F-stat	101.1	101.1	101.1	101.1	101.1	101.1
MH hat	-0.368	0.804	3.706*	-7.674*	-1.561	7.197***
	(1.351)	(0.960)	(1.769)	(3.015)	(2.498)	(1.544)
Grid	-0.605	-0.348	0.732	-1.018	0.868	1.361**
	(0.439)	(0.306)	(0.546)	(0.996)	(0.845)	(0.461)
Solar	0.188	0.0676	1.941**	-2.864*	-1.328	2.857***
	(0.524)	(0.378)	(0.684)	(1.165)	(0.843)	(0.597)
CREE	-0.075	0.150	0.857	-2.636*	1.045	1.727**
	(0.548)	(0.389)	(0.681)	(1.337)	(1.075)	(0.567)
First stage F-stat	64.50	64.50	64.50	64.50	64.50	64.50
Zone Fixed Effects	yes	yes	yes	yes	yes	yes
Mean (non-electrified VDCs)	5.8	3.8	31.2	31.8	13.8	4.7
# VDC clusters	3878	3878	3878	3878	3878	3878
Observations (individual)	1,453,824	1,453,824	1,453,824	1,453,824	1,453,824	1,453,824

Notes: Outcome variables from 2011 Nepal census microdata, collected for household members 10 and older. Power source variables are the most prevalent source of lighting for the VDC in 2011. Omitted group is kerosene/other. VDC-level controls include: Hill and Mountain region indicators, VDC area, elevation, slope, distance to measures of market access (road, city, population centers of 25 and 50 thousand), and VDC aggregates of 2001 household characteristics (number of households, electrification rate, and percent of households with a toilet and piped water). Individual-level controls include: age, age-squared, education level, household size (for ages 0-9, 10-17, and 18 and older), ethnicity, piped water, and toilet. Standard errors clustered at VDC level. *, **, *** indicate significance at the 10%, 5%, and 1% level, respectively.

Table III.4 Impact of CREE on percent of months in past year spent on each activity

	Chores	Extended Economic	Studies	Agriculture	Wage	Own business
	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: Females			
CREE hat	-69.45***	11.03*	-6.347	27.45*	24.25***	10.59**
	(20.250)	(4.623)	(3.900)	(13.110)	(6.271)	(3.939)
First stage F-stat	27.04	27.04	27.04	27.04	27.04	27.04
CREE hat	-48.15***	8.606**	-4.831	17.73	17.35***	7.791**
	(13.250)	(3.337)	(2.903)	(9.328)	(4.093)	(2.830)
Grid	-12.98***	1.689*	-0.967	6.232**	4.021***	1.850**
	(2.824)	(0.760)	(0.664)	(2.114)	(0.795)	(0.599)
Solar	-8.585***	0.967	-0.315	4.187*	2.556***	1.159*
	(2.244)	(0.661)	(0.570)	(1.720)	(0.667)	(0.522)
MH	-9.720***	1.667*	-1.025	5.039**	2.832***	1.635**
	(2.290)	(0.664)	(0.595)	(1.773)	(0.708)	(0.557)
First stage F-stat	45.79	45.79	45.79	45.79	45.79	45.79
Zone Fixed Effects	yes	yes	yes	yes	yes	yes
Mean (non-electrified VDCs)	29.7	4.4	24.9	28.1	3.2	2.5
# VDC clusters	3878	3878	3878	3878	3878	3878
Observations (individual)	1,613,594	1,613,594	1,613,594	1,613,594	1,613,594	1,613,594

	Chores	Extended Economic	Studies	Agriculture	Wage	Own business
	(1)	(2)	(3)	(4)	(5)	(6)
			Panel B: Males			
CREE hat	-4.223	-0.917	-12.25*	6.407	25.48**	-17.08*
	(3.844)	(2.776)	(6.063)	(10.140)	(9.840)	(6.659)
First stage F-stat	28.06	28.06	28.06	28.06	28.06	28.06
CREE hat	-1.936	0.723	-8.329	1.325	16.56*	-10.54*
	(2.851)	(2.078)	(4.530)	(7.609)	(6.776)	(4.641)
Grid	-0.963	-0.38	-2.053*	1.507	4.504***	-2.523**
	(0.595)	(0.422)	(0.889)	(1.562)	(1.317)	(0.888)
Solar	-0.0953	-0.017	-0.693	-0.12	1.826	-0.862
	(0.557)	(0.397)	(0.781)	(1.338)	(1.124)	(0.729)
MH	-0.648	0.322	-1.768*	0.015	3.394**	-0.781
	(0.543)	(0.392)	(0.810)	(1.341)	(1.144)	(0.772)
First stage F-stat	44.31	44.31	44.31	44.31	44.31	44.31
Zone Fixed Effects	yes	yes	yes	yes	yes	yes
Mean (non-electrified VDCs)	5.8	3.8	31.2	31.8	13.8	4.7
# VDC clusters	3878	3878	3878	3878	3878	3878
Observations (individual)	1,453,824	1,453,824	1,453,824	1,453,824	1,453,824	1,453,824

Notes: Outcome variables from 2011 Nepal census microdata, collected for household members 10 and older. Power source variables are the most prevalent source of lighting for the VDC in 2011. Omitted group is kerosene/other. VDC-level controls include: Hill and Mountain region indicators, VDC area, elevation, slope, distance to measures of market access (road, city, population centers of 25 and 50 thousand), and VDC aggregates of 2001 household characteristics (number of households, electrification rate, and percent of households with a toilet and piped water). Individual-level controls include: age, age-squared, education level, household size (for ages 0-9, 10-17, and 18 and older), ethnicity, piped water, and toilet. Standard errors clustered at VDC level. *, **, *** indicate significance at the 10%, 5%, and 1% level, respectively.

Table III.5 Impact of MH and CREE on percent of months in past year spent on each activity

	Chores	Extended Economic	Studies	Agriculture	Wage	Own business
	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: Females			
MH hat	-17.19**	3.59	2.036	3.309	5.414*	3.219
	(6.369)	(2.758)	(1.792)	(4.778)	(2.159)	(1.845)
CREE hat	-51.58***	9.488*	-3.427	16.93	18.54***	8.518**
	(14.670)	(3.962)	(3.270)	(10.110)	(4.606)	(3.284)
Grid	-15.50***	2.339	0.067	5.647*	4.894***	2.385*
	(3.915)	(1.342)	(0.987)	(2.867)	(1.191)	(0.963)
Solar	-11.29**	1.664	0.795	3.560	3.493**	1.733
	(3.476)	(1.305)	(0.921)	(2.577)	(1.126)	(0.914)
Zone Fixed Effects	yes	yes	yes	yes	yes	yes
Mean (non-electrified VDCs)	29.7	4.4	24.9	28.1	3.2	2.5
K-P Wald F-stat for weak IV	19.93	19.93	19.93	19.93	19.93	19.93
# VDC clusters	3878	3878	3878	3878	3878	3878
Observations (individual)	1,613,594	1,613,594	1,613,594	1,613,594	1,613,594	1,613,594

	Chores	Extended Economic	Studies	Agriculture	Wage	Own business
	(1)	(2)	(3)	(4)	(5)	(6)
			Panel B: Males			
MH hat	-1.1	1.152	0.973	-7.642	3.979	3.692
	(1.756)	(1.259)	(2.261)	(4.165)	(3.706)	(2.136)
CREE hat	-2.164	1.143	-6.944	-2.546	16.86*	-8.277
	(3.199)	(2.324)	(4.818)	(8.555)	(7.621)	(5.051)
Grid	-1.111	-0.108	-1.156	-0.996	4.696*	-1.06
	(0.885)	(0.634)	(1.210)	(2.261)	(1.980)	(1.215)
Solar	-0.256	0.279	0.282	-2.845	2.035	0.730
	(0.858)	(0.626)	(1.169)	(2.130)	(1.826)	(1.142)
Zone Fixed Effects	yes	yes	yes	yes	yes	yes
Mean (non-electrified VDCs)	5.8	3.8	31.2	31.8	13.8	4.7
K-P Wald F-stat for weak IV	19.71	19.71	19.71	19.71	19.71	19.71
# VDC clusters	3878	3878	3878	3878	3878	3878
Observations (individual)	1,453,824	1,453,824	1,453,824	1,453,824	1,453,824	1,453,824

Notes: Outcome variables from 2011 Nepal census microdata, collected for household members 10 and older. Power source variables are the most prevalent source of lighting for the VDC in 2011. Omitted group is kerosene/other. VDC-level controls include: Hill and Mountain region indicators, VDC area, elevation, slope, distance to measures of market access (road, city, population centers of 25 and 50 thousand), and VDC aggregates of 2001 household characteristics (number of households, electrification rate, and percent of households with a toilet and piped water). Individual-level controls include: age, age-squared, education level, household size (for ages 0-9, 10-17, and 18 and older), ethnicity, piped water, and toilet. Standard errors clustered at VDC level. *, **, *** indicate significance at the 10%, 5%, and 1% level, respectively.

Table III.6 Evidence in support of instruments

	Difference in VDC population (# households)	Income (NLSS II) (Nepali rupees)	Income (NLSS III) (Nepali rupees)	Income (NLSS II and III) (Nepali rupees)
	(1)	(2)	(3)	(4)
Carpet-identified	-32.79	132.9	-437.9	-204.4
	(25.51)	(140.3)	(273.9)	(165.3)
Mean (non-identified)	369	3078	5108	4324
CREE-eligible	-5.14	41.08	505.0*	371.3*
	(23.69)	(118.4)	(230.5)	(145.6)
Mean (non-eligible)	428	3640	5763	4944
Zone Fixed Effects	yes	yes	yes	yes
Year Fixed Effects				yes
N (VDC)	3878	270	377	571
N (Individual)	N/A	3,782	5,885	9,667

Notes: VDC household population from 2001 and 2011 census. Income is per capita adjusted to 2010 Nepali rupees. VDC-level controls include: power source (most prevalent source of lighting for the VDC in 201 - omitted group is kerosene/other), Hill and Mountain region indicators, VDC area, elevation, slope, distance to measures of market access (road, city, population centers of 25 and 50 thousand), and VDC aggregates of 2001 household characteristics (number of households, electrification rate, and percent of households with a toilet and piped water). Individual-level controls include: age, age-squared, education level, household size (for ages 0-9, 10-17, and 18 and older), ethnicity, piped water, and toilet. Standard errors clustered at VDC level. *, **, *** indicate significance at the 10%, 5%, and 1% level, respectively.

Appendix. First stage logit regressions predicting household biogas use

	Census (2011)		NLSS II/III (2003, 2010)
	Male	Female	
	1	2	3
Logged Branch distance	-0.109	-0.107	-0.602**
	(0.088)	(0.088)	(0.196)
Logged Branch distance*Hill	-0.420***	-0.400***	0.111
	(0.092)	(0.094)	(0.197)
2001 Logged Branch distance	0.137*	0.135*	0.495***
	(0.063)	(0.064)	(0.142)
Household characteristics			
Electrified	□	□	□
Owns home	□	□	□
Piped water	□	□	□
Toilet	□	□	□
Radio	□	□	
Mobile phone			□
TV	□	□	□
Ethnicity	□	□	□
Household head education	□	□	□
Household size (by age groups)	□	□	□
Land owned (hectares)			□
Wood collection location			□
Number of cow/buffalo			□
Logged per capita income			□
VDC characteristics	□	□	□
2001 VDC aggregates of HH characteristics	□	□	□
Year fixed effects			□
VDC clusters	2736	2736	530
Observations	392,786	435,297	6,649

Notes: Census households are considered biogas households if it is their main cooking fuel. NLSS households are considered biogas households if it is their main cooking fuel OR they produce any biogas at home. Household samples include households using biogas, dung, or wood as cooking fuel. Includes all VDCs from Terai and Hill region as well as 190 VDCs from the mountain region that had at least one biogas plant installed by 2011. Sample limited to VDCs with >10 hectares forest cover and >1% forest cover in 2001. VDC controls: proportion of 2001 households in VDC with female land ownership, migrant in the household, involvement in agriculture, own business, owning land, owning livestock, average number of livestock, and main fuel being dung, wood, and LPG/kerosene; VDC area, elevation, slope, annual precipitation, 2001 population, change in population 2001-2011, and region; having at least 25k and 50k inhabitants; distance to Kathmandu, the nearest road, the nearest municipality, and the nearest pop centers of 25k and 50k; proportion of forest cover under CFUG management in pre-2001 and post-2001; the proportion of protected forest cover, and distance to the nearest biogas branch in 2001. Standard errors clustered at the VDC level. *, **, *** indicate significance at the 10%, 5%, and 1% level, respectively.