Decentralized Renewable Energy to Grow Manufacturing? Evidence from Microhydro Mini-grids in Nepal*

Robyn C. Meeks,†
Hope Thompson,‡
Zhenxuan Wang§

November 2024

Abstract

Firms in developing countries often identify electricity as a major constraint to operations. Decentralized renewable energy sources, which are often promoted as a tool to achieve sustainable development, could help alleviate these constraints by providing "clean" electricity to locations that are difficult to reach with the centralized electric grid. We investigate whether electrification in Nepal – via microhydro plants and their mini-grids – helped grow the manufacturing sector and thereby induce structural transformation. Mini-grids led to a small but statistically significant increase in manufacturing establishments. Following electrification, females and males were more likely to be employees and less likely to be self-employed. Likewise, usual employment activities shifted from labor in agriculture to salary and wage work. In locations with smaller generation capacities, the impacts of mini-grids on labor-related outcomes were smaller. There is suggestive evidence of larger impacts in locations with better market access. (JEL Codes: O13, O14, Q42, Q56)

Keywords: electricity, manufacturing, employment, renewable energy

*Earlier versions of this paper were circulated as "Grid versus Off-grid in Nepal: Electricity Services and Enterprise Development." We thank David Lam, Shaun McRae, Dean Yang, Kelsey Jack, Michael Greenstone, Edson Severini, Kate Sims, Meera Mahadevan, Faraz Usmani, and seminar participants at Duke University, University of Michigan, University of Chicago, University of Pennsylvania, University of Oklahoma, the World Bank and many conferences for comments. We are indebted to Satish Gautam, Tilak Limbu, Sagar Gnawali, Narayan Gyawali, and Shyamala Nepal for many discussions. Andrew Bracken, Louis Vayo, Brendan Hall, Amanda Kaminsky, Dipendra Bhattarai, and Homer Pagkalinawan provided excellent research assistance. Financial support was provided by the University of Michigan Rackham Research Grant and the ADVANCE Crosby Award. Hope Thompson worked on this project while an NSF Graduate Research Fellow and PhD student at the University of Michigan; this paper does not reflect the position of the Federal Emergency Management Agency. All errors are our own.

†Duke University, Sanford School of Public Policy. Email: robyn.meeks@duke.edu.

‡Federal Emergency Management Agency. Email: hope.f.thompson@gmail.com.

§Department of Agricultural and Resource Economics, North Carolina State University, Duke University. Email:zhenxuan.wang@ncsu.edu.

1 Introduction

Developed to facilitate high income countries' greenhouse gas emissions reduction commitments made under the Kyoto Protocol, the Clean Development Mechanism (CDM) is a market-based approach to accelerating the diffusion of "clean" technologies while also stimulating development in low and middle income countries. As of 2018, 303.8 billion USD was invested in such climate and sustainable development projects (United Nations Framework Convention on Climate Change, 2018), promoting technologies ranging from biogas for cooking, energy efficient lighting and housing upgrades, and electrification via microhydro power and their associated mini-grids (United Nations Framework Convention on Climate Change, 2024).[1] The impacts of the CDM program have been evaluated empirically (see, e.g., Sutter and Parreno, 2007; Dechezleprêtre et al., 2008; Popp and Tang, 2016; Meeks et al., 2019; Mori-Clement, 2019); however, whether these technologies sufficiently promote development in low and middle income countries is debated (Zhang and Wang, 2011; Fowlie and Meeks, 2021).

Technologies supported via climate finance mechanisms such as CDM could potentially address some persistent development challenges. For example, growing the manufacturing sector can bring structural transformation and modernize a country's economy, by shifting labor from the agricultural sector to skilled, better-paying jobs (Tybout, 2000). Yet insufficient and unreliable electricity access may limit industrial activity and economic growth in many locations (Rud, 2012; Fisher-Vanden et al., 2015; Allcott et al., 2016; Abeberese, 2017; Abeberese et al., 2021; Fried and Lagakos, 2023). Achieving 100% electricity access – particularly in remote locations – remains a persistent challenge in many low and lower-middle income countries.[2] Although electrification rates increased worldwide in recent decades, a basic struggle remains: whether and how best to electrify

[1]Such projects can earn certified emission reduction credits for each tonne of CO_2 equivalent abated.

[2]The significant cost of constructing long-distance, high-voltage transmission lines prevents extending the grid to many poor, rural communities (Bhattacharyya and Palit, eds, 2014) and, when "fully electrifying" small villages does occur, it can even reduce welfare (Burlig and Preonas, 2021).

remote, small communities (Burgess et al., 2023).

With an estimated 47 million individuals connected to 19,000 mini-grids across 134 countries (ESMAP, 2019), decentralized renewable energy sources and their associated mini-grids can fill this gap and play a substantial role in increasing electricity access in these difficult-to-reach locations worldwide (International Energy Agency, 2010). With their generation sources situated near load centers (i.e., the population to which it provides electricity), mini-grids avoid the construction costs of high-voltage transmission lines and electrify rural locations at a lower cost than grid extensions (Harvey, 1993; Mainali and Silveira, 2011; ESMAP, 2019; Burgess et al., 2023).

Even with extensive investment in mini-grids, electrification strategies relying on the technology are controversial. Some question whether these technologies are sufficient to support development (United Nations Development Programme, 2011) and firms' growth, powering electric equipment and increasing workers' productivity. There are multiple reasons as to why decentralized renewable energy sources may induce limited – or no – effects on manufacturing and structural transformation. First, many mini-grids may be powered by generation sources with capacities insufficient to power substantial changes in the economy.[3] For this reason, populations may perceive mini-grids as inferior to grid electrification (Burgess et al., 2023) and invest less in enterprises following their construction. Second, mini-grids are often constructed to provide services to remote and rural communities, which may face constraints to manufacturing growth other than electricity access. Yet, causal evidence on the impacts of mini-grids remains limited, with a particular gap on the extent to which heterogeneities in generation capacity and access to markets matter in those effects.

In this paper, we study the impacts of microhydro plants with generation capacities of up to 100 kW, on manufacturing establishments and the allocation of labor in rural

[3]For example, Aklin et al. (2017) study solar micro-grids in India through a randomized experiment. The particular technology in their study, however, provided households with only 5 hours of electricity per day to power two light sources and charge a phone.

Nepal.[4] We provide evidence on two research questions. First, can decentralized renewable energy – as a source of electrification, more broadly – increase manufacturing and shift labor away from the agricultural sector? Second, do these impacts differ depending on proximity to the existing markets or the system's generation capacity?

Nepal, a lower-income country in South Asia with a population just under 30 million people (World Bank, 2020), is a suitable location for this study. Only 14.7% of the country's rural population had access to electricity as of 2001 and 68.8% of firms identified electricity as a major constraint to their business operations (World Bank, 2020). Since then, Nepal experienced one of the world's greatest increases in electrification.[5] With an estimated 1,519 mini-grids installed in the country – the fourth highest in the world, after Afghanistan, Myanmar, and India (ESMAP, 2019) – this technology plays an important role in the country's recent rural electrification gains. In communities with microhydro, the average capacity is 38 kW, which is sufficient to power activities such as sawing, milling, sewing, processing foods, and running mechanical workshops.

Our analyses hinge on data locating microhydro sites, which we collected from Nepal's Alternative Energy Promotion Center (AEPC), the government entity created in the 1990s to coordinate international donors' funding for renewable energy projects. In addition, we digitized data collected via the country's Census of Manufacturing Establishments (2006/2007 and 2011/2012) and the National Economic Census (2017/2018) to create a panel dataset of manufacturing establishments. Two rounds of microdata (2001 and 2011) on individuals' employment status and work activities from the National Population Census provide labor outcomes.

To estimate the impact of micro-hydro construction in Nepal over time, we construct an instrumental variable for the number of microhydro plants constructed in a munic-

[4]Nepal's Central Bureau of Statistics defines manufacturing as the "physical or chemical transformation of materials or components into new products, whether the work is performed by power-driven machines or by hand."

[5]Other countries rapidly electrified during this period include Bangladesh, India, Kenya, Myanmar, and Rwanda (ESMAP, 2019).

ipality by a given year using two sources of variation.[6] First, we exploit the variation over time in the funding that AEPC received from bilateral and multilateral international donor organizations for microhydro plants and their mini-grids. The year-to-year variation in microhydro plant construction is determined by – and therefore positively correlated with – these national budgets for microhydro in Nepal, but coordinated and dispersed through AEPC in a way that is plausibly exogenous to individual municipalities within the country.[7] Second, we exploit cross-sectional variation in whether a location within Nepal is geo-physically appropriate for microhydro plants and their mini-grids. The key characteristics that determine microhydro feasibility are year-round river flow and a river slope sufficient to generate electricity. When AEPC and donor organizations sought to rapidly increase microhydro plant construction in 2006, they launched a GIS study to identify all geophysically appropriate locations. The classification of sites as appropriate or inappropriate for microhydro serves as our second source of variation. Our main estimates, which use panel data for 747 municipalities within Nepal, include municipality fixed effects that control for time-invariant differences between municipalities and province-year fixed effects that control for changes over time that affect municipalities within a province similarly.

Our study produces three main results. First, we find that rural electrification via microhydro plants led to a small and statistically significant increase in formal manufacturing establishments employing 10 or more individuals. Given a very low baseline number of manufacturing establishments, the overall presence of manufacturing remained limited post-electrification in these locations. Robustness checks using alternative instrumental variables and different identification methods produce similar results. Supplemental evidence using the Nepal Living Standards Survey panel dataset suggests that

[6] This empirical strategy is inspired by existing research on the impacts of dams (Duflo and Pande, 2007; Severnini, 2022) and grid electrification (Dinkelman, 2011; Lipscomb et al., 2013).

[7] We refer to municipalities throughout this description, as that is the lowest spatial unit in our main regressions. For additional outcomes using the census microdata, the spatial unit is the village development council (VDC), which represents a cluster of villages. We explain spatial units in greater detail later.

non-agricultural and informal household enterprises, as well as their net revenue, also grew from microhydro.

Second, and consistent with the first findings, individuals' labor shifts away from self-employment and own agricultural/farming work to work as an employee and earning salary or wages. These labor impacts imply the start of a structural transformation within the economy and, together with the manufacturing establishment results, indicate that such mini-grids can support some manufacturing gains.

Our third key finding is that both generation capacity and access to market centers matter for mini-grid impacts, albeit to different extents. Manufacturing establishments increased significantly in all groups (below and above 50 km from population centers, as well as the below and above median MHP generation capacity). The labor effects are significantly smaller from microhydro plants of smaller generation capacity (below the median system size) compared to the larger generation sizes. The impacts of MHP construction in locations farther from market centers – which we proxy for by distance to population centers of 25,000 people or more – are relatively weaker compared to those constructed closer, though not significantly different. Individuals are less likely to become employees, working for salary and wages, and more likely to remain self-employed, working on their family farms, in these locations. These results add nuance to the story: although decentralized renewables can support increased manufacturing and labor transformation, electrification alone is insufficient.

We address three potential concerns regarding this type of instrument (Gallea, 2023).[8] First, to support the claim that the causal relationships we identify are unaffected by selection bias and spurious time trends, we conduct Monte Carlo simulations proposed by Christian and Barrett (2017). Second, given that residuals may be correlated across locations with similar exposure to shocks (Adao et al., 2019), such as the national-level funding for microhydro, we employ the arbitrary clustering method proposed by Colella

[8] Although not a standard shift-share instrument, our instrument is susceptible to the same weaknesses.

et al. (2019). Third, we provide three types of evidence in support of the excludability of the instrument, conditional on fixed effects. First, we show that the instrument does not predict changes in the number of schools, the number of students, or the distance to the nearest health facility – which would provide an alternative channel through which to affect labor and manufacturing. Second, we show that the instrument does not predict changes in population, which would occur if increased migration to microhydro locations provided an alternative channel through which manufacturing establishments and salary and wage work increase. Lastly, we show that results are robust to controlling for the interaction of average municipality slope – a construction cost shifter for road infrastructure – and year fixed effects to support our claim that these geophysical characteristics did not affect development through other channels that change over time.

This paper makes several contributions to the literature. First, it contributes to a broad body of causal evidence on the extensive margin impacts of electrification on industrial development (Lipscomb et al., 2013; Rud, 2012; Peters et al., 2011; Kassem, 2024), and the reallocation of labor across sectors (Dinkelman, 2011; Chaurey and Le, 2022; Fetter and Usmani, 2024).[9] Interestingly, the effects that we find are not gendered – both male and female labor is affected – which is in contrast with some existing literature.

Second, this paper is part of a small but growing body of evidence on heterogeneous effects of electrification. Several recent papers – all studies in India – investigate specific heterogeneities: across community characteristics (i.e., small versus large villages in Burlig and Preonas (2021)), the presence of contemporaneous economic shocks (i.e., the guar boom interacting with electrification in Fetter and Usmani (2024)), and the actual electricity source (i.e., household surplus gains from off-grid solar versus grid electrification in Burgess et al. (2023)). Our findings that the effects of microhydro are significantly smaller when the community's generation capacity is below median capacity (of 40 kW)

[9] There is also a larger literature on the intensive margin, estimating the impacts on and response of firms to electricity shortages and outages (Allcott et al., 2016; Alam, 2013; Fisher-Vanden et al., 2015; Cole et al., 2018; Abeberese, 2019; Abeberese et al., 2021; Mahadevan, 2021; Fried and Lagakos, 2023).

and also substantially – although not statistically significantly – in locations farther from population centers, provide a plausible, yet under-explored, explanation as to why studies on household electrification find substantial effects in some settings (see, e.g., Dinkelman, 2011; Grogan and Sadanand, 2013; Khandker et al., 2013; Barron and Torero, 2017; Fetter and Usmani, 2024), but not others (see, e.g., Burlig and Preonas, 2021; Lee et al., 2020b).[10] Moreover, this heterogeneity is particularly important in the case of mini-grids, which are often deployed to remote locations that are isolated from existing markets.

Third, this work contributes to a relatively small body of causal evidence on the economic effects of decentralized renewables and mini-grids in low and middle income countries. This area of research is important given the investments in these technologies worldwide through finance mechanisms aimed to both induce development, while also delivering environmental benefits and mitigating climate change. Aklin et al. (2017) finds that solar micro-grids that provide households with limited power – only 5 hours of electricity per day to power two light sources and charge a phone – had limited effects. Burgess et al. (2023) find that households in Bihar, India gain more surplus from the grid than off-grid solar. Our findings that decentralized renewables powering mini-grids can induce both growth in manufacturing and a shift in labor – particularly when constructed to generate a larger magnitude of power – are important complements.[11]

The paper proceeds as follows. Section 2 provides a conceptual framework as to how electrification might impact manufacturing and lead to structural transformation, shifting labor from the traditional sector to the modern sector. Section 3 provides background information on manufacturing establishments, labor, and electricity in Nepal. Section 4 describes the electrification data, as well as the microdata from the manufacturing and household censuses. Sections 5 and 6 cover our instrumental variable and empirical strat-

[10]Papers reviewing the electrification literature have offered a variety of potential explanations for heterogeneity in findings, such as the empirical methods used, the duration of the study period, study location, and the source of electrification) (see, e.g., Jiménez, 2017; Bayer et al., 2020; Moore et al., 2020; Lee et al., 2020a; Chakravorty and Pelli, 2022).

[11]We also note important, but distinct research that studies the effects of market integration on renewable energy expansion in Chile (Gonzales et al., 2023).

egy, respectively. Section 7 presents the main results, robustness checks, and supplemental evidence. Section 8 investigates heterogeneous impacts and Section 9 concludes.

2 Conceptual Framework

In presenting a conceptual framework, we have two overarching goals. First, we aim to provide a synopsis as to how electrification of a community – the co-benefit from a micro-hydro mini-grid – could induce structural transformation, growing manufacturing enterprises and shifting labor from low productivity activities to higher productivity activities. Second, we seek to illustrate how electrification via mini-grids does not necessarily bring the same benefits as grid electrification due to at least two additional potential constraints: a limit on the magnitude of power available for each consumer and the higher probability of being constructed in remote locations with limited access to markets.

Following Midrigan and Xu (2014) and Fried and Lagakos (2023), we consider a scenario, in which there are two types of firms: those that operate in the traditional sector and those that operate in the modern sector. Both types of firms use capital and labor in the production process; however, firms in the traditional sector do not require electricity, whereas modern firms do.[12] Modern sector firms are more productive than the traditional sector firms.

In a community without access to electricity, a firm may either operate in the traditional sector without electricity or within the modern sector by fully self-generating electricity. Self-generation is expensive, so most firms will choose to operate in the traditional sector in locations where there is no grid.[13] As a result, labor in these locations will be primarily allocated to the traditional sector. Firms will remain small and relatively

[12]We assume, however, that electricity reliability (i.e., frequency of outages) and service quality (i.e., voltage fluctuations) are the same across different electricity sources.

[13]Self generation requires not only on-going fuel costs but also the large upfront cost to purchase a generator. In much of rural Nepal, generators were prohibitively expensive for most enterprises, so prior to community electrification many would rely on manual labor and basic fuels (e.g., kerosene lamps for lighting).

unproductive in their use of capital and labor. In this scenario, individuals are primarily either self-employed on their own farms or employed elsewhere in the traditional sector.

When a community is electrified via the national grid, firms – both formal manufacturing establishments and informal household enterprises – can use electricity as an input at a substantially lower cost per unit of electricity than was previously feasible. Firms may choose to shift to the modern sector, as it is more productive due to the modern technologies now feasible. And electrification may either increase the productivity of existing businesses (e.g., clothing producers can make more items in a given amount of time with electric sewing machines than person-powered machines) or enable new businesses that were not previously feasible (e.g., an enterprise dependent on refrigeration is only be possible post-electrification).[14] New firms would enter the modern sector (either existing traditional sector firms shifting to the modern sector or those newly developed in modern sector) and existing modern firms would increase in size. If there is an increase in the number and size of modern sector firms, individuals may shift from self-employment in agriculture to working as employees for salary and wages in businesses.

There are two characteristics common to decentralized renewables and their mini-grids that differ from grid electricity and might act as constraints on the structural transformation illustrated above. First, given the limited generation capacity of small-scale decentralized renewables, it is not uncommon for mini-grid operators to restrict the quantity of power provided per customer, including firms, via the mini-grid. Second, the propensity to construct mini-grids in remote locations, which by definition are far from market centers, limits access to both inputs in the production process and markets for end product sales. As a result, it is not obvious ex ante that mini-grid electrification would result in structural transformation.

[14] In our study setting – the hills of Nepal – electricity is not commonly used for irrigation and therefore we do not focus on the potential for mini-grids to increase irrigation and therefore agricultural productivity. Grain mills may have increased productivity when a location gains access to electricity. These are typically run as small businesses and therefore we consider this as a form of business productivity.

3 Background on Nepal: Manufacturing and Electrification

3.1 Manufacturing Establishments and Employment

Nepal, a country with three distinct ecological regions (the flat terai region, hills, and mountains), has an economy historically driven by the agricultural sector. As of 2001, agriculture, forestry, and fishing contributed 35.3% of GDP value added, whereas manufacturing contributed only 8.7% (World Bank, 2020).

The relative strength of these sectors has implications for employment. According to 2001 International Labor Organization estimates, unemployment was low (e.g., 2.0% of the male labor force was unemployed) and labor force participation rates were high (e.g., 90.2% among the male population age 15 years or older). Yet a substantial proportion of the population was in "vulnerable employment" due to a high rate of self-employment and a low rate of salary and wage workers (83.9% and 16.1% of total employment, respectively) (World Bank, 2020).

Using 2001 census microdata for communities that were not yet electrified but eventually have a microhydro plant constructed, we can better understand baseline employment in unelectrified locations (Appendix Table A1). Few individuals – female or male – were employers. Employees accounted for 9.8% of males and 2.8% of females. Most individuals worked for themselves ("own account workers"), 54.3% and 60.9% of males and females respectively. The "other" group, which includes unpaid family workers and individuals not reporting any employment status, represented approximately one-third of both males and females. Individuals' usual work activity within the past 12 months show that over half of both females (54.8%) and males (50.8%) reported own agriculture / farming as their main activity. Owning one's own business constituted the next largest group for males (33.7%) but not for females (1.7%). Similarly, 8.7% of males are in salary and wage positions, compared with less than 1% of females. Conversely, 10.3% of females report housework to be their usual activity, in comparison to only 1.2% of males. High percentages of both females and males report studying as their usual activity (20.6% and 28.5%, respectively).[15] The remainder worked in extended economic activities, collecting fuel and water and preparing goods for home consumption.

Overall, these statistics are consistent with an agriculture-dominated subsistence economy with limited manufacturing. Indeed, only 21.6% of these municipalities had a manufacturing establishment that was formally registered with the government and employs 10 or more people.[16] Since then, the number of manufacturing establishments has steadily increased over time across Nepal. Between 2001/2002 and 2006/2007, the number of registered manufacturing establishments within the country increased slightly, from 3,213 to 3,446. The types of establishments that grew during that period included those milling grains, producing carpets and rugs, woodworking, and building furniture, among others (Central Bureau of Statistics, 2014). The following period (2006/2007 to 2011/2012) experienced larger gains in the number of establishments, increasing to 4,076 by 2011/2012.[17]

As we will cover in the next section, electrification also increased substantially during this latter period; however, the extent to which changes in electrification drove any increases in manufacturing, particularly in rural locations, is not obvious.

3.2 Electrification

The state-owned Nepal Electricity Authority (NEA) is responsible for transmission and distribution of electricity through the country's national grid. Almost all of Nepal's electricity (99%) is generated via hydroelectric sources (Mainali and Silveira, 2011). Generation for the national grid is typically large-scale and consolidated at points such that transmission connecting to load centers is necessary. Electricity is transmitted through high-voltage lines across the terai and into the Kathmandu Valley and some of the largest

[15]The census collects data for individuals 10 years and older.
[16]Calculations based on the 2006/2007 Census of Manufacturing Establishments data.
[17]Calculations based on data from the Census of Manufacturing Establishments.

population centers in the hill and mountain regions.[18]

Connecting the remaining rural communities to the grid has been slow for multiple reasons. First, extending the national grid to remote communities is often prohibitively expensive given the high costs of purchasing the associated infrastructure (e.g., substations) and constructing high-voltage transmission lines over long distances, particularly in mountainous terrain like much of Nepal (Bhattacharyya and Palit, eds, 2014). Second, communities comprised of traditional sector firms typically consist of households with limited income and asset ownership, including limited electric appliances. This, in conjunction with few manufacturing establishments, can result in low demand for electricity upon a community's initial connection to the grid. Third, rural communities are often located farther from market centers, which may both provide inputs to the manufacturing process as well as opportunities for sales.

These factors contributed to substantial rural-urban differences in electrification rates. In 2001, 85.7% of the urban population had access to electricity, in contrast to 14.7% of the rural population. With 86.1% of the population inhabiting rural areas, most of its people were impacted by the low electrification rates (World Bank, 2020).

Starting in the early 2000s, the country began to prioritize rural electrification. This induced a substantial increase in the percent of the rural population with access to electricity, as depicted in Figure 1. By 2018, 93.5% of the rural population had access to electricity (World Bank, 2020).[19] Noticeably, there were not comparable improvements in all rural services over this time period. For example, we do not witness a similar increase in the rural population using basic or safe drinking water sources or hand-washing facilities during this period (also shown in Figure 1).

The following sub-sections document the main pathways for community electrifica-

[18] In an effort to electrify district headquarters in remote regions during the 1980s, the government also constructed several mini-hydro (100 – 1000 kW) plants that electrify some regional government headquarters and their surrounding areas.

[19] These changes in electrification over time are also illustrated by the maps in Appendix Figure A1.

tion in Nepal during our study period.[20]

3.2.1 Electrification through Microhydro Plants with Mini-Grids

Microhydro plants generate between 10 kW and 100 kW of electricity. A mini-grid then distributes the electricity to residential consumers and enterprises (World Bank, 2016). In Nepal, these microhydro mini-grids are typically decentralized and not interconnected with the national electricity grid.

As a technology, microhydro is not new to Nepal; however, the technology's prevalence increased greatly since the 2000s. Figure 2 documents the increases in both the number of microhydro plants and their installed capacity (kW) between 1998 and 2018. The uptick in microhydro plant construction contributed substantially to the country's rural electrification gains during this period. Maps in Figure 3 illustrate how the microhydro plant construction varied across Nepal over time. This variation was driven by two key factors – geographic characteristics and external donor funding – as explained below.

Certain geophysical characteristics determine whether a location is appropriate for plant construction. Microhydro systems are typically run-of-river (i.e., there is no dam or reservoir of water), so they require continuous, year-round river flow. Unlike solar-powered mini-grids, they do not require battery storage.[21] Part of a river's flow is diverted to a channel that runs alongside the contours of a hill, in order to maintain a high elevation. From the channel, the water passes through a closed pipe with a large drop in elevation, connecting to a turbine located at a substantially lower elevation below. The water falling to the lower elevation moves the turbine, generating electricity (Harvey, 1993). Due to these design requirements, a location's river slope is a main geophysical determinant of microhydro plant construction and they are typically targeted to the hill

[20]During this time, individual households could purchase rooftop solar home systems. The capacity of these systems is not sufficient for electrifying a community nor is it sufficient to support manufacturing, particularly establishments large enough to employ 10 or more people, and therefore we do not consider them here. However, the solar home systems could power small household enterprises.

[21]The absence of a dam limits the system's negative impacts on the environment, such as requiring large quantities of concrete, flooding valleys for reservoirs, etc.

and mountain regions where year-round rivers flow through terrain with sufficient slope (Harvey, 1993).[22]

The increased construction of microhydro plants over time was induced by large investments made by bilateral and multilateral donor organizations. When AEPC and international donors sought to rapidly expand microhydro funding and construction in the mid-2000s, AEPC and partners undertook a study to identify locations with the geographic conditions necessary for microhydro plants. This study lasted between 2005 and 2008 and had two components: a GIS-based desk study (the "carpet study") and a field-based feasibility study (Alternative Energy Promotion Centre, 2012). The carpet study used GIS and spatial data to remotely identify locations physically appropriate for microhydro plants (Müller et al., 2016). Beyond the necessary geophysical conditions described above, the carpet study ensured construction locations were proximate to load centers to prevent plant construction far from communities to use the electricity. Through the carpet study, 882 Village Development Committees (VDCs) – which from 1990 to 2017 were the primary local administrative units in the country, with one VDC representing a small cluster of villages – were identified as geophysically appropriate for a microhydro plant.

AEPC and partners intended to avoid building microhydro plants in locations where the national electricity grid was likely to soon reach (Alternative Energy Promotion Center, 2009); however, in practice, the Nepal Electricity Authority (NEA) and AEPC communicated little and, as a result, microhydro plant site selection was relatively uninformed by future electricity grid placement. Although some plants were constructed more than 100 km from the grid, others were constructed within 10 km (Appendix Figure A2).

Not all locations identified as appropriate through the carpet study had microhydro plants constructed by the end of our study period (Appendix Figure A3). After the carpet study, in-person feasibility studies were conducted in the GIS-identified VDCs to assess community demand for microhydro. Communities identified through the carpet study

[22] Solar home systems were targeted to electrify individual houses in the highest mountain regions, as transporting microhydro equipment to these places is too difficult.

were eligible for a subsidy, coordinated by AEPC and funded by bilateral and multilateral international donor organizations. The subsidy covered approximately 50% of the system cost and the community mobilized funding for the balance (Kumas et al., 2015).[23]

3.2.2 Electrification through Community Grid Connections

Microhydro plants were not the only pathway for rural electrification at this time. Communities could also be newly-electrified as a result of grid extensions. In 2004, the Community Rural Electrification Programme (CREP) launched as a collaboration between the Government of Nepal and NEA to expand access to electricity services in unelectrified VDCs. Through CREP, communities could submit an application for a connection to the national grid, which was evaluated primarily based on a cost estimate. If the cost was deemed acceptable, the Government of Nepal would subsidize 90% (Nepal Electricity Authority, 2018). Due to transmission line construction expenses, community distance from the existing national grid was the main determinant of extension cost, so typically only communities located within 25 km of the existing grid were eligible for CREP.

4 Data and Variable Construction

The analyses utilize datasets collected by Nepal's Central Bureau of Statistics, the NEA and the AEPC. We describe these datasets and the variables created from them.

4.1 Electrification Data

We combine data on the main sources of community electrification in Nepal: microhydro plants and their associated grids, the national grid, and extensions to that grid. Datasets

[23]The subsidy increased over time. In 2006, it was 10,000 Nepali rupees (NPR) per household (HH), not to exceed 85,000 NPR/kW (1 NPR = 0.0104 USD) for the system. In 2009, it was 15,000 NPR/HH (125,000 NPR/kW maximum). In 2013, the subsidy changed for some sites, with remote and very remote locations receiving 15,000 NPR/HH (100,000 NPR/kW) and 25,000 NPR/HH (130,000 NPR/kW), respectively (Kumas et al., 2015). Communities were also responsible for managing and maintaining the microhydro mini-grid, so these arrangements and rules vary across sites.

are described below and additional supporting information is in Data Appendix A1.

4.1.1 Microhydro plants

AEPC provided datasets on microhydro plant siting and construction. The first dataset is comprised of the carpet study output: a list of locations, at the VDC-level, that were identified through the carpet study as being geophysically appropriate for microhydro plant construction.[24] These data are based only on the GIS desk study, not the field visits that determined community demand for the microhydro plants.

The second AEPC dataset provides details on the actual microhydro plant construction through 2018. Data include the location (VDC and district) of microhydro plants, plants' construction completion date, and the plants' expected capacities.[25] We use these data to create variables counting the total number of microhydro plants per year per location – VDC, municipality, district, and the entire country.

4.1.2 National grid and community grid extensions

We map the coverage of the national electricity grid, including the 132 kV, 66 kV, and 33 kV lines. These data, available at the NEA website,[26] allow us to calculate locations' distances to the national electric grid. We use data on the location of grid extensions funded via the CREP, provided by the entity coordinating the program, the National Association for Community Electricity Users Nepal (NACEUN). With these data, we can perform robustness checks dropping the CREP-electrified locations.

[24] We do not have the GIS layers of data that were used to conduct the study, as some of the government and NEA datasets are not available to the public. For this reason, we use the outputs of the GIS study.

[25] Plant capacity data are not available for all locations.

[26] NEA website: www.nea.org.np.

4.2 Geo-spatial Data

Given the input files used to perform the national GIS "carpet study" are not publicly-available, we use alternative geo-spatial datasets from OpenStreetMap and NASA's Shuttle Radar Topography Mission to compute one key component that determines whether a location is geophysically appropriate for a microhydro plant: river slope. Details on the sources and processing of these data are documented in Data Appendix A2.

Using these data, we calculate the length of rivers within a VDC, the average elevation and slope of a VDC, and – by restricting attention to cells through which a river flows – the average river gradient. We create four binary variables indicating whether a VDC's average river slope (in degrees) falls within one of the following gradient bins: 0-3, 3-20, 20-30, or greater than 30. These variables both allow us to check the extent to which river slope predicts a location's designation as geophysically appropriate via the carpet study and provide an alternative set of instrumental variables for robustness checks.

4.3 Data on Manufacturing Establishments

With data from the Government of Nepal's Central Bureau of Statistics, we compile a panel dataset of the number of manufacturing establishments that employ 10 or more people per municipality in a given year. Data are from the 2006/2007 and 2011/2012 iterations of the Nepal Census of Manufacturing Establishments (Nepal Central Bureau of Statistics, 2014) and the 2017/2018 National Economic Census (Nepal Central Bureau of Statistics, 2019). Together, these provide one baseline iteration, collected before the carpet study was completed, and two post-carpet study iterations for this outcome variable. To use all three rounds of data together, we address the changes in administrative boundaries, from VDCs to municipalities, which occurred in 2015. Further details on the steps to build the manufacturing establishment panel dataset are in Data Appendix A3.

The Census of Manufacturing Establishments and the National Economic Census data have important commonalities. They both use the same definitions for "establishments" and "manufacturing," permitting us to use the three census rounds as a consistent count of manufacturing establishments over time.[27] Notably, their definition of manufacturing includes "physical or chemical transformation of materials or components into new products, whether the work is performed by power-driven machines or by hand." By definition, these data incorporate manufacturing establishments in both electrified and non-electrified locations. By nature of the data collection process, these establishments are all registered with the government; these data do not capture informal enterprises.

The panel data are complemented by cross-sectional data from the Census of Manufacturing Establishments survey in 2010/2011. These provide more detailed data on Nepal's manufacturing establishments, including the number of employees (persons who work in or for the establishment and receive pay, in cash or in kind, at regular intervals) and the total establishment benefits (the establishments' sum of direct wages, salaries, and non-monetary compensation, including both cash remuneration for work performed and time not worked due to holidays or for other reasons).

4.4 Individuals' Employment Status and Activities

Nepal's National Population Census is implemented every 10 years by the Central Bureau of Statistics. Micro data, identifiable at the VDC level, are available for a random sample of households from the 2001 and 2011 census iterations. This results in a microdata sample of 841,567 (15.5% of households) and 520,624 (12.2% of households) households, in 2001 and 2011 respectively.[28] Across the two census rounds, there are microdata on 2,442,232 males and 2,610,184 females.

The census microdata contain household and individual characteristics and the economic and non-economic activities of each family member age 10 years and older. Out-

[27] The definition of "establishment" is an economic unit, under single ownership, engaged in one economic activity type at single physical location.

[28] Due to political unrest, 83 VDCs were not included in the 2001 census enumeration.

come variables used in this analysis include individuals' employment status and individuals' usual work activities in past 12 months. Employment status can be as an employer, employee, own account work (i.e., self-employed), or other, which includes unpaid family work as well as those that do not report an employment status. Work activities consist of own agriculture/farming, wage or salaried work, and small business activities, extended economic work (collecting fuel and water, preparing goods for consumption at home), household chores (cooking, cleaning, child care, etc.), and studies. Agricultural work outside the family that is performed for a salary or wage is covered by the second category. Complete descriptions of the census variables are in Data Appendix A4.

4.5 Household Enterprises

We use data on small, non-agricultural household enterprises from the Nepal Living Standards Survey (NLSS). The NLSS is a household survey implemented by the country's Central Bureau of Statistics. We use data from two surveys rounds, which were conducted in 2003/2004 (NLSS-II) and 2010/2011 (NLSS-III), as a stacked panel. The datasets have samples of 3,912 and 5,988 households, respectively.[29] Both rounds collect detailed information on non-agricultural household enterprises, including the number of enterprises operated by the household, whether the enterprise is formally registered with the government, the number of people in the household working in the enterprise, the number of employees hired by the enterprise, and the gross and net household enterprise income.

5 Instrumental Variable: Microhydro Plant Construction

OLS regressions estimating the effect of a microhydro plant built on business enterprises or labor allocations are likely biased. For example, locations anticipating growth in enterprises may be more likely to invest in microhydro plants, even if the location is not

[29] Conflict in Nepal continued through 2006. The NLSS-II did not cover areas with active conflict in 2003 to 2004. As a result, the NLSS-II had a smaller sample size than the NLSS-III.

geo-physically appropriate for the technology. If microhydro plants are constructed in locations that are geo-physically for the technology – and therefore provide insufficient and only seasonal electricity services – then OLS estimates of microhydro mini-grids will be downward biased. To avoid such sources of bias, we employ an instrumental variable approach.

5.1 Construction of Instrumental Variable

To estimate the impact of community electrification via microhydro plants constructed across Nepal over time, we exploit the exogenous variation in their annual construction budget through an instrumental variable estimation. Our instrument, Z, is the predicted number of microhydro plants constructed in a particular location by a given year. We create the instrument by interacting measures of the two factors driving variation in microhydro plant construction over time across Nepal: cross-sectional differences across locations in the geophysical suitability for plant construction and variation over time in the national annual budget for microhydro plant construction.

In the following sub-sections, we outline the two sources of variation employed in constructing the instrumental variable and describe a set of alternative IVs used for robustness checks.

5.1.1 Step 1: A Measure of Geophysical Suitability for Microhydro

Our first objective is to identify a measure of a location's geophysical suitability for microhydro plant construction. The AEPC data contains a straightforward measure, which is an output of the carpet study: a binary indicator equaling 1 if the VDC was identified as geophysically appropriate for microhydro ("carpet study identified") and 0 otherwise.

To shed light on this variable and the information it captures, we estimate a linear probability model, regressing this binary variable on baseline (i.e., pre-carpet study) VDC and household characteristics. Results are in Table 1. As expected, locations in the hill and mountain regions were significantly more likely to be identified as being appropriate for microhydro plants, relative to the flatter, terai region. Similarly, locations with an average river slope (in degrees) between 20 and 30 or 30 and 50 degrees are significantly more likely to be identified as appropriate for microhydro than those with a smaller average river slope. River length and population density are not significant predictors of carpet study identification. The carpet-identified locations are more likely to be farther from the nearest city, road, and electric grid relative to the those not identified.[30]

5.1.2 Step 2: District Microhydro Plant Construction Budgets over Time

Our second objective is to develop a measure capturing the year-to-year variation in annual national budgets for microhydro plants, which were determined by bilateral and multilateral donors' investments and then coordinated through AEPC. These were determined at the country-level and are exogenous to individual locations (i.e., VDCs or municipalities). To proxy for the annual national budget for microhydro plants, we use data on the total number of microhydro plants constructed per year in Nepal, which were illustrated in Figure 2. As suggestive evidence to support the argument that the national microhydro budgets are exogenous to local conditions, we show that the annual national budget for microhydro plants does not closely follow indicators of the country's overall economic prosperity (Appendix Figure A4).

5.1.3 Step 3: Interaction to Create the Instrumental Variable

We bring together the two measures from Steps 1 and 2 and interact them to create the instrumental variable, Z_{it}. The IV proxies for the predicted number of microhydro plants constructed in location, i, by a given year, t. The location, i, can be either at the municipality or VDC level, depending on the dataset used in the analysis.

[30]The one baseline household characteristic for which the difference between groups is statistically significant and could change over time is the presence of toilets. Therefore, we control for access to toilets when possible.

The instrument is constructed as follows:

$$Z_{it} = \text{carpet}_i \times N_t \tag{1}$$

in which the first term – carpet_i – is a binary indicator for whether location i was identified by the GIS carpet study as being appropriate for microhydro plant construction based on its geophysical characteristics. The second term, N_t, is the total number of microhydro plants constructed in Nepal as of year t, which provides a proxy measure of the nationwide budget for microhydro construction. The instrument varies by location and over time, capturing the variation in funding over time for microhydro plants that is directed to locations that are geophysically appropriate for the technology. Conditional on the location and year fixed effects, the exclusion restriction is that the microhydro annual national funding allocated to municipalities that are geophysically appropriate for microhydro plants does not affect the number of enterprises or labor outcomes through any channel other than through the increase in the number of microhydro plants built.

5.2 Alternative Set of Instrumental Variables

As was shown in Table 1, the average river slope within a VDC significantly predicts whether a location was identified as geophysically appropriate for microhydro. Using these data, we construct an alternative set of instrumental variables that do not rely on the carpet study output and can be used in robustness checks.

The set of alternative instrumental variables are three interaction terms, $\text{SlopeBin}_i^b \times N_t$, where $\{\text{SlopeBin}_i^b\}$ is a series of indicators defined by which of the three slope bins $b \in B = \{3-20, 20-30, > 30\}$ the average river slope in location i falls in. The 0-3 category is omitted and used as the reference group. These slope bins are then interacted with N_t, which is the proxy for nationwide budget for microhydro plant construction in year t, as it was calculated previously for use in Equation 1.

For transparency and to build confidence in our primary instrument, we redo our main 2SLS regressions using these instrumental variables as robustness checks.

6 Empirical Strategy

To estimate the impacts of microhydro on enterprises and employment activities, we use the instrumental variable in 2SLS regressions. Given data and analyses are at different location levels, either municipality or VDC, we illustrate the empirical approach separately for the manufacturing establishments and employment activities.

6.1 Number of Manufacturing Establishments

We estimate the first-stage equation, using the municipality-level construction of the instrumental variable depicted in Equation 1. This first-stage is as follows:

$$\text{MHP}_{mt} = \beta \text{Z}_{mt} + \lambda_m + \theta_{j(m)t} + \epsilon_{mt}, \tag{2}$$

in which MHP_{mt} is the cumulative number of microhydro plants in municipality m by year t. The instrumental variable in these analyses is $Z_{mt} = \text{Carpet}_m \times N_t$, where Carpet_m equals 1 if the municipality contained *any* VDCs identified in the GIS study as appropriate for microhydro construction and 0 otherwise. The remainder of the instrumental variable is as constructed in Equation 1. We include municipality fixed effects, λ_m, to control for time-invariant characteristics, such as proximity to urban centers, elevation, and land gradient. Lastly, we control for province-year fixed effects, $\theta_{j(m)t}$, to allow the time effects to differ by province within Nepal thereby capturing the changes over time that affect all municipalities within a province similarly.

In robustness checks, we add a vector of municipality-year controls that are the interactions of the logarithm of municipality average elevation and slope with year fixed effects. These control for characteristics that could potentially have also affected development in ways – other than microhydro feasibility – that could change over time.

In the second-stage regression, we estimate the following:

$$\text{Establishments}_{mt} = \beta\widehat{\text{MHP}}_{mt} + \lambda_m + \theta_{j(m)t} + \xi_{mt}, \tag{3}$$

in which the first-stage regression's predicted microhydro construction, $\widehat{\text{MHP}}_{mt}$, is used to estimate the impact on the number of manufacturing establishments (with 10 or more employees) within municipality m in province j during time period t. The province-time and municipality fixed effects (as well as the municipality-year controls in robustness checks) remain the same as in the first-stage regression. Standard errors are clustered at the district level, which is one level above municipalities.

The outcome variable is the inverse hyperbolic sine transformation of the number of manufacturing establishments, which permits us to interpret the coefficient as a log-linear regression specification (Bellemare and Wichman, 2020). This transformation is preferred over the log transformation, as it allows us to retain the observations with zero manufacturing establishments, which is not uncommon among rural municipalities.

As with other instrumental variable estimates, the 2SLS estimates here represent local average treatment effect; that is the effect for observations that comply with the instrument. Compliers in our setting are those municipalities that have more microhydro plants constructed due to the increase in microhydro funding nationally. Our instrumental variable estimates do not capture the effects of microhydro constructed in locations that are not geophysically appropriate for the technology.

6.2 Individual Employment Activities

We implement an analogous approach using the census microdata to estimate the impacts of microhydro on individual (male and female) employment activities. Given that males and females often engage in different activities and may be differentially affected by electrification, we run these regressions separately by sex.

The regressions in both the first and second stages differ from those in the previous sub-section for two reasons. First, the census microdata are at the individual level and analysis at this level allows us to control for individual and household characteristics. Second, because the microdata are available for only 2001 and 2011 and the shift from VDCs to municipalities as the primary administrative unit of governance had not yet occurred, our "treatment" variable remains at the VDC level. We match the VDC-level MHP and carpet study records with the individual-level data based on the VDC where each individual is located. With the combined data, we estimate the following 2SLS regressions:

$$\text{MHP}_{ivt} = \beta_1 \text{Z}_{ivt} + \gamma_1' \text{X}_{ivt} + \eta_v + \theta_{j(v)t} + \epsilon_{ivt}, \tag{4}$$

$$\text{Labor}_{ivt} = \beta_2 \widehat{\text{MHP}}_{ivt} + \gamma_2' \text{X}_{ivt} + \phi_v + \delta_{j(v)t} + \xi_{ivt}, \tag{5}$$

in which MHP_{ivt} is the cumulative number of microhydro plants in VDC v (where i is located) by time t. The instrumental variable in these analyses is $z_{ivt} = \text{Carpet}_{iv} \times N_t$, where Carpet_{iv} equals 1 if the VDC (where i is located) was identified as appropriate for a microhydro plant and 0 otherwise.[31] X_{ivt} is a vector of individual-level controls including the individual's age, level of education, the size of their household, and whether the household has a toilet. Standard errors in these regressions are clustered at the district level. We include VDC fixed effects to control for time-invariant VDC characteristics. Lastly, we include province-year fixed effects to control for changes over time that impact all VDCs within a province similarly.

[31]Note that data on MHP and the instrumental variable are at VDC level. We match the individual-level census data with the VDC-level data based on the VDC where each individual is located. We then estimate all the regression models at the individual level so that we can control for individual characteristics. We find very similar coefficient estimates when excluding all the individual-level controls, as shown in Table A25 and A26.

7 Results

In this section, we present results from our first stage regressions and evidence in support of the instrument's validity. Second-stage results estimating the impacts of microhydro mini-grids are then followed by a series of robustness checks.

7.1 First-Stage Results

First-stage regression results are presented in Table 2. We show the first-stage results for each of the samples used in our main analyses: the CME panel (column 1), the census microdata sample of males (column 2), and the census microdata sample of females (column 3). Given the observations in these datasets are at different levels (municipalities versus individuals), the fixed effects and clustering of standard errors differ between column 1 and columns 2 and 3. Results in all columns indicate that the instrument performs well in predicting the cumulative number of microhydro plants in a municipality (CME sample) or VDC (census samples) in a given year. The point estimates are all statistically significant at the 1 percent level and show a strong correlation between funding directed towards microhydro and microhydro plant construction. F-statistics on the first-stage regressions fall between 48.39 and 57.65.

7.2 Validity of the Instrument

Causal inference using the instrumental variable above relies on the assumption that, conditional on controls, the interaction between the proxy measure for Nepal's nationwide budget for microhydro construction and whether a location is geophysically appropriate for a microhydro plant only affects manufacturing establishments and labor through the construction of a microhydro plant. The main concern with this assumption is that this interaction may affect manufacturing and labor through alternative channels such as increases in infrastructure (i.e., roads), facilities (i.e., schools or health centers), or migration into the location. We present both qualitative and quantitative evidence on all three of these potential channels, as well as report on a broader test, to build confidence in the instrument's validity.

First, Nepal is a country experiencing tremendous migration, particularly from rural areas. It would would be problematic if the interaction instrument predicted increases in migration to these locations, as an increase in manufacturing establishments could occur through an increase in population rather than through microhydro. We do not believe this is occurring, as most of the country's migration is rural to urban, with migrants moving either to Kathmandu, the capital city, or abroad for work. Nevertheless, we can check whether the instrument, Carpet $\times$ N_t, predicts changes in population using VDC-level census data. Our results show that the instrument does not predict changes in population size overall, or male and female population sizes separately (Appendix Table A6, col 1-3).

Second, it would be problematic if the interaction instrument predicted increases in facilities such as schools or health facility construction, which could occur, for example, if bilateral and multilateral funding organizations were targeting school construction to these locations receiving microhydro investments. Again, we do not believe this to be the case; unlike the construction of larger dams in Nepal, which independent power producers are investing in, these smaller-scale microhydro systems do not come with social safe-guards or investments in local facilities. To check this assertion, we test the correlation between the instrument and indicators of facilities using the NLSS data. We find the instrument does not predict changes in the number of schools, the number of students, or the distance to the nearest health facility; if anything, the instruments predicts a small magnitude and marginally significant decrease in the number of health facilities in these locations (Appendix Table A6, col 4-7).

Third, it would violate the exclusion restriction if the instrument predicted construction of roads in these municipalities. This is the concern raised by Lee et al. (2020a) and others regarding the validity of geographic cost-based instruments, which use characteristics that reduce the cost of electrification, but also potentially reduce the cost of other investments, particularly roads. Notably, our instrument is not cost-based. In fact, the geophysical characteristics that make a location appropriate for a microhydro plant – rivers and steep gradient – are associated with higher construction costs for road infrastructure in Nepal (Shrestha, 2020) and decrease the likelihood that roads will change in these municipalities during our study period. Despite countless efforts, we have not been able to acquire data on changes in roads over time during our study period, so we cannot conduct tests analogous to those reported above for schools, health facilities, and population. Nevertheless, to support our claim that these characteristics did not affect development in other ways that could change over time, we show results are robust to including the interaction of average elevation and slope within a municipality with year fixed effects.

As further support for the validity of the instrument, we conduct Monte Carlo simulations proposed by Christian and Barrett (2017), employ the arbitrary clustering method proposed by Colella et al. (2019), replicate the analyses using an alternative set of instrumental variables, as well as perform additional robustness checks. Results of these tests are presented in the Appendix (Section A5).

Lastly, for the IV approach to be valid, locations that are identified by the GIS carpet study (i.e., carpet=1) and those that are not (i.e., carpet=0) should have parallel trends in the absence of investment on microhydro plants. Due to data limitations, we are not able to directly investigate the trends of the main outcomes for these two groups of regions.[32] To provide support of this assumption, we conduct placebo tests to ensure that our instrument does not predict the main outcomes in the untreated (non-electrified) regions. These placebo tests indicate that there is no correlation between the instrumental variable and the three main sets of outcome variables: the number of manufacturing establishments (Appendix Table A3), employment status (Appendix Table A4), and type of usual employment activities (Appendix Table A5).

[32] We only have two years of data on individual employment status and three years of data on manufacturing establishments.

7.3 Second-Stage Results

We employ the predicted cumulative number of microhydro plants from the first-stage regressions in the second stage to estimate the impacts on enterprises and labor outcomes.

7.3.1 Impacts on Manufacturing Establishments

Table 3 presents the impacts of microhydro plant construction on the number of manufacturing establishments (employing 10 or more people) within the municipality. The dependent variable is the inverse hyperbolic sine of the number of manufacturing establishments. The independent variables is the cumulative number of microhydro plants (MHPs) in the municipality in that year. Therefore, the coefficients are the percent increase in manufacturing establishments from one additional microhydro plant constructed within a municipality.

We find that microhydro construction within a municipality leads to a small and statistically significant increase in manufacturing establishments. Results in column 1 show a 42.7 percent increase in manufacturing establishments on average resulting from one additional microhydro plant constructed within the municipality. Column 2, our preferred specification, replaces year fixed effects with province-year fixed effects to allow changes over to time to differ by provinces. The coefficient indicates a 32.8 percent increase in manufacturing establishments on average resulting from one additional microhydro plant constructed within the municipality. Column 3 provides an additional check, adding municipality-year controls, which account for the fact that location characteristics could not only affect microhydro plant placement, but also other development in ways that could change over time. Results show that the coefficient is quite stable and the results are robust to their inclusion.

Given the low baseline mean of 0.216 manufacturing establishments per municipality, an increase of 32.8% means that there are 0.287 enterprises per municipality on average following the construction of one additional microhydro plant. In other words, less than one-third of municipalities, on average, had such a manufacturing establishment after the microhydro construction. Given the census of manufacturing establishment only includes enterprises with 10 or more employees; there could be increases in smaller manufacturing establishments that are not captured here.

Given the spatial boundaries change over the time period covered by this dataset, as detailed in Data Appendix A3.2, we present results employing alternative approaches to addressing the boundary changes and show that results are robust to these alternative methods (Appendix Table A2, columns 1 and 2).

7.3.2 Impacts on Labor Outcomes

Using the census microdata, we estimate the impacts of a microhydro plant constructed within a VDC on two labor outcomes: employment status and work activities. Results are presented separately for the male (Panel A) and female (Panel B) census samples.

Table 4 presents results of second stage regressions in which the dependent variable is the reported employment status in the past 12 months. The outcome variables are binary indicators equaling 1 if the employment status falls into that category (employer, employee, own account/self-employed, or other) and zero otherwise. Among the males, there is no significant impact on the probability of being an employer (column 1). There is a 9.5 percentage point increase the probability that a male works as an employee (column 2), up from a baseline of 9.8 percent. This increase in working as an employee comes with a decrease in self-employment ("own account" work) of 8 percentage points (column 3). Both of these are statistically significant at the 1% level. There is also no statistically significant decrease effect in the probability of males being employed in "other" work (column 4), which includes household family work.

The estimated impacts of microhydro construction on female employment status are similar to those of males. Females have a small (1.0 percentage point) and marginally significant decrease in the probability of being an employer. The estimated impacts on probability of being an employee (increase of 2.8 percentage points) or self-employed (decrease of 6 percentage points) are statistically significant and qualitatively similar to the effects among males, albeit of smaller magnitudes. There are no statistically significant effects on ”other” employment, which includes unpaid family work (column 4).

Table 5 reports the second stage results with usual work activities as the dependent variable. Both males and females have reductions in the probability of working in own agriculture (column 1) and increases in the probability of work activities that are for salary and wages (column 2) that are both statistically significant and economically meaningful. Only among males is there a marginally statistically significant and small in magnitude, increase in work activity for one's own non-agricultural enterprise (column 3). There are some shifts in activities related to home production among males and females: males reduce their probability of extended economic work (collecting fuel and water, preparing goods for consumption at home) (column 4) and females increase the probability of household chore work (cooking, cleaning, child care, etc.) (column 5). Notably, both males and females experience statistically significant increases in probability of studying that are of comparable magnitudes (column 6). Given we saw no evidence of impacts on the number of schools or total students, we interpret this last result to mean that children are shifting their time from agriculture to additional studies.

We show results are robust to multiple additional tests, such as employing arbitrary clustering methods, dropping certain locations and using alternative identification methods. These can be found in the Appendix.

7.4 An Economic Value of the Impacts of Microhydro Plants

We provide additional evidence that the microhydro plants had an economic impact on these communities. First, we provide suggestive evidence that the additional microhydro plants brought increased employment and employee financial benefits along with the increase in the overall number of manufacturing establishments. Second, we present evidence that microhydro also increased household non-agricultural enterprises, indicating that smaller, informal businesses also benefited from electrification.

7.4.1 Manufacturing Establishments

We use cross-sectional survey data from the 2011 Census of Manufacturing Establishments in IV regressions, similar to those in Equations 2 and 3. In the cross-section, we omit province-year fixed effects and location-specific fixed effects. In their absence, we include controls for VDC characteristics and we define the "MHP number" as the cumulative number of microhydro plants in a VDC by the end of 2011.

Results from these regressions are in Table 6. The first-stage results in column 1 indicate a strong first-stage, with an F-stat of 33.03. Second-stage results, in the remaining columns, indicate that an additional microhydro plant constructed within a VDC by 2011 is associated with an additional 45 employees (column 2) and 3,550 thousand Nepali rupees in total annual benefits per VDC (column 3).[33] Based on the average 2011 exchange rate, these benefits equal 2,664 USD per month per VDC.[34]

We interpret these cross-sectional results with caution, but note their consistency with our main findings. The greater number of employees working for these enterprises per VDC is consistent with both the growth in the number of enterprises (Table 3) and the increase in the probability of working as an employee (Table 4) and for salary and wages (Table 5). The greater total benefits (in column 3 of Table 6) provides us with some indication that these shifts in labor, translate into additional monetary benefits for individuals in these communities.

[33] Analysis is at the Village Development Committee (VDC) level, as the government change in boundaries had not yet occurred at the time of the 2011 survey.

[34] The average exchange rate in 2011 was 1 Nepali Rupee to 0.0135 USD.

7.4.2 Household Non-Agricultural Enterprises

The magnitude of the labor shifts presented in Tables 4 and 5 may seem large, given the relatively modest increases found in manufacturing establishments. The manufacturing establishments in the census data, however, capture only formal manufacturing establishments of 10 or more employees. Yet some of the labor changes captured in the census microdata are likely due to changes in the smaller and informal enterprises.

To better understand the relationship between microhydro and small, non-agricultural household enterprises, we employ household data from the Nepal Living Standards Survey (NLSS). Using the NLSS in an unbalanced, stacked panel, we estimate 2SLS regressions with our instrumental variable with measures of non-agricultural household enterprises as our second-stage outcome variable.

Table 7 presents these results. The first-stage results (Column 1) show a strong first-stage. Columns 2 - 6 present results for non-agricultural household enterprise outcomes (inverse hyperbolic sine). We find that with a plant constructed, the number of household non-agricultural enterprises increases by 15.7 percent (column 2); however, there is no significant increase in formal enterprises (column 3). This indicates that the growth in household non-agricultural enterprises occurs among the informal enterprises. There is a 21.8 percent increase in the number of employees (column 4). Reported revenues of the household non-agricultural enterprises, both in the gross revenues (column 5) and net revenues (column 6), also increase. This growth in revenues could be coming as the result of increased productivity among existing household enterprises, not just in new enterprises. There is no significant impact on the farm net revenue (column 7).

8 Heterogeneous Impacts of Microhydro

As described in Section 3, locations were targeted for microhydro according to two main characteristics: whether their geo-physical properties made them appropriate for microhydro plant construction and if there were no plans to extend the national electricity grid to that location in the near future. The actual siting and construction of microhydro plants resulted in two important types of heterogeneity across plants: the distance of the site to major population centers (Figure A5) and the generation capacity of those plants, which are by definition up to 100 kW.

These characteristics could play a role in the extent to which microhydro mini-grids affect manufacturing and employment outcomes. For example, the effects on manufacturing may vary depending on proximity to population centers (in our study, we have a measure of major population centers of 25,000 people or more), as such centers may provide access to markets for things such as the supply of inputs in manufacturing process or demand for the outputs produced. Furthermore, generation capacity and the extent to which manufacturers can power production may also play an important role. Greater generation capacity in a community can mean power beyond minimum residential needs. As a result, the variation in these characteristics across sites provides a unique opportunity to test for heterogeneities in the impacts of microhydro – and electrification more broadly. We investigate these two types of heterogeneity in the subsections that follow.

8.1 Heterogeneity by Proximity to Population Centers

Microhydro plant constructed range in their distance to larger population centers of 25,000 people or more. The median distance of VDCs in which MHPs were constructed is just under 50 km; with the distances ranging from just a few km to more than 120 km (Figure A5). We use this 50 km distance to test the extent to which the effects of microhydro mini-grids differ in more (greater than 50 km from a population center) and less remote (less than 50 km from a population center) locations.

Panel A of Table 8 shows the effects of microhydro on manufacturing establishments for those municipalities with with average VDC distances that are above and below 50 km from a population center. In column 1, we can see that MHPs in both distance bins have statistically significant effects on manufacturing establishments. The coefficient of the close bin is roughly twice the magnitude of the more remote bin indicating potentially larger effects; however the differences between these two coefficients is not statistically significant, so we cannot reject the null hypothesis that the effects of microhydro in the two distance bins are the same.

We conduct similar analyses for the outcomes related to employment status and usual activities using the census microdata, with the notable difference that data are at the VDC level (and therefore we can estimate the heterogeneous impacts of MHPs as whether the distance of individual VDCs are below or above 50 km from a population center of 25,000 people or more). Results for employment status and usual activities are in Tables 9 and 10, respectively. In both tables, Panels A show results for males in all VDCs, whereas Panels B present results for females in all VDCs. The results of these heterogeneity analyses all show a similar pattern: the magnitude of the microhydro coefficients are notably larger in the closer distance bin (below 50 km) than the farther one (above 50 km), but the coefficients for the two bins are not statistically significantly different from one another.

8.2 Heterogeneity by Generation Capacity

Panel B of Table 8 shows the effects of microhydro on manufacturing establishments for those municipalities with average VDC MHP capacity that is above or below median. In column 2, we can see that MHPs in both groups have statistically significant effects on manufacturing establishments. The coefficient of the above median capacity group is roughly 1.5 times the magnitude of the below median capacity group indicating potentially larger effects; however, the differences between these two coefficients is not statistically significant.

As with the heterogeneity by distance analyses, we conduct similar analyses for microhydro generation capacity and outcomes related to employment status and usual activities. Tables 11 and 12, respectively, present those results for males in all VDCs (Panel

A) and females in all VDCs (Panel B). Interestingly, we see a different pattern – from the heterogeneity by distance results – emerge. In both tables, the coefficients for the VDCs with above median generation capacity are larger in magnitude than those for the below median capacity VDCs and in many columns – although not all – these differences are statistically significantly different from each other.

9 Conclusions

The results presented here provide several important contributions to our understanding of the economic impacts of electrification. First, it provides insights as to whether rural electrification, and decentralized renewable energy more specifically, can lead to structural transformation via changes in manufacturing and employment, shifting labor from the traditional sector to the modern. Electrification via microhydro mini-grids increased formal (i.e., government registered) manufacturing establishments. Even with the significant increase, the overall numbers remained relatively small. Informal enterprises also increased, likely also contributing to the shifts in labor. Individuals are more likely to be employees and less likely to be self-employed. Consistent with these findings, there is a shift from own agricultural work to salary and wage employment.

The shift away from agricultural work activities observed in Nepal differs from findings in historical studies of the United States. Loans provided by the Rural Electrification Administration starting in the 1930s, positively impacted agricultural employment, rural property values, and crop output as well as productivity, but had little non-agricultural economic impact (Kitchens and Fishback, 2015; Lewis and Severnini, 2020). Those loans, however, targeted rural farm cooperatives, which contrasts from the microhydro program in Nepal and provides a likely reason for differences in findings.

Second, we provide evidence that the generation capacity matters for electrification impacts. Many of the impacts of microhydro on labor-related outcomes – particularly the numbers of people working as employees and in salary and wage employment versus agricultural work – are significantly smaller in locations with below median generation capacity. There is some suggestive evidence that the proximity to population centers also plays a role in the impacts as well.

Taken together, these results suggest that decentralized renewables such as microhydro need not necessarily be constrained by the technology; however, the smaller capacity systems and the location in which these systems are often constructed – remote and distant from markets – may limit the opportunity for manufacturing development.

References

Abeberese, Ama Baafra, "Electricity Cost and Firm Performance: Evidence from India," *The Review of Economics and Statistics*, December 2017, *99* (5), 839–852.

_ , "The Effect of Electricity Shortages on Firm Investment: Evidence from Ghana," *Journal of African Economies*, April 2019.

_ , Charles Godfred Ackah, and Patrick Opoku Asuming, "Productivity Losses and Firm Responses to Electricity Shortages: Evidence from Ghana," *The World Bank Economic Review*, February 2021, *35* (1), 1–18.

Adao, Rodrigo, Michal Kolesár, and Eduardo Morales, "Shift-share designs: Theory and inference," *The Quarterly Journal of Economics*, 2019, *134* (4), 1949–2010.

Aklin, Michaël, Patrick Bayer, S. P. Harish, and Johannes Urpelainen, "Does Basic Energy Access Generate Socioeconomic Benefits? A Field Experiment with Off-Grid Solar Power in India," *Science Advances*, May 2017, *3* (5), e1602153.

Alam, Muneeza M., "Coping with Blackouts: Power Outages and Firm Choices," *Mimeo*, 2013.

Allcott, Hunt, Allan Collard-Wexler, and Stephen D. O'Connell, "How Do Electricity Shortages Affect Industry? Evidence from India," *American Economic Review*, March 2016, *106* (3), 587–624.

Alternative Energy Promotion Center, "Micro Hydro Implementation Guidelines," Technical Report 2009.

Alternative Energy Promotion Centre, "Mini Grid Outlook (1999-2012)," 2012.

Barron, Manuel and Maximo Torero, "Household Electrification and Indoor Air Pollution," *Journal of Environmental Economics and Management*, November 2017, *86*, 81–92.

Bayer, Patrick, Ryan Kennedy, Joonseok Yang, and Johannes Urpelainen, "The need for impact evaluation in electricity access research," *Energy Policy*, February 2020, *137*, 111099.

Bellemare, Marc F. and Casey J. Wichman, "Elasticities and the Inverse Hyperbolic Sine Transformation," *Oxford Bulletin of Economics and Statistics*, February 2020, *82* (1), 50–61.

Bhattacharyya, Subhes C. and Debajit Palit, eds, *Mini-Grids for Rural Electrification of Developing Countries*, Switzerland: Springer International Publishing, 2014.

Burgess, Robin, Michael Greenstone, Nicholas Ryan, and Anant Sudarshan, "Demand for Electricity on the Global Electrification Frontier," *Warwick Economics Research Papers*, 2023, *No: 1445.*

Burlig, Fiona and Louis Preonas, “Out of the Darkness and Into the Light? Development Effects of Rural Electrification in India,” *Energy Institute at Haas Working Paper*, May 2021, *WP 268R.*

Central Bureau of Statistics, *Development of Manufacturing Industries in Nepal: Current State and Future Challenges*, Kathmandu, Nepal: Central Bureau of Statistics, National Planning Commission Secretariat, Government of Nepal, 2014.

Chakravorty, Ujjayant and Martino Pelli, “Electrification and development: Empirical evidence on the effect of electricity provision on household welfare,” Technical Report, CIRANO 2022. https://www.cirano.qc.ca/fr/sommaires/2022s-05.

Chaurey, Ritam and Duong Trung Le, “Infrastructure maintenance and rural economic activity: Evidence from India,” *Journal of Public Economics*, October 2022, *214*, 104725.

Chen, Jiafeng and Jonathan Roth, “Logs with Zeros? Some Problems and Solutions,” *The Quarterly Journal of Economics*, 12 2023, p. qjad054.

Christian, Paul and Christopher B Barrett, “Revisiting the Effect of Food Aid on Conflict: A Methodological Caution,” *World Bank Policy Research Working Paper*, 2017.

Cole, Matthew A., Robert J.R. Elliott, Giovanni Occhiali, and Eric Strobl, “Power Outages and Firm Performance in Sub-Saharan Africa,” *Journal of Development Economics*, September 2018, *134*, 150–159.

Colella, Fabrizio, Rafael Lalive, Seyhun Orcan Sakalli, and Mathias Thoenig, “Inference with arbitrary clustering,” 2019.

Dechezleprêtre, A., M. Glachant, and Y. Ménière, “The Clean Development Mechanism and the international diffusion of technologies: an empirical study,” *Energy Policy*, 2008, *36*, 1273–83.

Dinkelman, Taryn, “The Effects of Rural Electrification on Employment: New Evidence from South Africa,” *The American Economic Review*, 2011, *101* (7), 3078–3108.

Duflo, Esther and Rohini Pande, “Dams,” *The Quarterly Journal of Economics*, 2007, *122* (2), 601–646.

ESMAP, *Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers*, Energy Sector Management Assistance Program Technical Report 014/19, World Bank, June 2019.

Fetter, T. Robert and Faraz Usmani, “Fracking, farmers, and rural electrification in India,” *Journal of Development Economics*, September 2024, *170*, 103308.

Fisher-Vanden, Karen, Erin T. Mansur, and Qiong (Juliana) Wang, “Electricity Shortages and Firm Productivity: Evidence from China’s Industrial Firms,” *Journal of Development Economics*, May 2015, *114*, 172–188.

Fowlie, Meredith and Robyn Meeks, "The Economics of Energy Efficiency in Developing Countries," *Review of Environmental Economics and Policy*, June 2021, *15* (2), 238–260.

Fried, Stephie and David Lagakos, "Electricity and Firm Productivity: A General-Equilibrium Approach," *American Economic Journal: Macroeconomics*, October 2023, *15* (4), 67–103.

Gallea, Quentin, "Weapons and war: The effect of arms transfers on internal conflict," *Journal of Development Economics*, 2023, *160*, 103001.

Gonzales, Luis E., Koichiro Ito, and Mar Reguant, "The Investment Effects of Market Integration: Evidence From Renewable Energy Expansion in Chile," *ECTA*, 2023, *91* (5), 1659–1693.

Grogan, Louise and Asha Sadanand, "Rural Electrification and Employment in Poor Countries: Evidence from Nicaragua," *World Development*, March 2013, *43*, 252–265.

Harvey, Adam, *Microhydro Design Manual: A Guide to Small-scale Power Schemes*, London, UK: Intermediate Technology Publications, 1993.

International Energy Agency, *World Energy Outlook 2010*, Paris, France: International Energy Agency, 2010.

Jiménez, Raúl, "Development Effects of Rural Electrification," Technical Report, Inter-American Development Bank January 2017. https://publications.iadb.org/handle/11319/8157.

Kassem, Dana, "Does electrification cause industrial development? Grid expansion and firm turnover in Indonesia," *Journal of Development Economics*, March 2024, *167*, 103234.

Khandker, Shahidur R., Douglas F. Barnes, and Hussain A. Samad, "Welfare Impacts of Rural Electrification: A Panel Data Analysis from Vietnam," *Economic Development and Cultural Change*, April 2013, *61* (3), 659–692.

Kitchens, Carl and Price Fishback, "Flip the Switch: The Impact of the Rural Electrification Administration 1935-1940," *Journal of Economic History*, 2015, *75* (4), 1161–1195.

Kumas, Priti, Tomoyuk Yamashita, Ajoy Karki, SC Rajshekar, Ashisha Shrestha, and Abhishek Yadav, "Nepal – Scaling Up Electricity Access through Mini and Micro Hydropower Applications: A Strategic Stock-taking and Developing a Future Roadmap," *World Bank Group Technical Report*, 2015.

Lee, David S, Justin McCrary, Marcelo J Moreira, and Jack Porter, "Valid t-ratio Inference for IV," *American Economic Review*, 2022, *112* (10), 3260–90.

Lee, Kenneth, Edward Miguel, and Catherine Wolfram, "Does Household Electrification Supercharge Economic Development?," *Journal of Economic Perspectives*, February 2020, *34* (1), 122–144.

—, —, and —, "Experimental Evidence on the Economics of Rural Electrification," *Journal of Political Economy*, April 2020, *128* (4), 1523–1565.

Lewis, Joshua and Edson Severnini, "Short- and Long-Run Impacts of Rural Electrification: Evidence from the Historical Rollout of the U.S. Power Grid," *Journal of Development Economics*, March 2020, *143.*

Lipscomb, Molly, A. Mushfiq Mobarak, and Tania Barham, "Development Effects of Electrification: Evidence from the Topographic Placement of Hydropower Plants in Brazil," *American Economic Journal: Applied Economics*, January 2013, *5* (2), 200–231.

Mahadevan, Meera, "You Get What You Pay For: Electricity Quality and Firm Dynamics," *Working Paper*, 2021, p. 31.

Mainali, Brijesh and Semida Silveira, "Financing Off-Grid Rural Electrification: Country Case Nepal," *Energy*, April 2011, *36* (4), 2194–2201.

Meeks, Robyn, Katharine R. E. Sims, and Hope Thompson, "Waste Not: Can Household Biogas Deliver Sustainable Development?," *Environmental and Resource Economics*, March 2019, *72* (3), 763–794.

Midrigan, Virgiliu and Daniel Yi Xu, "Finance and Misallocation: Evidence from Plant-Level Data," *American Economic Review*, February 2014, *104* (2), 422–458.

Moore, Nichols, Douglas Glandon, Janice Tripney, Tomasz Kozakiewicz, Shannon Shisler, John Eyres, Rami Zalfou, Maria Daniela Anda Leon, Varant Kurkjian, Birte Snilstveit, and Ari Perdana, "Effects of Access to Electricity Interventions on Socioeconomic Outcomes in Low- and Middle- Income Countries," *3ie Systematic Review*, August 2020. https://www.3ieimpact.org/sites/default/files/2020-11/SR45-ADB-electricity-interventions.pdf.

Mori-Clement, Yadira, "Impacts of CDM Projects on Sustainable Development: Improving Living Standards Across Brazilian Municipalities?," *World Development*, 2019, *113*, 222–236.

Mullahy, John and Edward C Norton, "Why transform Y? A critical assessment of dependent-variable transformations in regression models for skewed and sometimes-zero outcomes," Technical Report, National Bureau of Economic Research 2022.

Müller, Marc F., Sally E. Thompson, and Maggi N. Kelly, "Bridging the information gap: A webGIS tool for rural electrification in data-scarce regions," *Applied Energy*, June 2016, *171*, 277–286.

Nepal Central Bureau of Statistics, "National Census of Manufacturing Establishments 2011-2012," June 2014.

—, "National Economic Census 2018," July 2019.

Nepal Electricity Authority, "Nepal Electricity Authority Annual Report 2017-2018," Technical Report 2018.

Peters, Jörg, Colin Vance, and Marek Harsdorff, "Grid Extension in Rural Benin: Micro-Manufacturers and the Electrification Trap," *World Development*, May 2011, *39* (5), 773–783.

Popp, David and Tian Tang, "The Learning Process and Technological Change in Wind Power: Evidence from China's CDM Wind Projects," *Journal of Policy Analysis and Management*, 2016, *35* (1), 195–222.

Rud, Juan Pablo, "Electricity Provision and Industrial Development: Evidence from India," *Journal of Development Economics*, March 2012, *97* (2), 352–367.

Severnini, Edson, "The Power of Hydroelectric Dams: Historical Evidence from the United States over the Twentieth Century," *The Economic Journal*, December 2022, *133* (649), 420–459.

Shrestha, Slesh A., "Roads, Participation in Markets, and Benefits to Agricultural Households: Evidence from the Topography-Based Highway Network in Nepal," *Economic Development and Cultural Change*, April 2020, *68* (3), 839–864.

Sutter, C. and J.C. Parreno, "Does the Current Clean Development Mechanism deliver its sustainable development claim? An analysis of officially registered CDM projects.," *Climatic Change*, 2007, *84*, 75–90.

Tybout, James R., "Manufacturing Firms in Developing Countries: How Well Do They Do, and Why?," *Journal of Economic Literatureme*, 2000, *38*, 11–44.

United Nations Development Programme, "Towards an 'Energy Plus' Approach for the Poor: A Review of Good Practices and Lessons Learned from Asian and the Pacific," Technical Report 2011.

United Nations Framework Convention on Climate Change, "Achievements of the Clean Development Mechanism: Harnessing Incentive for Climate Action," Technical Report 2018.

_ , "Clean Development Mechanism: CDM Development Benefits," 2024. https://cdm.unfccc.int/about/ccb/index.html.

World Bank, "Reliable and Affordable Off-grid Electricity Services for the Poor: Lessons from the World Bank Group Experience," Technical Report 2016.

_ , "World Development Indicators," 2020.

Zhang, Junjie and Can Wang, "Co-benefits and additionality of the clean development mechanism: An empirical analysis," *Journal of Environmental Economics and Management*, 2011, *62* (2), 140–154.

Figures and Tables

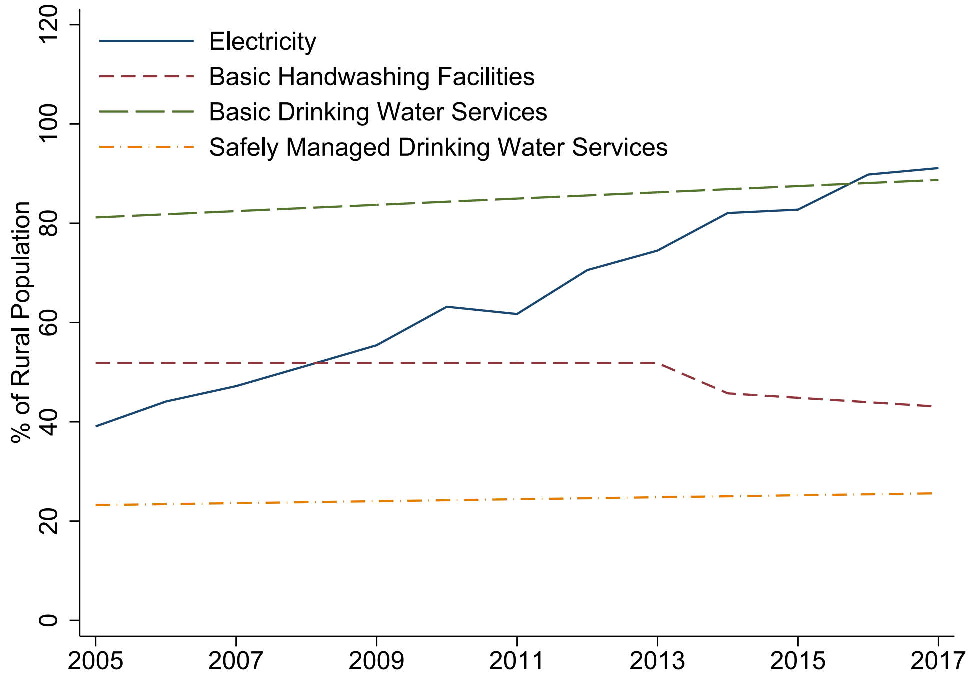

Figure 1: Rural Access to Electricity, Drinking Water, and Hand-washing Facilities in Nepal, 2005 to 2017

Notes: Figure created using data from the World Development Indicators (World Bank, 2020).

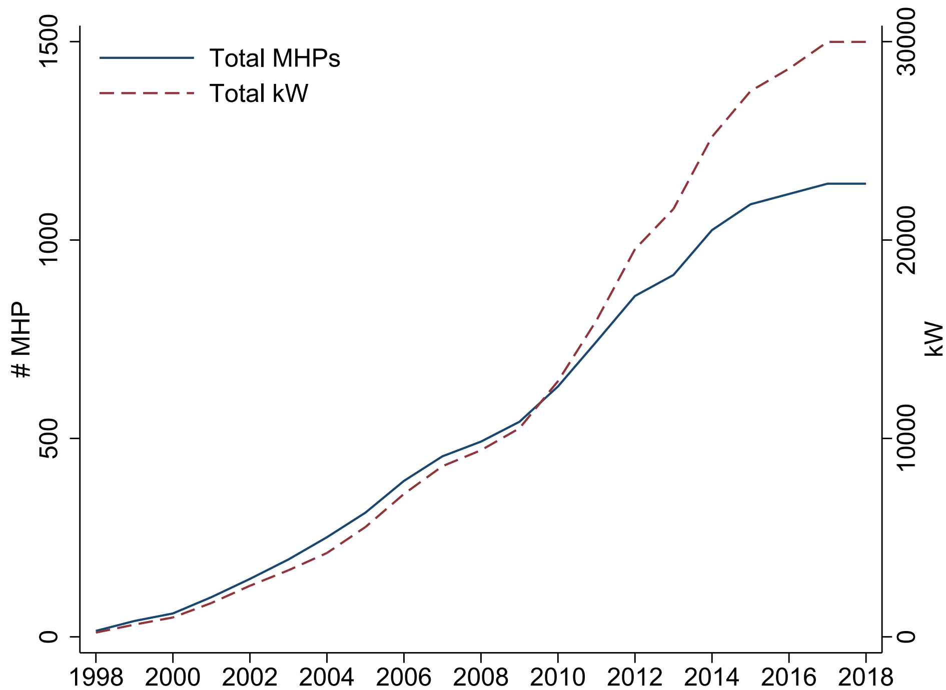

Figure 2: Microhydro Installed Capacity in Nepal Over Time

Notes: Figure created using data on microhydro plant construction over time from AEPC. The vertical access on the left depicts the number of microhydro plants constructed. The vertical access on the right shows the total installed capacity (kW) of those microhydro plants.

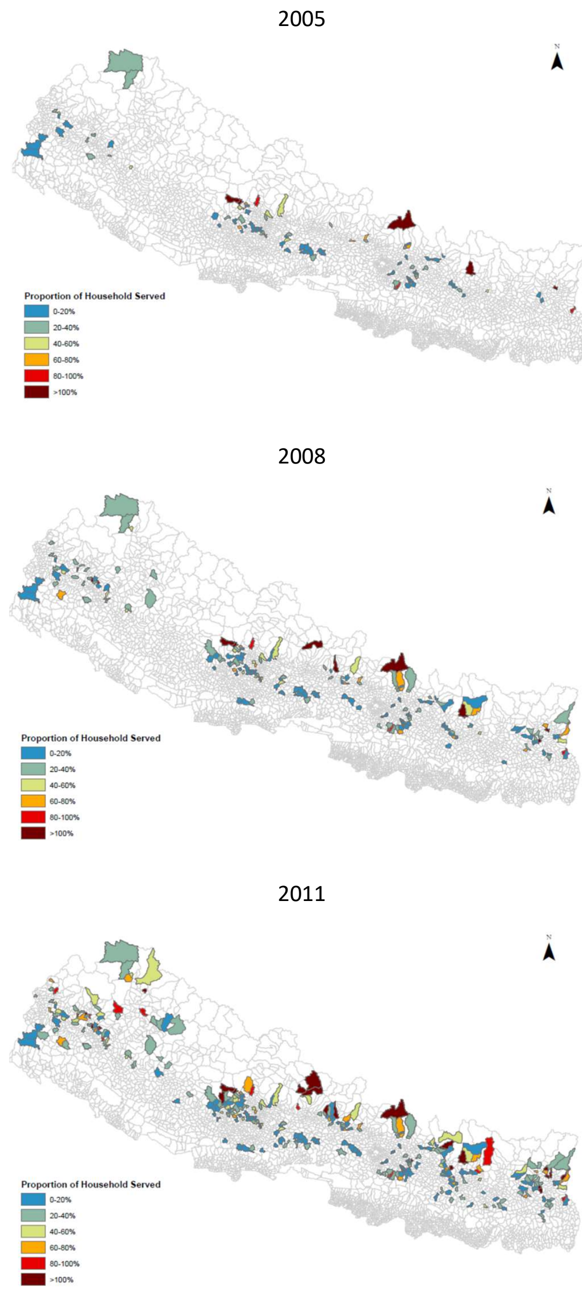

Figure 3: Microhydro Projects Completed Over Time (2005, 2008, 2011)

Notes: Map was created using data on microhydro plant construction from AEPC, the Transverse Mercator projection, and the Nepal Nagarkot TM Coordinate System. Color coding indicates the proportion of a VDC's population served by a microhydro plant.

Table 1: Correlates of GIS Carpet Study Identification of Geo-physically Appropriate Locations for Microhydro Plant Construction

	Carpet Study Identified
VDC Characteristics	
Hill or mountain regions	0.169***
	(0.019)
River slope bin [3, 20]	-0.020
	(0.015)
River slope bin [20, 30]	0.095***
	(0.022)
River slope bin [30, 50]	0.207***
	(0.033)
River Length (km)	-0.000
	(0.000)
Log distance to the nearest city (km)	0.037***
	(0.010)
Log distance to the nearest road (km)	0.072***
	(0.008)
Log distance to electric grid (km)	0.003***
	(0.001)
Population density	-0.002
	(0.004)
Household Characteristics	
Tap water access (2001)	-0.000
	(0.000)
Toilet access (2001)	-0.001***
	(0.000)
Electricity access (2001)	-0.000
	(0.000)
Home ownership (2001)	-0.031
	(0.094)
Households have television (2001)	0.001
	(0.001)
Constant	-0.185*
	(0.095)
Observations (VDCs)	3,852
R^2	0.284

Notes: The outcome variable is a binary variable equaling 1 if the VDC was identified as being geophysically appropriate for microhydro through the GIS carpet study and zero otherwise. ”Hill or mountain regions” is a binary indicator equaling 1 if the location is in the hill or mountains and 0 if located in the flat terai. The slope bins are binary indicators equaling 1 if the average river slope (in degree) within the VDC falls into one of the following categories: 3-20, 20-30, or greater than 30, and equaling 0 otherwise. The omitted group is between 0 and 3. Geographic data for distances are from ASTER Global DEM. Data on roads are from the Strategic Road Network. Data on household characteristics are from the 2001 census. Robust standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 2: First-Stage Instrumental Variable Regressions

	Cumulative Number of MHPs in a Municipality/VDC		
	(1) CME Sample	(2) Census Sample: Male	(3) Census Sample: Female
Carpet × N_t	0.225***	0.070***	0.071***
	(0.030)	(0.010)	(0.010)
Individual Controls		✓	✓
VDC FE		✓	✓
Municipality FE	✓		
Province-Year FE	✓	✓	✓
K-P F-Stats	57.65	50.34	48.39
Observations	2,241	2,371,140	2,531,500
Adjusted R^2	0.851	0.735	0.746
#Regions	747	3,974	3,974
Observation Level	Municipality	Household	Household

Notes: "Carpet×N_t" is the interaction between: an indicator of carpet identification at the municipality/VDC level and the cumulative number of microhydro plants in Nepal in a year. Individual controls include the individual's age and education, the household size (number of people) and caste, and house amenities (toilet and water access). Standard errors are clustered at the district level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 3: Impact on Manufacturing Establishments

	IHS(# Manufacturing Establishments)		
	(1)	(2)	(3)
MHP	0.427***	0.328***	0.330**
	(0.087)	(0.081)	(0.143)
Outcome Baseline Mean (Level)	0.216	0.216	0.216
K-P F-Stats	70.69	57.65	30.14
Observations	2,241	2,241	2,241
Municipality-Year Controls			✓
Municipality FE	✓	✓	✓
Year FE	✓		
Province-Year FE		✓	✓

Notes: These are second stage results. Observations are at the municipality level. MHP is the cumulative number of microhydro plants in a municipality from the first-stage regressions. The outcome variable is the inverse hyperbolic sine of the number of manufacturing establishments (employing 10 or more individuals) located within a municipality. Municipality-year controls include the time-invariant logarithm of average elevation and slope in a municipality, both interacted with year fixed effects. The baseline mean is the outcome variable raw mean (i.e., not the inverse hyperbolic sine) for those locations where microhydro plants are later constructed. Data sources are further described in Data Appendix A3. Standard errors are clustered at the district level and shown in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 4: Impact on Employment Status

	Reported employment status is:			
	Employer	Employee	Own Account Worker	Other
	(1)	(2)	(3)	(4)
A. Male				
MHP	-0.007	0.095***	-0.080***	-0.008
	(0.005)	(0.016)	(0.021)	(0.016)
Outcome Mean	0.018	0.219	0.365	0.395
K-P F-Stats	50.34	50.34	50.34	50.34
Observations	2,371,140	2,371,140	2,371,140	2,371,140
B. Female				
MHP	-0.010*	0.028***	-0.060**	0.042
	(0.006)	(0.006)	(0.029)	(0.027)
Outcome Mean	0.011	0.068	0.356	0.563
K-P F-Stats	48.39	48.39	48.39	48.39
Observations	2,531,500	2,531,500	2,531,500	2,531,500
#VDCs	3,974	3,974	3,974	3,974
Individual Controls	✓	✓	✓	✓
VDC FE	✓	✓	✓	✓
Province-Year FE	✓	✓	✓	✓

Notes: MHP is the cumulative number of microhydro plants in a VDC from the first-stage regressions. The outcome variables, which use microdata from the 2001 and 2011 iterations of the Nepal Population Census, are collected for household members 10 years of age and older. The outcome variables are responses to the individual's employment status. Additional variable descriptions provided in Data Appendix A4. Employment status can be as an employer, employee, own account work (i.e., self-employed), or other, which includes unpaid family work as well as those that do not report an employment status. The individual controls include the individual's age, the individual's education, the household size, and whether the household has a toilet. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table 5: Impact on Usual Activities

	Own Agriculture & Farming	Salary & Wage	Own Enterprise	Extended Economic	Household Work	Study
	(1)	(2)	(3)	(4)	(5)	(6)
A. Male						
MHP	-0.109***	0.072***	0.008*	-0.009*	0.002	0.020*
	(0.022)	(0.014)	(0.005)	(0.005)	(0.003)	(0.011)
Outcome Mean	0.296	0.211	0.084	0.011	0.017	0.298
K-P F-Stats	50.34	50.34	50.34	50.34	50.34	50.34
Observations	2,371,140	2,371,140	2,371,140	2,371,140	2,371,140	2,371,140
B. Female						
MHP	-0.088***	0.019***	-0.006	-0.015	0.037**	0.030***
	(0.030)	(0.005)	(0.004)	(0.016)	(0.017)	(0.011)
Outcome Mean	0.285	0.057	0.034	0.032	0.28	0.239
K-P F-Stats	48.39	48.39	48.39	48.39	48.39	48.39
Observations	2,531,500	2,531,500	2,531,500	2,531,500	2,531,500	2,531,500
#VDCs	3,974	3,974	3,974	3,974	3,974	3,974
Individual Controls	✓	✓	✓	✓	✓	✓
VDC FE	✓	✓	✓	✓	✓	✓
Province-Year FE	✓	✓	✓	✓	✓	✓

Notes: MHP is the cumulative number of microhydro plants in a VDC from the first-stage regressions. The outcome variables, which use microdata from the 2001 and 2011 iterations of the Nepal Population Census, are collected for household members 10 years of age and older. The outcome variables are the individual's usual work in the past 12 months. Categories of usual work activities include: agriculture, wage or salaried work, small business activities (owning one's own enterprise), extended economic work (collecting fuel and water, preparing goods for consumption at home), household chores (cooking, cleaning, child care, etc.), and studies. Additional variable descriptions provided in Data Appendix A4. The individual controls include the individual's age, the individual's education, the household size, and whether the household has a toilet. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table 6: IV Cross-sectional Results: Employment Numbers and Financial Benefits

	(1) MHP	(2) #Employees	(3) Total Annual Benefits (thousand Nepali rupees)
Carpet × N_t	0.041***		
	(0.007)		
MHP		45.334**	3,550.041**
		(17.942)	(1,734.082)
Outcome Mean (Level)		46.996	3,851.07
K-P F-Stats		33.03	33.03
Observations	3,942	3,942	3,942
VDC Controls	✓	✓	✓
District FE	✓	✓	✓
Regression	1st	2nd	2nd

Notes: These analyses use cross-sectional VDC-level data, collected via the Census of Manufacturing Establishments in 2011/2012. The variable MHP in these analyses is the cumulative number of microhydro plants in a VDC by the end of 2011 from the first-stage regressions. The "number of employees" is defined as the number of persons who work in or for the establishment and receive pay, in cash or in kind, at regular intervals. The "total benefits" is the sum of direct wages, salaries, and facilities, which includes both cash remuneration for work performed and time not worked due to holidays and for other reasons. The average exchange rate in 2011 was 1 Nepali Rupee to 0.0135 USD. Analysis is at the Village Development Committee (VDC) level, as the government change in boundaries had not yet occurred at the time of this CME iteration. VDC controls include the number of households as of 2001, the area of the VDC, if the VDC was already connected to the electrical grid as of 2001, the log elevation, distance to the grid in kilometers, the log distance to the nearest city, and the log distance to the nearest paved road. Standard errors in parentheses are clustered at the district level. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table 7: Impacts on Household Enterprises

		Non-Agricultural					
	MHP	Enterprises	Formal Enterprises	Enterprise Employees	Gross Revenue (NPR)	Net Revenue (NPR)	Farm Net Revenue (NPR)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Carpet × N_t	0.082***						
	(0.026)						
MHP		0.157**	0.016	0.218**	1.741**	1.724**	0.961
		(0.068)	(0.020)	(0.107)	(0.757)	(0.718)	(1.250)
Outcome Mean		0.360	0.083	1.208	183,782	99,273	37,178
K-P F-Stats		10.16	10.16	10.16	10.16	10.16	10.16
#VDCs	575	575	575	575	575	575	575
Observations	9,756	9,756	9,756	9,756	9,756	9,756	9,756
VDC Controls	✓	✓	✓	✓	✓	✓	✓
District FE	✓	✓	✓	✓	✓	✓	✓
Province-Year FE	✓	✓	✓	✓	✓	✓	✓

Notes: MHP is the cumulative number of microhydro plants in a VDC from the first-stage regressions. The outcome variables in columns 2 - 7 are transformed into the inverse hyperbolic sine. Outcome variables are collected through the Nepal Living Standards Survey (NLSS) in 2003 and 2010 in response to questions about non-agriculture enterprises. Formal enterprises are those enterprises that are registered with the government. Enterprise employees include non-farm employees, both household workers and hired workers. All revenues are in Nepali rupees (NPR). Village Development Committee (VDC) controls include the number of households, area, distance to the city, and distance to the road. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table 8: Heterogeneous Impacts on Manufacturing Establishments

Dep. Var.	IHS(# Manufacturing Establishments)	
	(1)	(2)
A. Distance to Population Center		
Below 50km	0.467***	
	(0.125)	
Above 50km	0.212***	
	(0.072)	
B. Average Capacity of MHP		
Above Median		0.595**
		(0.227)
Below Median		0.397***
		(0.101)
Outcome Baseline Mean	0.216	0.216
Observations	2,241	2,241

Notes: Each cell reports the 2SLS estimate of the coefficient for MHP, i.e., the cumulative number of microhydro projects. In Panel A, we estimate the heterogeneous impacts by distance to the nearest population center. We first calculate the distance between each VDC and the nearest population center (i.e., a VDC with at least 25 thousand population). Then for this municipality-level analysis, we take the average over the distances for all the VDCs in a municipality. In Panel B, we estimate the heterogeneous impacts by average capacity (in kW) of microhydro plants installed in the municipality. All regressions control for municipality and province-year fixed effects. Standard errors are clustered at the district level and shown in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 9: Heterogeneous Impacts by Market Access on Employment Status

	Reported employment status is:			
	Employer	Employee	Own Account Worker	Other
	(1)	(2)	(3)	(4)
A. Male				
Below 50km	-0.015**	0.110***	-0.097***	0.001
	(0.007)	(0.024)	(0.031)	(0.019)
Above 50km	0.002	0.077***	-0.061**	-0.019
	(0.006)	(0.018)	(0.023)	(0.021)
Observations	2,371,140	2,371,140	2,371,140	2,371,140
B. Female				
Below 50km	-0.013	0.030***	-0.064*	0.047
	(0.009)	(0.008)	(0.035)	(0.033)
Above 50km	-0.008	0.026***	-0.055*	0.037
	(0.006)	(0.006)	(0.032)	(0.032)
Observations	2,531,500	2,531,500	2,531,500	2,531,500

Notes: Each cell reports the 2SLS estimate of the coefficient for MHP, i.e., the cumulative number of microhydro projects. For each sample (i.e., male vs female), we estimate the heterogeneous impacts of MHP by the distance from a VDC to the nearest population center (i.e., a VDC with at least 25 thousand population). All regressions control for individual characteristics (age, education, household size, and whether the household has a toilet), VDC and province-year fixed effects. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table 10: Heterogeneous Impacts by Market Access on Usual Activities

VARIABLES	Agriculture	Salary & Wage	Own Enterprise	Extended Economic	Household Work	Study
	(1)	(2)	(3)	(4)	(5)	(6)
A. Male, All VDCs						
Below 50km	-0.128***	0.086***	0.006	-0.014**	0.004	0.039**
	(0.033)	(0.020)	(0.006)	(0.006)	(0.004)	(0.015)
Above 50km	-0.085***	0.056***	0.011	-0.003	0.000	-0.003
	(0.026)	(0.016)	(0.007)	(0.008)	(0.004)	(0.014)
Observations	2,371,140	2,371,140	2,371,140	2,371,140	2,371,140	2,371,140
B. Female						
Below 50km	-0.089**	0.018***	-0.009**	-0.035**	0.044*	0.052***
	(0.036)	(0.006)	(0.003)	(0.017)	(0.023)	(0.016)
Above 50km	-0.087**	0.019***	-0.002	0.009	0.028	0.004
	(0.038)	(0.005)	(0.005)	(0.024)	(0.020)	(0.012)
Observations	2,531,500	2,531,500	2,531,500	2,531,500	2,531,500	2,531,500

Notes: Each cell reports the 2SLS estimate of the coefficient for MHP, i.e., the cumulative number of microhydro projects. For each sample (i.e., male vs female), we estimate the heterogeneous impacts of MHP by the distance from a VDC to the nearest population center (i.e., a VDC with at least 25 thousand population). All regressions control for individual characteristics (age, education, household size, and whether the household has a toilet), VDC and province-year fixed effects. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table 11: Heterogeneous Impacts by MHP Capacity on Employment Status

	Reported employment status is:			
	Employer	Employee	Own Account Worker	Other
	(1)	(2)	(3)	(4)
A. Male				
Above Median	-0.018	0.425***	-0.436***	0.028
	(0.026)	(0.109)	(0.129)	(0.082)
Below Median	-0.009	0.107***	-0.090***	-0.008
	(0.005)	(0.019)	(0.026)	(0.019)
Observations	2,371,140	2,371,140	2,371,140	2,371,140
B. Female				
Above Median	-0.038	0.137***	-0.352**	0.253*
	(0.031)	(0.037)	(0.145)	(0.138)
Below Median	-0.012*	0.031***	-0.068**	0.049
	(0.007)	(0.007)	(0.034)	(0.032)
Observations	2,531,500	2,531,500	2,531,500	2,531,500

Notes: Each cell reports the 2SLS estimate of the coefficient for MHP, i.e., the cumulative number of microhydro projects. For each sample (i.e., male vs female), we estimate the heterogeneous impacts of MHP by whether the average installed capacity (in kW) is above or below the median of all microhydro projects. The median was 35 kW. All regressions control for individual characteristics (age, education, household size, and whether the household has a toilet), VDC and province-year fixed effects. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table 12: Heterogeneous Impacts by MHP Capacity on Usual Activities

VARIABLES	Agriculture	Salary & Wage	Own Enterprise	Extended Economic	Household Work	Study
	(1)	(2)	(3)	(4)	(5)	(6)
A. Male						
Above Median	-0.541***	0.324***	0.042*	-0.060*	0.011	0.109*
	(0.145)	(0.091)	(0.025)	(0.031)	(0.016)	(0.061)
Below Median	-0.121***	0.080***	0.009	-0.010*	0.003	0.023*
	(0.027)	(0.017)	(0.005)	(0.005)	(0.003)	(0.013)
Observations	2,371,140	2,371,140	2,371,140	2,371,140	2,371,140	2,371,140
B. Female						
Above Median	-0.451***	0.095***	-0.024	-0.071	0.157*	0.156**
	(0.160)	(0.027)	(0.020)	(0.092)	(0.086)	(0.068)
Below Median	-0.100***	0.020***	-0.007	-0.016	0.043**	0.036***
	(0.035)	(0.006)	(0.004)	(0.017)	(0.020)	(0.013)
Observations	2,531,500	2,531,500	2,531,500	2,531,500	2,531,500	2,531,500

Notes: Each cell reports the 2SLS estimate of the coefficient for MHP, i.e., the cumulative number of microhydro projects. For each sample (i.e., male vs female), we estimate the heterogeneous impacts of MHP by whether the average installed capacity (in kW) is above or below the median of all microhydro projects. The median was 35 kW. All regressions control for individual characteristics (age, education, household size, and whether the household has a toilet), VDC and province-year fixed effects. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

APPENDIX FOR ONLINE PUBLICATION:

Decentralized Renewable Energy to Grow Manufacturing?

Evidence from Microhydro Mini-grids in Nepal

DATA APPENDIX

A1 Data on Sources of Electrification

A1.1 Microhydro plant construction data

In 1996, the country's Alternative Energy Promotion Center (AEPC) was created within the Ministry of Science, Technology, and Environment to promote and coordinate donors' renewable energy investments. Various multilateral and bilateral donors and development organizations funded the construction of microhydro plants and mini-grids during the study period. These funding institutions include the United Nations Development Programme (UNDP), the World Bank, the Global Environment Fund (GEF), Practical Action, and the Governments of Denmark (Danida), Norway (Norad), and Germany (KfW). Over the years the funding for microhydro from these entities was delivered through a few programs and projects representing various coordinated efforts, such as the Energy Sector Assistance Programme Phases I and II (ESAP I and II), the Rural Energy Development Programme (REDP), Renewable Energy for Rural Livelihood (RERL), and National Rural and Renewable Energy Programme (NRREP).

AEPC collected data on the microhydro plants constructed over time. From AEPC, we received detailed lists of plant construction through 2018, including location, date, capacity, and number of households served. We combined several lists provided by AEPC to ultimately identify the locations of microhydro plants. These locations can be identified at the Village Development Committee level (VDC), which is akin to a collection of villages.

Assigning a microhydro plant to a VDC: The AEPC data provide information on the location at which the microhydro plant was constructed; however, the service areas of the microhydro mini-grids do not necessarily perfectly correspond with boundaries of the Village Development Committees (VDC) in which the plants are constructed. For example, there may be a place with river slope that is appropriate for a microhydro plant that is located between two population centers. The plant may be constructed between the two population centers. It is feasible that the construction is within one VDC but serving the population center located within a neighboring VDC.

To ensure that we are assigning the microhydro plant and its mini-grid to the correct VDC, we map in GIS both the AEPC construction data and the household census microdata on electrification status. Data on the baseline electrification status are available through the 2001 National Population Census. The census asked what the usual source of lighting was for each household.[35] We use these maps to determine which VDCs were likely electrified by a plant in a neighboring VDC based on the available microhydro capacity, the populations of both VDCs, and whether there was another likely source of electrification nearby. This allows us to confirm which VDCs are electrified via microhydro mini-grids. We exclude any VDC with an electrification rate of less than 5%, as the proportion electrified is low enough that we do not consider the community to be electrified.

Determining whether a plant is still operating: Microhydro first began to be constructed in the country during the 1960s, so some of the microhydro plant in the dataset quite old. Given the expected 20-year lifespan of the microhydro plants, we do not expect the oldest systems to still be functioning and do not include them in the dataset. We therefore consider those microhydro plants with capacity recently installed, in other words, those constructed after 1990 per the AEPC records, as those still being active and operating during our study period.

A1.2 Grid extension data

We obtained data from the NEA and the National Association for Community Electricity (NACEUN) on the locations electrified through grid extensions via the Community Rural Electrification Programme (CREP) and with an established Community Rural Electrification Entity (CREE) through 2015. These data, however, did not include the year of CREE establishment. Therefore, similar to the microhydro mini-grids, we use census microdata to confirm data of electrification. We assume that if the VDC electrification rate is below 30% in the 2011 census, the CREE had not yet been established. We define a VDC as CREE-electrified if any part of it contains a CREE that was established as of 2011. These are admittedly basic measures, but sufficient to allow us to control for the locations involved in the CREP and to drop them from the analyses in our robustness checks.

A2 GIS and Remotely-sensed Data

To better understand the GIS carpet study and the correlates of the GIS study microhydro identification, we calculate river slopes using several publicly-available geospatial data files. Geospatial data on river in Nepal come from OpenStreetMap, which are ESRI compatible shapefiles that include various water bodies (e.g. rivers). Data are available at: https://download.geofabrik.de/asia/nepal.html.

[35] Potential responses included: electricity, kerosene, biogas, solar, and other.

To compute VDC-level elevation and slope statistics, we use high-resolution topographic data for Nepal that are generated from NASA's Shuttle Radar Topography Mission (STRM). A description of these data is available here: https://www2.jpl.nasa.gov/srtm/. These data, which were released publicly in late 2015, provide "a 1 arc-second, or about 30 meters (98 feet), sampling." These data can be downloaded from the SRTM Tile grabber through the following website: https://dwtkns.com/srtm/.

Together, these datasets are used to compute river statistics at the VDC level. These statistics include river length, river elevation, and river slope (in degrees). We calculate the river length within a VDC, the fraction of VDC area with elevation/slope falling in four different categories, and river gradient by restricting attention to cells in a district through which a river flows. We use these to compute the fraction of river area falling into the four gradient categories. The end result are VDC-level calculations of average river slope (in degrees) within the following bins: 0-3, 3-20, 20-30, or greater than 30.

A3 Data on Manufacturing Establishments

To create a panel dataset of manufacturing establishments in Nepal over time, we had to address differences between the two main datasets and changes in the country's administrative boundaries over time. We document the process of addressing both issues in the subsections that follow.

A3.1 Addressing Differences Across Data Sources

The panel dataset of manufacturing establishments that we created uses data from the 2006/2007 and 2011/2012 iterations of the Nepal Census of Manufacturing Establishments (Nepal Central Bureau of Statistics, 2014) and the 2017/2018 National Economic Census (Nepal Central Bureau of Statistics, 2019).

The data sources have a couple of differences that must be addressed. We accommodate them as follows. First, whereas the Census of Manufacturing Establishments collected data only on manufacturing, the National Economic Census collected data for other industries as well. We limit the 2017/2018 data to the subset covering manufacturing establishments, such that it is comparable to the counts in the 2006/2007 and 2011/2012 rounds. Second, the Census of Manufacturing Establishments collected data only for establishments employing 10 or more individuals; thus, we excluded establishments employing fewer than 10 individuals from the National Economic Census data. The end result is a panel dataset counting the number of manufacturing establishments that employ 10 or more individuals within a municipality in 2006/2007, 2011/2012, and 2017/2018.

A3.2 Addressing Changing Administrative Boundaries

Starting in 1990, Village Development Committees (VDCs) became the primary administrative unit for local governance in Nepal. At the level below provinces, the country was divided into 77 districts and those districts were comprised of 3,974 VDCs. The electrification data, which are described in Appendix A1 and used as our treatment and control variables in regressions, are at the VDC level.

The passing of a new national constitution in 2015 brought about changes in the administrative units comprising the country. The VDCs in Nepal were dissolved and replaced by a new system of administrative units – the Gaunpalika or municipalities. There were 747 municipalities created to replace the VDCs. Districts, the second-level administrative country sub-division, largely remained the same, except 2 of the smallest districts were subsumed by larger districts. As a result there are 75 districts after the 2015 constitution instead of 77. These changes in administrative units are summarized in the following table.

	Administrative units below Province	
	Before 2015	After 2015 constitution
sub-province unit	77 districts	75 districts
sub-district unit	3,974 VDCs	747 municipalities

Our analyses that only use data prior to 2015-2016 – prior to the passing and operationalization of the municipality system – do not require any spatial adjustments. Those analyses that include data after 2015-2016 do require adjustments to ensure appropriate spatial matching.

To incorporate the 2018 municipality-level Census of Manufacturing Establishments data into the analysis, we must address these changes in administrative units during our study period. We use GIS files mapping between VDCs to municipalities, and then aggregate the VDC-level data to the municipality level.

Most VDCs were combined into one municipality. Therefore, we aggregate the total number of enterprises in these VDCs and consider it as the municipality-level measure. For the treatment variable, we consider a municipality as having microhydro power or a Community Rural Electrification Entity (CREE) if one of its VDCs has microhydro power or a CREE in a certain year.

The matching of VDCs to municipalities is not perfect; 17 of the 3,974 VDCs were divided and assigned across multiple municipalities. For these VDCs, we employ three methods to construct the municipality-level outcome measure. First, we equally divide the number of enterprises in a VDC by its corresponding number of municipalities, and then sum up this adjusted number. Second, we drop all the VDCs that are matched with multiple municipalities and omit the enterprises in these regions. Third, we simply aggregate the number of enterprises to the municipality level by double counting those VDCs. We can perform our analyses utilizing each of these three approaches. We use the first approach as our primary specification and the other two approaches as robustness checks.

A4 Details on Census Microdata Variables

Two of our main outcome variables are from Nepal's census, implemented in 2001 and 2011. Here we provide additional detail from the publicly available documentation on the World Bank's microdata library. We have copied parts of the information. Full details are available here:

https://microdata.worldbank.org/index.php/catalog/523/related-materials

A4.1 Employment Status

The census question and response options are as follows: What was XXXXX employment status?
1. Employer
2. Employee
3. Own account worker
4. Unpaid family worker

The description of these 4 categories is given below.

1. Employer - An employer is a person who operates her/his own economic enterprises or engages independently in a profession or a trade and hires one or more employees. In other word, if the person is operating her/his own profession or business by hiring employees regularly in the reference period then the employment status of that person is employer. To mention the employment status of employer encircle the "employer" option given in the category 1. If the employer had done other activities than management at that time also the status is "employer". But, while operating own activity at the peak time of the season for example, planting, harvesting in agriculture related activities, at a person may hire some people for 2, 4 days only, at that time the status of person is not "employer"

2. Employees - An employee is a person who works for public or private employer and receives remuneration in terms of wage, salary, commission, piece rates or pay in kind. The status of the person becomes employees if she/he works in government office, non government office or corporation or private enterprises or office, private home at any profession in industry sector getting salary, wage. In the reference period, if the enumerated person was usually engaged in doing work for others by getting salary, wage then her/his employment status becomes employees. Employees are getting salary, wage but they are not directly related to the profit and loss of the industry

3. Own Account Worker - An own account worker is a person who operates her/his economic enterprises or engages independently in a profession or trade and hires no employees in the last 12 month. To mention the status of own account worker should be encircled in category 3. People, who are engaged in household work like servant, cook, and getting salary, wage regularly but they are not engaged regularly in economic enterprises, these people are only for the housework purpose and not for industry. So, their employment status is own account worker. The economic enterprises (Industry) which is conducted by any member of the household and other members also work there without taking the salary, wage then the status of other members is also like the main person who conducts the industry "own account worker". To denote this employment status encircle the category 3. But the profession which is adopted by any member of the household and other members only helps her/him partially (Morning, evening or other time) then the status of that persons will be the "unpaid family worker". To denote the unpaid family worker it should be encircled on category 4 not in category 3.

4. Unpaid family worker - An unpaid family worker is a person who works without pay in economic enterprises operated by a person living in the same household. The industry mentioned in column 18 (Agriculture or others) which is conducted by any household member and other members (husband, wife, son, daughter, brother, sister, brother in law, etc) can support the activity without taking salary, wage. Except the people who are included in the occupation of column 17, the main person, who conducts the industry and the full time engaged members, other members who help partially for that industry should be included in the category 4. To denote their employment status should be encircled the category 4 "unpaid family worker"

A4.2 Usual Work Activities

The census question and response options are as follows: What work usually doing during the last 12 months? (For all persons of age 10 years and above)

1 Agriculture/ own cultivation

2 Salary/ wage
3 Own non-agricultural enterprises
4 Extended economic activity
5 Job seeker
6 Household work
7 Student
8 Not working

Work is defined as the activities that may or may not generate income. There may be economic or non economic activities. The enumerated individual may do the activities from serial code "1" through "7" as mentioned above, or may not do any work (as serial code "8") in the 12 months preceding the census enumeration day. But in this question, the intention is to explore the most frequent activity done by the individual in terms of time spent. The enumerator should encircle or indicate the proper code of the activity that was done for most of the time during the last 12 months.

For the purpose of census enumeration, the above mentioned activities are further elaborated as following.

1. Own agriculture/farming: The category own agriculture/farming includes all activities related to agriculture. The activities included in the agricultural work are elaborated as following. Agricultural Activities: 1. All the activities like digging, plowing, planting, sowing, weeding, caring, cutting or chopping, harvesting, drying, sifting or removing impurities, packing, collecting seeds etc. in the course of production of crops (rice, wheat, maize, millet, barley, etc), cash crops, vegetables, fruits (orange, banana, mango, jackfruit, apple, peer, guava etc.) are known as the agricultural works or farming activities. 2. Similarly, all the activities like raising livestock: cow, buffalo, sheep, goat, pig, rabbit, etc., and raising poultry like chicken, duck and other birds with the purpose of meat or egg production are also included in the agricultural work or farming activities. 3. Activities like making of fish-ponds, breeding agricultural works. 4. The activities like planting of trees in the wood land and forest, weeding, planting the grass, weeding the grass, and related protection activities are also agricultural work. Similarly, bee-hiving, farming of silkworm are also included in the agricultural work. But agriculture works do not include the activities carried out in manufacturing industries like food stuff production industries, grinding industry, bamboo related materials or goods production industries, and saw-mill, etc. Own agriculture or farming means the agricultural works or farming activities that have been operated by the enumerated individuals investing their own capital in cash or kinds, or both, and labor, and who bear the profit or loss from their production. If the enumerated person has involved most of her/his time during reference period of last 12 months in own agricultural work or farming, then enumerator should mark or encircle the code 1 to indicate ″own agriculture or farming″. If the enumerated person has also invested most of her/his time in the agricultural activity operated by anyone of the household members, then the enumerator should encircle the code to indicate ″own agriculture work or farming″ for each person who is involved in agricultural activities. But if the enumerated person has involved most of her/his time in agricultural activities operated by others in charge of salary or wage or any kind of labor participation, then the enumerator should encircle code ″2″ to indicate the activity as salary or wage.

2. Salary/Wage Activity: The category includes the person who works for salary/wage most of time during the 12 months of the reference period. The enumerator should encircle code ″2″ to indicate salary/wage activity. If the enumerated person has spent most of the time in any kind of activities in the sectors like government or non-government institutions or manufacturing establishments or private home or business during the last 12 months of reference period, then the enumerator should encircle code ″2″ to indicate salary/wage. The domestic workers like gothala (shepherd or cowboy or herdsman), hali (ploughman), cook, or kamaiya (bondman) are kept for doing any activity in account of salary/wage, then for this case also the enumerator should encircle code 2.

3. Own non-agriculture enterprises or business: Non-agriculture enterprises include all kinds of business or enterprises operated by the household except one's own agriculture or farming activity. One's own non-agricultural enterprise is defined as any kind of business activities operated by household or member(s) investing capital (in terms of cash or kinds or labor) and bearing the profits or losses of the business. If the enumerated person has contributed most of her/his time in own any kind of non-agricultural enterprise or business in the reference period, then the enumerator should encircle code ″3″ to indicate her/his activity. Also if any of the household members has operated any kind of non-agricultural enterprise and the enumerated person has devoted most of her/his time in that enterprise during the reference period, then her/his activity should be encircled in code ″3″. But if enumerated person has worked in a non-agricultural enterprise or business receiving any kind of remuneration like salary, wage, or labor, then the activity of the person should be encircled in code ″2″. The activity of such person should not be encircled in code ″3″.

4. Extended Economic Work: Extended economic work is defined as activities like collecting firewood, fetching drinking water in the household for own consumption. Processing food and grinding grains in dhiki, janto (traditional grinding tools) or in a mill, or kelaune (picking grains) work; making pickle, titaura (rolled and dried fruit juices, tamarind), masyaura (dried preparation of the pulse for curry), or similar kinds of making food stuff for the consumption of the household. If any member(s) of household has contributed most of her/his time in such activities, then the activity of the person should be encircled in code 4.

5. Seeking Economic Work: Seeking job is defined as the activity of looking for or searching job- or work-related activities to generate income. In such conditions, the person seeking job should be actively involved in seeking a job or work and should be available for work.

6. Household Work: Household chores or work means the activities carried out by a person like cooking, feeding household members; taking care of children, aged persons, and ill member(s) of household; teaching their own children; cleaning the house and its courtyard, and washing related works. When the household member who often undertakes such activities for other household member(s) does so without any remunerations or wages, then such activities are called ”household chores”. Such activities carried out by the person for own self and family member(s) without any salary or wage is counted as not income generating work with economic perspective. If any of the enumerated male or female persons has contributed most of his/her time during the reference period in activities like cooking, feeding for household members; taking care of children, aged persons, and ill member(s) of household; teaching own children; cleaning the house and its courtyard, and washing related works, then her/his activity should be encircled in code ”6” to indicate household chores. Similarly, if the person was not able to do any income generating work or has worked for short duration due to the reasons of pregnancy or Sutkeri (woman who has just given birth to a baby) or taking care of children, then the activity of such person should be encircled in code ”6”. But if any person undertakes these activities like cooking, feeding for household members; taking care of children, aged persons, and ill member(s) of household; teaching their own children; cleaning the house and its courtyard, and washing related works for any remuneration like salary, or wage (cash or kinds), then such activities are income generating works. As mentioned above if an enumerated male or female person has carried out such activities while receiving remuneration during the reference period, then her/his activity should be encircled in code ”2” to indicate salary/wage but should not be encircled in code 6.

7. Study (student): Study (student) means the student (boy or girl) who has enrolled or not in school, college, university or other any academic institutes for achieving education or any kind of training during the reference period.

8. No work done: If a person has not undertaken any economic or income related activities (activities mentioned in codes ″1″, ″2″, ″3″, or ″4″), or not even sought any job or not doing non-economic work (activities mentioned in code 6 and ″7″), then the person’s activity status is ″no work done″.

DETAILS ON ROBUSTNESS CHECKS

A5 Robustness Checks

We show results are robust to multiple additional tests, such as employing arbitrary clustering methods, dropping certain locations and using alternative identification methods.

A5.1 Arbitrary Clustering

Our instrumental variables are constructed based on geographic characteristics, which might be highly correlated between nearby regions. In addition, as Adao et al. (2019) suggest, the regression residuals from a shift-share design could be correlated across regions with similar shares, making the typical robust or clustered standard errors too small.

To address this, we employ the arbitrary clustering method proposed by Colella et al. (2019) for the inference in two different ways.[36] First, we account for spatial correlations among nearby regions using the distance between districts. Specifically, we construct a distance matrix based on the pair-wise distance among districts and use this matrix to define the correlation structure. We test two distance cutoffs, 50km and 100km, within which the error terms of two observations are assumed to be correlated. Second, we account for correlations among regions with similar geographic characteristics. In the spirit of Gallea (2023), we leverage the Bray-Curtis index to measure the pairwise dissimilarity between two districts, which is mainly used for abundance data with continuous values. Results are robust to this alternative inference method, for manufacturing establishments (Table A7), employment status (Table A8), and usual activities (Table A9). A complete discussion of both arbitrary clustering approaches employed is in Appendix A6.

A5.2 Monte Carlo Simulations

To support the claim that the causal relationships we identify are unaffected by selection bias and spurious time trends, we conduct Monte Carlo simulations proposed by Christian and Barrett (2017). This test is based on a randomization inference method. Within a given year, the number of newly constructed microhydro plants is randomly assigned to regions (i.e., municipalities for the CME data or VDCs for the census data) that have new microhydro plants. We then calculate the corresponding cumulative number of microhydro plants using these randomized assignments. We generate 500 randomized allocations

[36] When attempting the command package developed by Adao et al. (2019), we encounter the same issue described by Gallea (2023); if we include all of our standard controls and fixed effects, then the variation of the instrument is close to idiosyncratic and therefore the standard errors estimated are near zero.

of microhydro plants and then estimate the baseline 2SLS model using these randomized microhydro variables. Reassuringly, the distribution of the estimated coefficients shift towards zero (Table A10), as expected when the identification is unaffected by spurious time trends. Full details as to how we operationalize this placebo test are in Appendix A7.

A5.3 Valid t-ratio Inference

Following Lee et al. (2022), we adjust the standard errors from our baseline model estimates and construct the corresponding tF confidence intervals. Table A11 show the results. In Column (1), we duplicate our baseline coefficient estimates for each outcome variable. Column (2) and (3) report the tf adjustment factors and the adjusted standard errors. In the last column, we present the tF 95% confidence intervals. The statistically significance remains for the variables of interests, e.g., the manufacturing establishments, the employment status, and the salary/wage activities.

A5.4 Dropping the CREP Areas

As discussed in Section 3.2.2, rural communities could be electrified by one alternative means: extension of the electrical grid through the Community Rural Electrification Program. To ensure that we are not capturing any effects of the CREP, we perform a series of robustness checks, running our main regressions again but dropping locations that were at some point during the study period electrified via the CREP. All of our results are robust to dropping these locations. The estimated impacts of microhydro mini-grids are similar qualitatively and close in magnitude for the results on manufacturing establishments (Appendix Table A2, Column 3), employment status (Appendix Table A12), and usual work activities (Appendix Table A13) analyses.

A5.5 Poisson Model

Recent work suggests that the inverse hyperbolic sine transformation could be sensitive to scaling of the outcome and the presence of zeros in the data (Chen and Roth, 2023; Mullahy and Norton, 2022). We conduct robustness checks for the analyses on manufacturing establishments using a Poisson model, as recommended by (Chen and Roth, 2023), to address this issue and account for its nature of count data. We do this through a control-function approach. Specifically, we use the raw number of manufacturing establishments as the outcome variable and estimate the second-stage regression via the Poisson pseudo-maximum likelihood approach, adding the residuals from the first-stage as controls. Column (4) of Table A2 presents the coefficient estimates. The coefficient estimate indicates that one additional microhydro plant constructed, on average, leads to an almost 150% increase in manufacturing establishments. The magnitude of the effect here is much larger compared to our baseline results, which is probably because the Poisson model can better capture the extensive margin by effectively accounting for the entry of new establishments in specific municipalities.

A5.6 Adding Linear Trends

To account for the differential trends across regions, we add interactions between linear time trends and baseline characteristics in each municipality/VDC. The characteristics include the number of households, the length of road, the distance to the nearest city, the length of river. For the municipality-level analyses, we also add the number of manufacturing establishments in 2008. Our conclusions still hold (Table A14, A15, and A16).

A5.7 OLS specifications

Lastly, we also use difference-in-differences regressions. With insufficient periods of pre-intervention data, we cannot provide standard evidence in support of the parallel trends assumption and therefore put less weight on these results. We do find that these difference-in-differences estimates tell the same story qualitatively: microhydro is associated with increases in manufacturing establishments (Appendix Table A19, column 1 and 2), shifts from self-employment to being an employee (Appendix Table A20, Panels A, B, E, and F), and movement from agricultural activities to work for salary and wages (Appendix Table A21, Panels A, B, E, and F).

Not surprisingly, the OLS coefficients overall are smaller in magnitude than the IV estimates. Microhydro mini-grids can be – and were – constructed in some locations that were not geophysically appropriate for the technology (Appendix Figure A3). For example, they were sometimes constructed at sites that do not actually have year-round river flow. Such sites would benefit less from microhydro construction than those with year-round river flow, because the plants could only generate electricity during particular seasons. These locations would be captured in our difference-in-differences estimate, but not in the instrumental variables estimate.

A5.8 Alternative Instruments

As an additional robustness check, we use the average river slope variables described in Section 5.2 as a set of alternative instrumental variables. The first-stage regression results for the manufacturing and census datasets, all have strong first stages (Appendix Table A17). We re-do these main analyses, using these alternative instruments in the first-stage, and have similar findings: an additional microhydro plant constructed within a municipality led to a 24.3 percent increase in manufacturing establishments (Appendix Table A19, Column 3) and individuals shift to work as an employee (Appendix Table A20, Panels C and G) for salary and wages and away from agricultural work activities (Appendix Table A21, Panels C and G).

To address the concerns on the use of short year panels, we employ a two-sample IV approach to leverage more year-to-year variations from MHP construction. Specifically, we estimate the first-stage regression instead using an annual panel of MHP construction at either the municipality level or the VDC level. The data covers all the years between 2008 and 2018. The results are presented in Table A18. We then use the residuals from these first-stage regressions as controls in a control-function version of the section-stage regression. The results have similar magnitudes as our baseline model (Table A19 Column 4, Table A20 Panels D and H, and Table A21 Panels D and H).

A5.9 Microhydro Capacity

The analyses in the main paper use the number of microhydro plants constructed in each region and year. In our data, about 94% of the microhydro plants report their capacities. As a robustness check, we estimate the regression models instead using these capacity measures. We define the capacity in two ways: (1) the cumulative capacity of microhydro plants; (2) the cumulative capacity per capita. Since we only have the population data for 2001 and 2011 (which correspond to the years of the census sample), for the analysis of manufacturing establishments (with the data for 2006, 2011, and 2018), we extrapolate the population using the 2001 and 2011 records, assuming the constant population growth rate.

Table A27 reports the estimation results of the first-stage regressions. The coefficient estimates of our instrumental variable are all positive and statistically significant. The F-stats range from 27 to 49. Table A28 reports the 2SLS estimation results for the impacts on manufacturing establishments. Table A29 and A30 report the estimation results for the impacts on employment status and usual activities. Our main conclusions generally hold.

A6 Arbitrary Clustering

Our instrumental variables are constructed based on geographic characteristics, which might be highly correlated between nearby regions. In addition, as Adao et al. (2019) suggest, the regression residuals from a shift-share design could be correlated across regions with similar shares, and therefore making the typical robust or clustered standard errors too small. To address this issue, we employ the arbitrary clustering method proposed by Colella et al. (2019) for the inference in two different ways.

First, we account for spatial correlations among nearby regions using the distance between districts. Specifically, we construct a distance matrix based on the pair-wise distance among districts and use this matrix to define the correlation structure. We test two distance cutoffs, 50km and 100km, within which the error terms of two observations are assumed to be correlated.

Second, we account for correlations among regions with similar geographic characteristics. In the spirit of Gallea (2023), we leverage the Bray-Curtis index to measure the pairwise dissimilarity between two districts, which is mainly used for abundance data with continuous values. The dissimilarity between district i and j is defined as follows

$$BC_{ij} = 1 - \frac{2\sum_{k=1}^{K} \min(W_{ik}, W_{jk})}{\sum_{k=1}^{K}(W_{ik} + W_{jk})},$$

where W_{ik} is the k-th dimension of geographic characteristics for district i. Here, the series of geographic characteristics include average slope, average elevation, river length, the proportion of river with slope falling into each category (i.e., 0-3, 3-20, 20-30, 30-50 in degrees), and the proportion of river with elevation falling into each category (i.e., 0-250, 250-1000, 1000-3000, $\geq$3000 in meters). This index has the value between 0 and 1, and a higher value means less similarity between two districts. With all the pairwise Bray-Curtis index, we can create a dissimilarity matrix and use it to define the strength of the error dependence. We test two dissimilarity cutoffs, the median and the 3rd quartile of all the pairwise Bray-Curtis index values. Lastly, we also tried the Bartlett-kernal approach that assumes a distance linear decay in the correlation structure.

The arbitrary clustering method can be easily applied to our analyses on the manufacturing establishment data. However, we have difficulty in implementing this method directly on our individual-level census data due to the huge sample size. To mitigate the computation burdens, we aggregate the individual-level census data to the VDC level as follows. First, we regress the outcomes of interest, the independent variable (i.e., number of MHP), and the instrumental variable on the fixed effects and control variables. This is to partial out the controls and high dimensional fixed effects. Second, we obtain the regression residuals and aggregate them to the VDC level by taking the average. Third, we perform the weighted regression analysis using this VDC-level data where the weight is the number of individuals in each VDC in our sample.

The results of the estimates using the arbitrary clustering methods are presented in Table A7, A8, and A9. In the first two rows of each table, we report the coefficient estimates and the standard errors clustered at the district level. The standard errors computed from the arbitrary clustering method are reported below in parenthesis. As is shown in Table A8 and A9, the coefficient estimates from the aggregated VDC-level data are almost the same as those from the individual-level data. Our results are robust to this alternative inference method.

A7 Placebo Test with Randomization Inference

As Christian and Barrett (2017) suggest, the common spurious trends between the time-series part of the IV (i.e., microhydro construction budgets over time in our case) and the outcome variables might pose threats to the exclusion restriction assumption. To mitigate the concern, we perform a placebo test following Christian and Barrett (2017).

This test is based on a randomization inference method where we introduce randomness into the endogenous variable (i.e., the cumulative number of microhydro plants) while keeping everything else unchanged. Specifically, within a given year, the number of newly constructed microhydro plants is randomly assigned to regions (i.e., municipalities for the CME data or VDCs for the census data) that have new microhydro plants. The randomization is without replacement and we generated 500 randomized allocations of microhydro plants. Based on these assignments, we calculate the corresponding cumulative number of microhydro plants. We then estimate the primary 2SLS model using these randomized microhydro variables. If the identification were unaffected by spurious time trends, the distribution of coefficients should shift towards zero relative to our main estimates.

Table A10 reports summary statistics of the coefficient estimates generated from the 500 randomizations for all the main outcome variables. In the last five columns, we report the mean, 10th percentile, median, 90th percentile, and the proportion of estimates that are closer to zero compared to our baseline estimates. Reassuringly, the distribution of these estimates shift towards zero.

APPENDIX of FIGURES

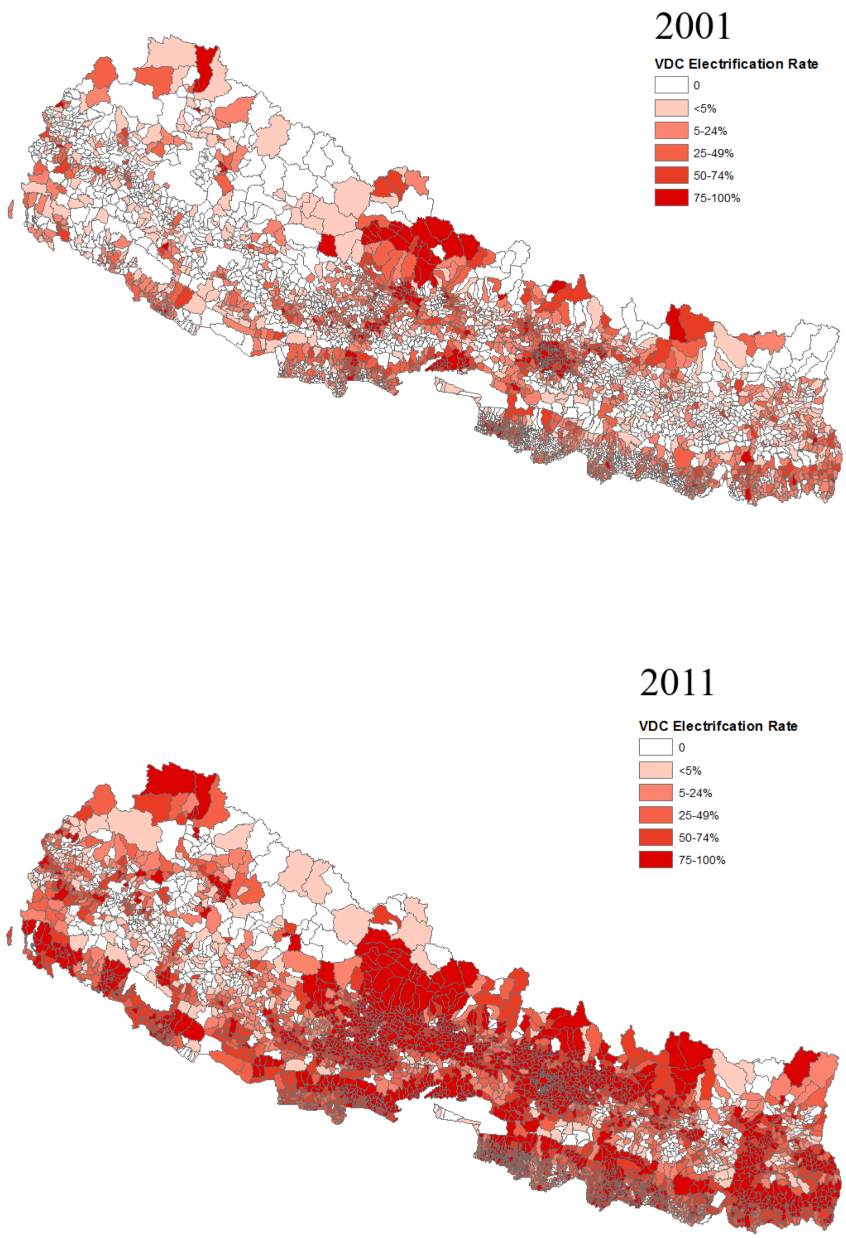

Figure A1: Electrification Rates at Village Development Committee (VDC) Level, 2001 and 2011

Notes: Map was created using the Transverse Mercator projection and the Nepal Nagarkot TM Coordinate System with data from the 2001 and 2011 Nepal Household Census. Blank spaces in the northwestern region were not sampled in 2001 due to unrest in those districts.

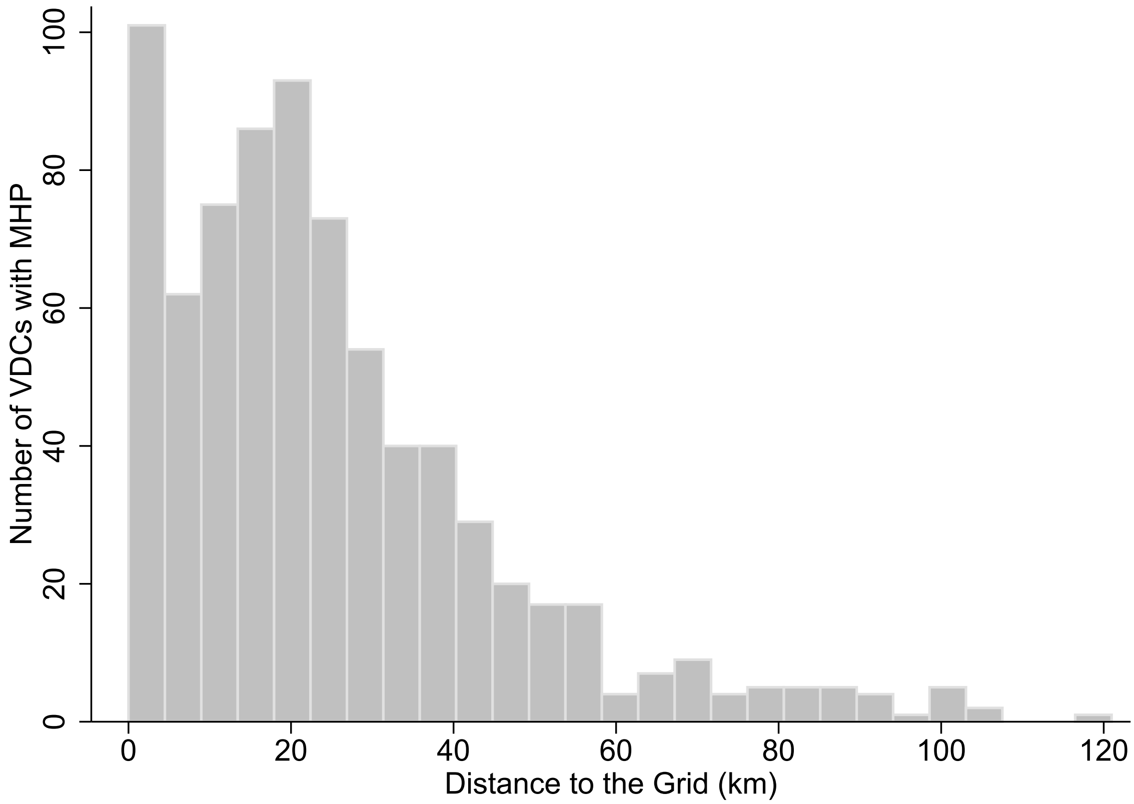

Figure A2: Proximity of Microhydro Sites to the Electrical Grid (km)

Notes: Figure uses data from Alternative Energy Promotion Center in Nepal.

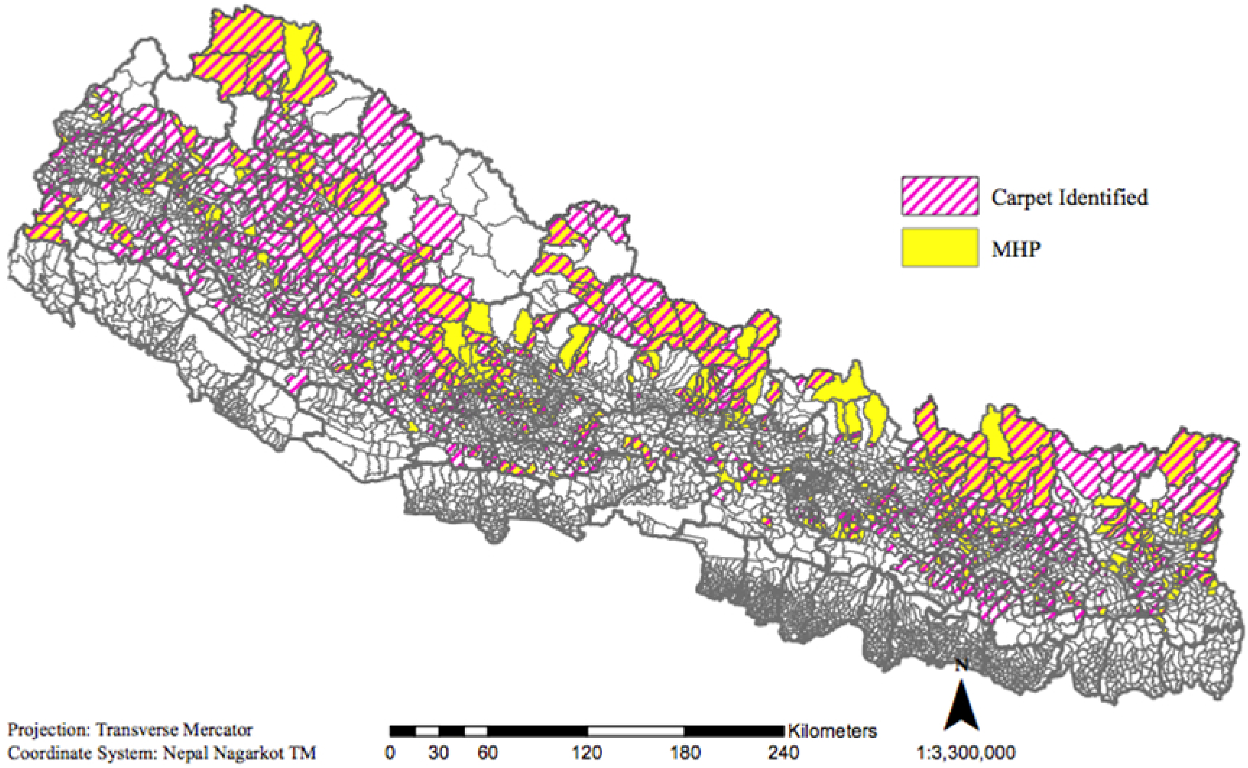

Figure A3: Village Development Committees (VDCs) Identified in GIS Study and VDCs Electrified with Microhydro Power (MHP) by 2011

Notes: Map was created using data on GIS study results and microhydro plant construction from AEPC, the Transverse Mercator projection, and the Nepal Nagarkot TM Coordinate System. The map shows that not all carpet-identified locations had microhydro plants constructed and microhydro could be constructed in locations not carpet-identified, outside of the AEPC process.

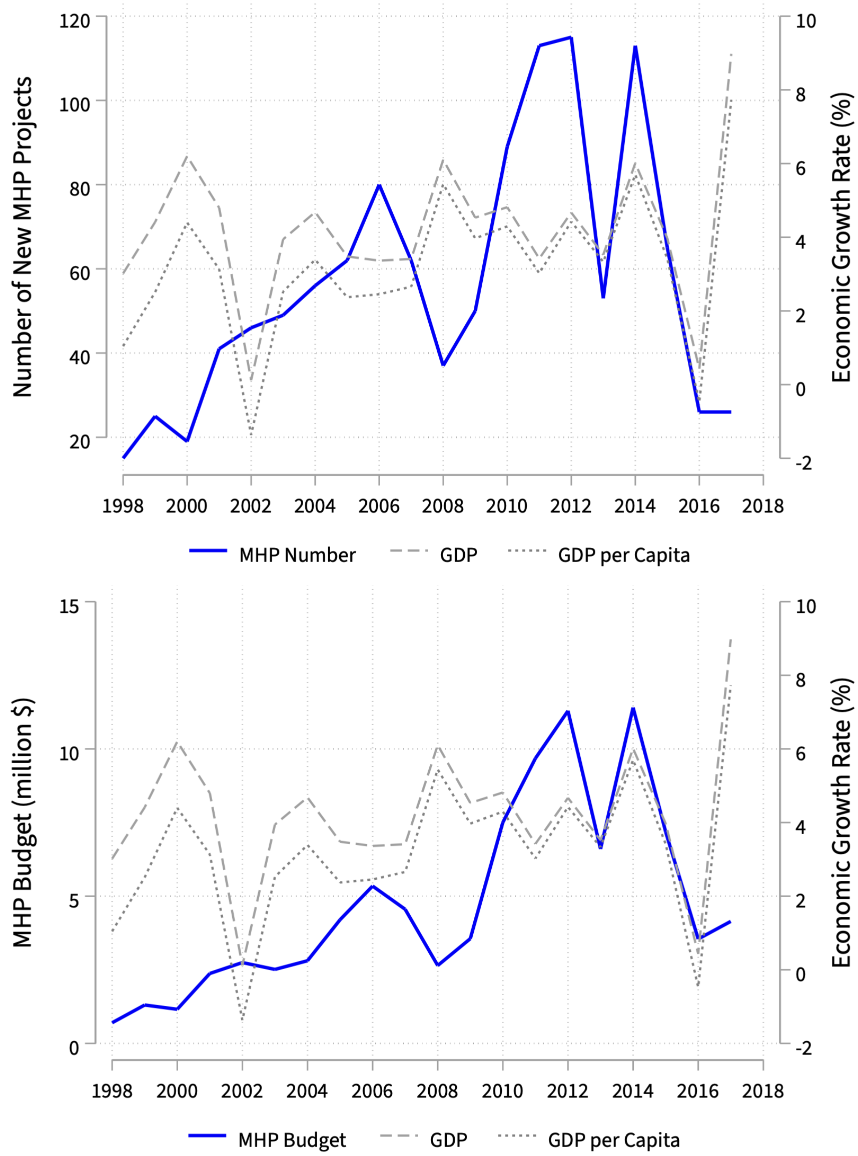

Figure A4: MHP Budget and Economic Growth Rate

Notes: The figure plots the economic growth rates and national MHP investments in Nepal. The blue line in the top panel shows the number of new MHP projects in a year. The blue line in the bottom panel shows the number of estimated MHP budgets in a year. The gray lines in both panels show the growth rates of GDP and GDP per capita.

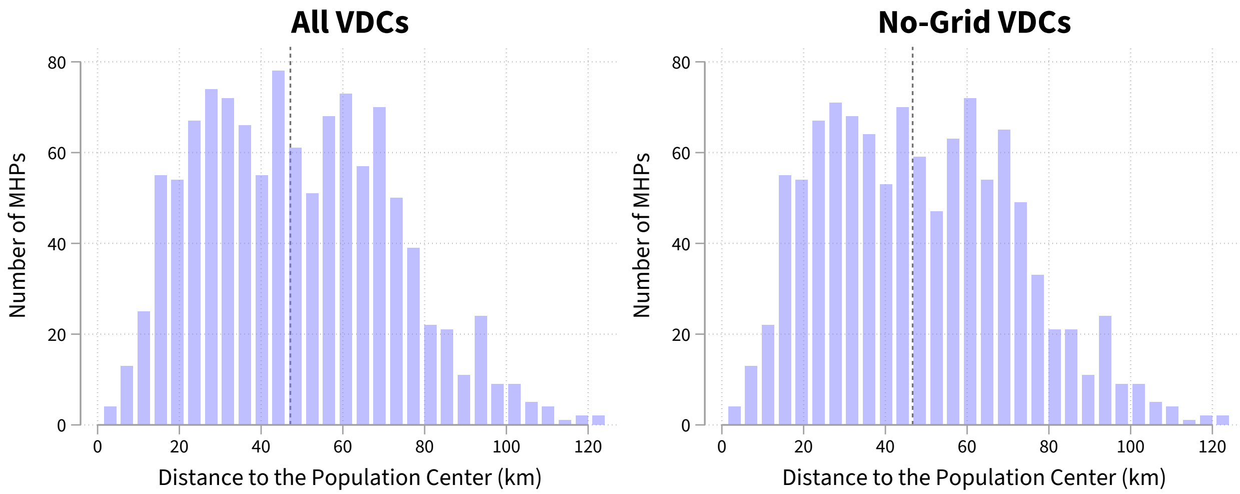

Figure A5: Distribution of Microhydro Plants Distances from Population Centers

Notes: The figure shows the distribution of microhydro plants (MHPs) by their distance to the nearest population center (in kilometers). The left panel includes all VDCs, while the right panel focuses only on no-grid VDCs. The vertical dashed lines represent the median distance.

APPENDIX OF TABLES

Table A1: Employment Statistics in Locations Prior to Microhydro Plant Construction

Individual employment of:		Males	Females
Employment status is:			
	employer	0.017	0.018
	employee	0.098	0.028
	own account	0.543	0.609
	other	0.342	0.346
Usual work activity is:			
	agriculture	0.508	0.548
	salary & wage	0.087	0.020
	own enterprise	0.337	0.017
	extended economic	0.016	0.051
	household work	0.012	0.103
	study	0.285	0.206
Observations (individuals)		100,780	110,093

Notes: Baseline means are the variable raw means in Village Development Committees (VDCs) where microhydro plants will be constructed but were not yet at baseline. Employment variables are from the 2001 Nepal Population Census, which collected data for household members 10 years of age and older. Employment status can be as an employer, employee, own account work (i.e., self-employed), or other, which includes unpaid family work as well as those that do not report an employment status. Usual work activities consist of household chores (cooking, cleaning, child care, etc.), extended economic work (collecting fuel and water, preparing goods for consumption at home), studies, agriculture, wage or salaried work, and small business activities.

Table A2: Robustness Checks on Manufacturing Establishments

	IHS(# Manufacturing Establishments)			
	Exclude Duplicates (1)	Double Count (2)	Exclude CREP (3)	Poisson Model (4)
MHP	0.322***	0.331***	0.307***	1.482***
	(0.080)	(0.081)	(0.081)	(0.210)
Observations	2,241	2,241	1,842	2,241
Municipality FE	✓	✓	✓	✓
Province-Year FE	✓	✓	✓	✓

Notes: Observations are at the municipality level. MHP is the cumulative number of microhydro plants in a municipality. The outcome variable is the inverse hyperbolic sine of the number of manufacturing establishments (employing 10 or more individuals) located within a municipality. Municipality-year controls include the logarithm of average elevation and slope in a municipality, both indicated with year fixed effects. The baseline mean is the outcome variable raw mean (i.e., not the inverse hyperbolic sine) for those locations in which microhydro plants are later constructed. Data sources are further described in Data Appendix A3. Each column in this table presents a different way of addressing the changing spatial boundaries from VDCs to municipalities, as the administrative boundaries shifted from 2,974 VDCs to 747 municipalities and resulted in multiple VDCs per municipality. Most prior VDCs were cleanly encapsulated by one single new municipality; however, some VDCs were covered by new multiple municipalities (further explained in Appendix A3.2). We can exclude such VDCs (column 1) or double count them (column 2). In column 3, We exclude regions with any CREP grid connection as a robustness check. In column 4, we estimate the second-stage with using a Poisson model and the control function approach. Robust standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table A3: IV Placebo Test with Manufacturing Establishments

Dep. Var.:	IHS(#Manufacturing Establishments)		
	Equal Divide	Exclude Duplicates	Double Count
	(1)	(2)	(3)
Carpet × N_t	-0.001	-0.001	-0.001
	(0.049)	(0.049)	(0.049)
Observations	387	387	387
Municipality FE	✓	✓	✓
Province-Year FE	✓	✓	✓

Notes: For the placebo test, the sample is limited to untreated (non-electrified) locations. Locations considered electrified and therefore excluded from the sample are those with microhydro, those electrified via the grid (through CREP grid extensions or historical grid access), or those with households reporting in the 2011 census using solar energy for lighting. The outcome variable is the inverse hyperbolic sine of the number of manufacturing establishments (employing 10 or more individuals) located within a municipality. Municipality-year controls include the logarithm of average elevation and slope in a municipality, both indicated with year fixed effects. The baseline mean is the outcome variable raw mean (i.e., not the inverse hyperbolic sine) for those locations in which microhydro plants are later constructed. Data sources are further described in Data Appendix A3. Each column in this table presents a different way of addressing the changing spatial boundaries from VDCs to municipalities, as the administrative boundaries shifted from 2,974 VDCs to 747 municipalities and resulted in multiple VDCs per municipality. Most prior VDCs were cleanly encapsulated by one single new municipality; however, some VDCs were covered by new multiple municipalities (further explained in Appendix A3.2). We can equally divide such VDCs (column 1), exclude them (column 2), or double count them (column 3). Robust standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table A4: IV Placebo Test with Census Employment Status

Dep. Var.:	Reported employment status is:			
	Employer	Employee	Own Account Worker	Other
	(1)	(2)	(3)	(4)
A. Male				
Carpet × N_t	-0.000	0.002	-0.002	0.001
	(0.001)	(0.001)	(0.003)	(0.002)
Observations	114,111	114,111	114,111	114,111
B. Female				
Carpet × N_t	0.000	0.001	-0.001	0.000
	(0.001)	(0.001)	(0.003)	(0.003)
Observations	121,983	121,983	121,983	121,983
Individual Controls	✓	✓	✓	✓
VDC FE	✓	✓	✓	✓
Province-Year FE	✓	✓	✓	✓

Notes: For the placebo test, the sample is limited to untreated (non-electrified) locations. Locations considered electrified and therefore excluded from the sample are those with microhydro, those electrified via the grid (through CREP grid extensions or historical grid access), or those with households reporting in the 2011 census using solar energy for lighting. Data on the microhydro project construction (timing and location) are based on Alternative Energy Promotion Center records and used to create the MHP variable. The outcome variables, which use microdata from the 2001 and 2011 iterations of the Nepal Population Census, are collected for household members 10 years of age and older. The outcome variables are responses to the individual's employment status. The other group includes both unpaid family workers and those that did not state an employment status. Additional variable descriptions provided in Appendix A4. The individual controls include the individual's age, the individual's education, the household size, and whether the household has a toilet. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table A5: IV Placebo Test with Census Usual Activities

	Agriculture (1)	Salary & Wage (2)	Own Enterprise (3)	Extended Economic (4)	Household Work (5)	Study (6)
A. Male						
Carpet × N_t	-0.003	0.001	0.001	-0.000	-0.001	0.002
	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	114,111	114,111	114,111	114,111	114,111	114,111
B. Female						
Carpet × N_t	-0.003	0.001	0.000	0.002	-0.000	0.000
	(0.004)	(0.001)	(0.000)	(0.003)	(0.003)	(0.001)
Observations	121,983	121,983	121,983	121,983	121,983	121,983
Individual Controls	✓	✓	✓	✓	✓	✓
VDC FE	✓	✓	✓	✓	✓	✓
Province-Year FE	✓	✓	✓	✓	✓	✓

Notes: For the placebo test, the sample is limited to untreated (non-electrified) locations. Locations considered electrified and therefore excluded from the sample are those with microhydro, those electrified via the grid (through CREP grid extensions or historical grid access), or those with households reporting in the 2011 census using solar energy for lighting. Data on the microhydro project construction (timing and location) are based on Alternative Energy Promotion Center records and used to create the MHP variable. The outcome variables, which use microdata from the 2001 and 2011 iterations of the Nepal Population Census, are collected for household members 10 years of age and older. The outcome variables are the individual's usual work in the past 12 months: agriculture, salary/wage, own economic enterprises, extended economic enterprises, household work, and study. Additional variable descriptions provided in Appendix A4. The individual controls include the individual's age, the individual's education, the household size, and whether the household has a toilet. Standard errors are clustered at the district level and shown in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table A6: Robustness Checks on Correlations between IV and Other Economic Factors

VARIABLES	(1) Population Size	(2) #Male	(3) #Female	(4) #Schools	(5) #Students	(6) #Health Facilities	(7) Distance to Health Facilities
Carpet × N_t	0.000	0.001	-0.000	0.026	-0.041	-0.018*	0.001
	(0.003)	(0.003)	(0.003)	(0.020)	(0.044)	(0.011)	(0.029)
Observations	7,338	7,338	7,338	531	531	531	499
Adjusted R^2	0.957	0.956	0.957	0.479	0.277	0.809	0.559
VDC Controls	✓	✓	✓	✓	✓	✓	✓
VDC FE	✓	✓	✓				
District FE				✓	✓	✓	✓
Province-Year FE	✓	✓	✓	✓	✓	✓	✓

Notes: All the outcome variables are measured in inverse hyperbolic sines and are at the VDC level. Data on population size, number of males, females, and households are collected from the 2001 and 2011 iterations of the Nepal Population Census at the VDC level. Data on school and health facilities are collected through the Nepal Living Standards Survey (NLSS) at the community level in 2003 and 2010, and we aggregate the data to the VDC level. VDC controls include the number of households as of 2001, the area of the VDC, if the VDC was already connected to the electrical grid as of 2001, the log elevation, distance to the grid in kilometers, the log distance to the nearest city, and the log distance to the nearest paved road. We exclude locations with CREP grid extensions. Standard errors are clustered at the district level and shown in parentheses. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

Table A7: Impact on Manufacturing Establishments: Arbitrary Clustering

	Dep. Var.: IHS(#Manufacturing Establishments)		
	Equal Divide (1)	Exclude Duplicates (2)	Double Count (3)
MHP	0.328	0.322	0.331
	(0.081)***	(0.080)***	(0.081)***
A. Arbitrary Clustering by Spatial Distance			
30 km	(0.082)***	(0.081)***	(0.083)***
60 km	(0.097)***	(0.095)***	(0.098)***
B. Arbitrary Clustering by Geographic Dissimilarity			
Median	(0.129)**	(0.127)**	(0.130)**
3rd Quartile	(0.140)**	(0.140)**	(0.140)**
Bartlett	(0.130)**	(0.128)**	(0.131)**

Notes: MHP is the cumulative number of microhydro plants in a municipality from the alternative IV first-stage regressions. In the first two rows, we report the coefficient estimates and the corresponding standard errors clustered at the district level. In panel A, we report standard errors using the arbitrary clustering method with different thresholds on spatial distance among districts. In panel B, we report standard errors using the arbitrary clustering method with different thresholds (i.e., at the median, the 3rd quantile, or using the Bartless method) on geographic dissimilarity that is measured by district-level average elevation, average slope, river length, the proportion of river with slope falling into 0-3, 3-20, 20-30, 30-50 (in degrees); and with elevation falling into 0-250, 250-1000, 1000-3000, ≥3000 (in meters). *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table A8: Impact on Employment Status: Arbitrary Clustering

Dep. Var.:	Reported employment status is:			
	Employer	Employee	Own Account Worker	Other
	(1)	(2)	(3)	(4)
A. Male				
MHP	-0.007	0.094	-0.080	-0.008
	(0.005)	(0.016)***	(0.021)***	(0.016)
A1. Arbitrary Clustering by Spatial Distance				
30 km	(0.005)	(0.016)***	(0.022)***	(0.016)
60 km	(0.005)	(0.017)***	(0.024)***	(0.018)
A2. Arbitrary Clustering by Geographic Dissimilarity				
Median	(0.003)**	(0.013)***	(0.017)***	(0.013)
3rd Quartile	(0.004)*	(0.012)***	(0.017)***	(0.012)
Bartlett	(0.004)*	(0.013)***	(0.018)***	(0.013)
B. Female				
MHP	-0.010	0.028	-0.060	0.043
	(0.006)*	(0.006)***	(0.029)**	(0.027)
B1. Arbitrary Clustering by Spatial Distance				
30 km	(0.006)	(0.006)***	(0.030)**	(0.028)
60 km	(0.006)*	(0.006)***	(0.033)*	(0.031)
B2. Arbitrary Clustering by Geographic Dissimilarity				
Median	(0.004)**	(0.005)***	(0.026)**	(0.025)*
3rd Quartile	(0.003)***	(0.005)***	(0.023)***	(0.021)**
Bartlett	(0.004)**	(0.005)***	(0.024)**	(0.023)*

Notes: MHP is the cumulative number of microhydro plants in a municipality from the alternative IV first-stage regressions. In the first two rows, we report the coefficient estimates and the corresponding standard errors clustered at the district level. In panel A1 & B1, we report standard errors using the arbitrary clustering method with different thresholds on spatial distance among districts. In panel A2 & B2, we report standard errors using the arbitrary clustering method with different thresholds (i.e., at the median, the 3rd quantile, or using the Bartless method) on geographic dissimilarity that is measured by district-level average elevation, average slope, river length, the proportion of river with slope falling into 0-3, 3-20, 20-30, 30-50 (in degrees); and with elevation falling into 0-250, 250-1000, 1000-3000, $\geq$3000 (in meters). *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table A9: Impact on Usual Activities: Arbitrary Clustering

	Own Agriculture & Farming (1)	Salary & Wage (2)	Own Enterprise (3)	Extended Economic (4)	Household Work (5)	Study (6)
A. Male						
MHP	-0.108	0.072	0.008	-0.009	0.002	0.020
	(0.022)***	(0.014)***	(0.005)*	(0.005)*	(0.003)	(0.011)*
A1. Arbitrary Clustering by Spatial Distance						
30 km	(0.022)***	(0.014)***	(0.004)*	(0.005)*	(0.003)	(0.011)*
60 km	(0.025)***	(0.014)***	(0.004)**	(0.005)*	(0.003)	(0.013)
A2. Arbitrary Clustering by Geographic Dissimilarity						
Median	(0.018)***	(0.011)***	(0.004)**	(0.003)***	(0.003)	(0.008)**
3rd Quartile	(0.018)***	(0.010)***	(0.003)***	(0.004)**	(0.002)	(0.007)***
Bartlett	(0.018)***	(0.011)***	(0.004)***	(0.004)**	(0.002)	(0.008)**
B. Female						
MHP	-0.088	0.018	-0.006	-0.015	0.037	0.030
	(0.030)***	(0.005)***	(0.004)	(0.016)	(0.017)**	(0.011)***
B1. Arbitrary Clustering by Spatial Distance						
30 km	(0.031)***	(0.005)***	(0.004)	(0.015)	(0.018)**	(0.012)***
60 km	(0.034)***	(0.005)***	(0.004)	(0.015)	(0.018)**	(0.012)**
B2. Arbitrary Clustering by Geographic Dissimilarity						
Median	(0.024)***	(0.003)***	(0.003)*	(0.009)	(0.015)**	(0.007)***
3rd Quartile	(0.023)***	(0.004)***	(0.002)**	(0.013)	(0.014)***	(0.007)***
Bartlett	(0.023)***	(0.003)***	(0.003)*	(0.012)	(0.014)***	(0.008)***

Notes: MHP is the cumulative number of microhydro plants in a municipality from the alternative IV first-stage regressions. In the first two rows, we report the coefficient estimates and the corresponding standard errors clustered at the district level. In panel A1 & B1, we report standard errors using the arbitrary clustering method with different thresholds on spatial distance among districts. In panel A2 & B2, we report standard errors using the arbitrary clustering method with different thresholds (i.e., at the median, the 3rd quantile, or using the Bartless method) on geographic dissimilarity that is measured by district-level average elevation, average slope, river length, the proportion of river with slope falling into 0-3, 3-20, 20-30, 30-50 (in degrees); and with elevation falling into 0-250, 250-1000, 1000-3000, $\geq$3000 (in meters). *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table A10: Placebo Test with Randomization Inference

Variable	Baseline	Simulated Coefficients				
		Mean	p10	p50	p90	% Closer to 0
A. CME Sample						
# Manufacturing Establishments	0.328***	0.311	0.280	0.295	0.310	92.0%
B. Census Male						
Employment Status						
Employer	-0.007	-0.006	-0.006	-0.006	-0.006	100.0%
Employee	0.095***	0.087	0.082	0.086	0.092	96.8%
Own Account Worker	-0.080***	-0.073	-0.078	-0.073	-0.069	96.8%
Other	-0.008	-0.007	-0.008	-0.007	-0.007	99.4%
Usual Activities						
Agriculture	-0.109***	-0.099	-0.105	-0.099	-0.094	97.6%
Salary & Wage	0.072***	0.066	0.062	0.066	0.070	96.8%
Own Enterprise	0.008*	0.008	0.007	0.008	0.008	82.4%
Extended Economic	-0.009*	-0.008	-0.009	-0.008	-0.008	96.0%
Household Work	0.002	0.002	0.002	0.002	0.002	19.0%
Study	0.020*	0.018	0.017	0.018	0.019	97.8%
C. Census Female						
Employment Status						
Employer	-0.010*	-0.010	-0.010	-0.010	-0.009	75.6%
Employee	0.028***	0.026	0.024	0.026	0.027	95.2%
Own Account Worker	-0.060**	-0.056	-0.059	-0.056	-0.053	93.2%
Other	0.042	0.040	0.038	0.040	0.042	85.2%
Usual Activities						
Agriculture	-0.088***	-0.082	-0.087	-0.082	-0.078	94.2%
Salary & Wage	0.019***	0.017	0.016	0.017	0.018	99.0%
Own Enterprise	-0.006	-0.005	-0.006	-0.005	-0.005	100.0%
Extended Economic	-0.015	-0.014	-0.015	-0.014	-0.013	97.4%
Household Work	0.037***	0.034	0.032	0.034	0.036	96.2%
Study	0.030***	0.028	0.026	0.028	0.030	95.4%

Notes: We perform a placebo test using the randomization inference method following Christian and Barrett (2017), where we randomly assign the number of newly constructed microhydro plants for each year among the regions that have new microhydro plants. We then calculate the cumulative number of microhydro plants based on these randomly assigned incremental numbers. Column (2) duplicates our baseline estimates. The last five columns report summary statistics of the coefficient estimates from 500 randomizations, including the mean, 10th percentile, median, 90th percentile, and the proportion of estimates that are closer to 0 compared to the baseline estimates.

Table A11: Robustness Check using Valid t-ratio Inference

	Coef. (1)	tF Adjustment Factor (2)	Adjusted S.E. (3)	95% CI (4)
A. CME Sample				
# Manufacturing Establishments	0.328	1.071	0.087	[0.158, 0.498]
B. Census Male				
Employment Status				
Employer	-0.007	1.092	0.005	[-0.018, 0.004]
Employee	0.095	1.092	0.017	[0.061, 0.129]
Own Account Worker	-0.080	1.092	0.023	[-0.125, -0.035]
Other	-0.008	1.092	0.017	[-0.042, 0.026]
Usual Activities				
Agriculture	-0.109	1.092	0.024	[-0.156, -0.062]
Salary & Wage	0.072	1.092	0.015	[0.042, 0.102]
Own Enterprise	0.008	1.092	0.005	[-0.003, 0.019]
Extended Economic	-0.009	1.092	0.005	[-0.020, 0.002]
Household Work	0.002	1.092	0.003	[-0.004, 0.008]
Study	0.020	1.092	0.012	[-0.004, 0.044]
C. Census Female				
Employment Status				
Employer	-0.010	1.099	0.007	[-0.023, 0.003]
Employee	0.028	1.099	0.007	[0.015, 0.041]
Own Account Worker	-0.060	1.099	0.032	[-0.122, 0.002]
Other	0.042	1.099	0.030	[-0.016, 0.100]
Usual Activities				
Agriculture	-0.088	1.099	0.033	[-0.153, -0.023]
Salary & Wage	0.019	1.099	0.005	[0.008, 0.030]
Own Enterprise	-0.006	1.099	0.004	[-0.015, 0.003]
Extended Economic	-0.015	1.099	0.018	[-0.049, 0.019]
Household Work	0.037	1.099	0.019	[0.000, 0.074]
Study	0.030	1.099	0.012	[0.006, 0.054]

Notes: We follow Lee et al. (2022) to calculate the tf confidence intervals using the adjusted standard errors. Column (1) duplicates our baseline estimates. Column (2) and (3) report the tF adjustment factors and adjusted standard errors. Column (4) presents the 95% confidence interval calculated using the adjusted standard errors.

Table A12: Robustness Check of Excluding CREP Regions: Employment Status

Dep. Var.:	Reported employment status is:			
	Employer	Employee	Own Account Worker	Other
	(1)	(2)	(3)	(4)
A. Male				
MHP	-0.006	0.096***	-0.089***	-0.002
	(0.006)	(0.018)	(0.023)	(0.018)
K-P F-Stats	42.02	42.02	42.02	42.02
Observations	2,250,697	2,250,697	2,250,697	2,250,697
B. Female				
MHP	-0.011	0.029***	-0.071**	0.053*
	(0.007)	(0.006)	(0.032)	(0.030)
K-P F-Stats	39.43	39.43	39.43	39.43
Observations	2,389,391	2,389,391	2,389,391	2,389,391
Individual Control	✓	✓	✓	✓
VDC FE	✓	✓	✓	✓
Province-Year FE	✓	✓	✓	✓

Notes: We exclude regions with any CREP grid connection as a robustness check. MHP is the cumulative number of microhydro plants in a VDC from the first-stage regressions. The outcome variables, which use microdata from the 2001 and 2011 iterations of the Nepal Population Census, are collected for household members 10 years of age and older. The outcome variables are responses to the individual's employment status. The other group includes both unpaid family workers and those that did not state an employment status. Additional variable descriptions provided in Appendix A4. The individual controls include the individual's age, the individual's education, the household size, and whether the household has a toilet. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table A13: Robustness Check of Excluding CREP Regions: Usual Activities

	Own Agriculture & Farming	Salary & Wage	Own Enterprise	Extended Economic	Household Work	Study
	(1)	(2)	(3)	(4)	(5)	(6)
A. Male						
MHP	-0.118***	0.074***	0.010**	-0.011**	0.003	0.026**
	(0.024)	(0.016)	(0.005)	(0.005)	(0.003)	(0.011)
K-P F-Stats	42.02	42.02	42.02	42.02	42.02	42.02
Observations	2,250,697	2,250,697	2,250,697	2,250,697	2,250,697	2,250,697
B. Female						
MHP	-0.102***	0.020***	-0.005	-0.013	0.041**	0.035***
	(0.033)	(0.005)	(0.004)	(0.017)	(0.019)	(0.011)
K-P F-Stats	39.43	39.43	39.43	39.43	39.43	39.43
Observations	2,389,391	2,389,391	2,389,391	2,389,391	2,389,391	2,389,391
Individual Controls	✓	✓	✓	✓	✓	✓
VDC FE	✓	✓	✓	✓	✓	✓
Province-Year FE	✓	✓	✓	✓	✓	✓

Notes: We exclude regions with any CREP grid connection as a robustness check. MHP is the cumulative number of microhydro plants in a VDC from the first-stage regressions. The outcome variables, which use microdata from the 2001 and 2011 iterations of the Nepal Population Census, are collected for household members 10 years of age and older. The outcome variables are the individual's usual work in the past 12 months: agriculture, salary/wage, own economic enterprises, extended economic enterprises, household work, and study. Additional variable descriptions provided in Appendix A4. The individual controls include the individual's age, the individual's education, the household size, and whether the household has a toilet. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table A14: Adding Linear Trends Interacted with Baseline Covariates: CME Analysis

Dep. Var.:	IHS(#Manufacturing Establishments)		
	Equal Divide	Exclude Duplicates	Double Count
	(1)	(2)	(3)
MHP	0.439***	0.421***	0.448***
	(0.133)	(0.130)	(0.135)
K-P F-Stats	23.65	23.65	23.65
Observations	2,241	2,241	2,241
Baseline × Treads	✓	✓	✓
Municipality FE	✓	✓	✓
Province-Year FE	✓	✓	✓

Notes: We add interactions between linear time trend and baseline covariates, including the number of households, the length of road, the distance to the nearest city, the length of river, and the number of manufacturing firms. The outcome variable is the inverse hyperbolic sine of the number of manufacturing establishments (employing 10 or more individuals) located within a municipality. Municipality-year controls include the logarithm of average elevation and slope in a municipality, both indicated with year fixed effects. The baseline mean is the outcome variable raw mean (i.e., not the inverse hyperbolic sine) for those locations in which microhydro plants are later constructed. Data sources are further described in Data Appendix A3. Each column in this table presents a different way of addressing the changing spatial boundaries from VDCs to municipalities, as the administrative boundaries shifted from 2,974 VDCs to 747 municipalities and resulted in multiple VDCs per municipality. Most prior VDCs were cleanly encapsulated by one single new municipality; however, some VDCs were covered by new multiple municipalities (further explained in Appendix A3.2). We can equally divide such VDCs (column 1), exclude them (column 2), or double count them (column 3). Robust standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table A15: Adding Linear Trends Interacted with Baseline Covariates: Employment Status

Dep. Var.:	Reported employment status is:			
	Employer	Employee	Own Account Worker	Other
	(1)	(2)	(3)	(4)
A. Male				
MHP	0.002	0.070***	-0.059***	-0.012
	(0.006)	(0.016)	(0.021)	(0.017)
K-P F-Stats	47.68	47.68	47.68	47.68
B. Female				
MHP	-0.009	0.031***	-0.040	0.018
	(0.007)	(0.007)	(0.030)	(0.029)
K-P F-Stats	46.55	46.55	46.55	46.55
Baseline × Treads	✓	✓	✓	✓
Individual Controls	✓	✓	✓	✓
VDC FE	✓	✓	✓	✓
Province-Year FE	✓	✓	✓	✓

Notes: We add interactions between linear time trend and baseline covariates, including the number of households, the length of road, the distance to the nearest city, and the length of river. Data on the microhydro project construction (timing and location) are based on Alternative Energy Promotion Center records and used to create the MHP variable. The outcome variables, which use microdata from the 2001 and 2011 iterations of the Nepal Population Census, are collected for household members 10 years of age and older. The outcome variables are responses to the individual's employment status. The other group includes both unpaid family workers and those that did not state an employment status. Additional variable descriptions provided in Appendix A4. The individual controls include the individual's age, the individual's education, the household size, and whether the household has a toilet. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table A16: Adding Linear Trends Interacted with Baseline Covariates: Usual Activities

	Agriculture	Salary & Wage	Own Enterprise	Extended Economic	Household Work	Study
	(1)	(2)	(3)	(4)	(5)	(6)
A. Male						
MHP	-0.065***	0.057***	0.003	-0.006	-0.001	0.007
	(0.020)	(0.015)	(0.005)	(0.006)	(0.003)	(0.011)
K-P F-Stats	47.68	47.68	47.68	47.68	47.68	47.68
B. Female						
MHP	-0.073**	0.027***	0.002	0.004	0.012	0.020*
	(0.032)	(0.006)	(0.004)	(0.016)	(0.018)	(0.011)
K-P F-Stats	46.55	46.55	46.55	46.55	46.55	46.55
Baseline × Treads	✓	✓	✓	✓	✓	✓
Individual Controls	✓	✓	✓	✓	✓	✓
VDC FE	✓	✓	✓	✓	✓	✓
Province-Year FE	✓	✓	✓	✓	✓	✓

Notes: We add interactions between linear time trend and baseline covariates, including the number of households, the length of road, the distance to the nearest city, and the length of river. Data on the microhydro project construction (timing and location) are based on Alternative Energy Promotion Center records and used to create the MHP variable. The outcome variables, which use microdata from the 2001 and 2011 iterations of the Nepal Population Census, are collected for household members 10 years of age and older. The outcome variables are the individual's usual work in the past 12 months: agriculture, salary/wage, own economic enterprises, extended economic enterprises, household work, and study. Additional variable descriptions provided in Appendix A4. The individual controls include the individual's age, the individual's education, the household size, and whether the household has a toilet. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table A17: First-Stage Instrumental Variable Regressions: Slope IV

Dep. Var.:	Cumulative #MHPs in a Municipality/VDC		
	(1) CME Sample	(2) Census Sample: Male	(3) Census Sample: Female
$[3, 20] \times N_t$	0.034***	0.004	0.004
	(0.013)	(0.003)	(0.003)
$[20, 30] \times N_t$	0.193***	0.030***	0.030***
	(0.021)	(0.004)	(0.004)
$[30, 50] \times N_t$	0.399***	0.067***	0.068***
	(0.044)	(0.014)	(0.015)
Individual Controls		✓	✓
VDC FE		✓	✓
Municipality FE	✓		
Province-Year FE	✓	✓	✓
K-P F-Stats	22.68	18.07	18.39
Observations	2,241	2,371,140	2,531,500
Adjusted R^2	0.853	0.722	0.734
#Regions	747	3,974	3,974
Observation Level	Municipality	VDC	VDC

Notes: There are three instrumental variables in these regressions, which are created by the following interactions: [a binary indicator variable equaling 1 if the average river slope falls into one of the following categories: 3-20, 20-30, or greater than 30, and equaling 0 otherwise] $\times$ [MHP number over year in Nepal]. The omitted group is the average river slope between 0 and 3. Individual controls include age, education, household size (number of people), house amenities (toilet, water), and caste. Standard errors are clustered at the district level and shown in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A18: First-Stage Instrumental Variable Regressions: Two-Sample IV

Dep. Var.:	Cumulative #MHPs in a Municipality/VDC	
	Municipality (1)	VDC (2)
Carpet × N_t	0.225*** (0.030)	0.059*** (0.008)
VDC FE		✓
Municipality FE	✓	
Province-Year FE	✓	✓
Observations	8,217	43,417
#Regions	747	3,974

Notes: In this analysis, we estimate the first-stage regression using the annual panel of MHP construction. "Carpet × N_t" is the interaction between: an indicator of carpet identification at the municipality/VDC level and the cumulative number of microhydro plants in Nepal in a year. Standard errors are clustered at the district level and shown in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A19: Impact on Manufacturing Establishments: OLS & Alternative IV

Dep. Var.:	IHS(#Manufacturing Establishments)			
	OLS	OLS Restricted Sample	Slope IV	Two-Sample IV
	(1)	(2)	(3)	(4)
MHP	0.048***	0.053**	0.243***	0.328***
	(0.015)	(0.022)	(0.085)	(0.066)
#Municipalities	747	448	747	747
Observations	2,241	1,344	2,241	2,241
Municipality FE	✓	✓	✓	✓
Province-Year FE	✓	✓	✓	✓

Notes: MHP is the cumulative number of microhydro plants in a municipality. The outcome variable is the inverse hyperbolic sine of the number of manufacturing establishments (employing 10 or more individuals) located within a municipality. Column 1 shows the OLS estimation results. In column 2, we estimate the OLS model by restricting the sample to regions with river length above 50km. In column 3, we estimate the model using indicators for the average river slope in a region as the instrumental variables. In column 4, we estimate the model using a two-sample IV approach. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table A20: Impact on Employment Status: OLS & Alternative IV

Dep. Var.:	Reported employment status is:			
	Employer	Employee	Own Account Worker	Other
	(1)	(2)	(3)	(4)
A. Male, OLS	-0.001	0.019***	-0.012***	-0.005**
	(0.001)	(0.002)	(0.003)	(0.002)
B. Male, OLS Restricted Sample	-0.001	0.020***	-0.016	-0.003
	(0.004)	(0.007)	(0.016)	(0.012)
C. Male, Slope IV	-0.017*	0.180***	-0.133***	-0.030
	(0.010)	(0.034)	(0.035)	(0.026)
D. Male, Two-Sample IV	-0.008	0.110***	-0.094***	-0.009
	(0.006)	(0.017)	(0.022)	(0.019)
E. Female, OLS	-0.002**	0.005***	-0.006	0.003
	(0.001)	(0.001)	(0.004)	(0.004)
F. Female, OLS Restricted Sample	-0.003	0.004	-0.006	0.006
	(0.003)	(0.003)	(0.020)	(0.019)
G. Female, Slope IV	-0.028**	0.059***	-0.076*	0.044
	(0.011)	(0.012)	(0.040)	(0.041)
H. Female, Two-Sample IV	-0.012*	0.033***	-0.071**	0.051
	(0.007)	(0.006)	(0.032)	(0.031)

Notes: Each cell in the table reports the coefficient estimate of MHP, which is the cumulative number of microhydro plants in a municipality. In panel B and F, we restrict the sample to regions with river length above 50km. The outcome variables are responses to the individual's employment status. The other group includes both unpaid family workers and those that did not state an employment status. All regressions control for VDC fixed effects, province-year fixed effects, and individual characteristics. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table A21: Impact on Usual Activities: OLS & Alternative IV

	Agriculture (1)	Salary & Wage (2)	Own Enterprise (3)	Extended Economic (4)	Household Work (5)	Study (6)
A. Male, OLS	-0.021***	0.015***	0.001	-0.000	0.001*	0.002
	(0.003)	(0.002)	(0.001)	(0.001)	(0.001)	(0.002)
B. Male, OLS Restricted Sample	-0.021*	0.016**	-0.003	-0.001	0.001	0.010*
	(0.011)	(0.007)	(0.005)	(0.003)	(0.001)	(0.005)
C. Male, Slope IV	-0.205***	0.153***	0.001	-0.014	0.008*	0.012
	(0.042)	(0.032)	(0.007)	(0.009)	(0.005)	(0.018)
D. Male, Two-Sample IV	-0.126***	0.084***	0.010*	-0.011**	0.002	0.023*
	(0.022)	(0.016)	(0.005)	(0.005)	(0.003)	(0.012)
E. Female, OLS	-0.014***	0.004***	-0.002**	-0.003	0.010***	0.003
	(0.004)	(0.001)	(0.001)	(0.002)	(0.004)	(0.002)
F. Female, OLS Restricted Sample	-0.018	0.002	0.003	-0.009	0.007	0.012**
	(0.016)	(0.003)	(0.003)	(0.008)	(0.007)	(0.005)
G. Female, Slope IV	-0.173***	0.048***	-0.011*	-0.016	0.080***	0.025
	(0.048)	(0.010)	(0.006)	(0.025)	(0.028)	(0.019)
H. Female, Two-Sample IV	-0.104***	0.022***	-0.006	-0.017	0.042**	0.036***
	(0.032)	(0.005)	(0.004)	(0.018)	(0.019)	(0.011)

Notes: Each cell in the table reports the coefficient estimate of MHP, which is the cumulative number of microhydro plants in a municipality from the alternative IV first-stage regressions. In panel B and F, we restrict the sample to regions with river length above 50km. The outcome variables are the individual's usual work in the past 12 months: agriculture, salary/wage, own economic enterprises, extended economic enterprises, household work, and study. All regressions control for VDC fixed effects, province-year fixed effects, and individual characteristics. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table A22: Heterogeneous Impacts on Manufacturing Establishments by Distance to a City

Dep. Var.	IHS(# Manufacturing Establishments)	
	All	No-Grid
	(1)	(2)
Below 50km	0.427***	0.309
	(0.097)	(0.319)
Above 50km	0.084	0.040
	(0.079)	(0.233)
Outcome Baseline Mean	0.216	0.183
Observations	2,241	531

Notes: Each cell reports the 2SLS estimate of the coefficient for MHP, i.e., the cumulative number of microhydro projects. We estimate the heterogeneous impacts by distance to a city. We first calculate the distance between each VDC and the nearest city. Then for this municipality-level analysis, we take the average over the distances for all the VDCs in a municipality. All regressions control for municipality and province-year fixed effects. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table A23: Heterogeneous Impacts on Employment Status by Distance to a City

	Reported employment status is:			
	Employer	Employee	Own Account Worker	Other
	(1)	(2)	(3)	(4)
A. Male, All VDCs				
Below 50km	-0.010*	0.102***	-0.083***	-0.009
	(0.006)	(0.019)	(0.023)	(0.013)
Above 50km	0.008	0.065***	-0.068	-0.004
	(0.011)	(0.022)	(0.043)	(0.044)
Observations	2,371,140	2,371,140	2,371,140	2,371,140
B. Male, No-grid VDCs				
Below 50km	-0.013	0.047***	-0.035	0.001
	(0.009)	(0.017)	(0.024)	(0.017)
Above 50km	0.007	0.022	-0.020	-0.009
	(0.009)	(0.020)	(0.037)	(0.036)
Observations	505,062	505,062	505,062	505,062
C. Female, All VDCs				
Below 50km	-0.014**	0.030***	-0.054**	0.038*
	(0.007)	(0.007)	(0.024)	(0.021)
Above 50km	0.006	0.018**	-0.087	0.063
	(0.009)	(0.009)	(0.081)	(0.084)
Observations	2,531,500	2,531,500	2,531,500	2,531,500
D. Female, No-grid VDCs				
Below 50km	-0.015*	0.012*	-0.022	0.025
	(0.009)	(0.006)	(0.028)	(0.028)
Above 50km	0.003	0.008	-0.063	0.052
	(0.007)	(0.007)	(0.067)	(0.070)
Observations	556,872	556,872	556,872	556,872

Notes: Each cell reports the 2SLS estimate of the coefficient for MHP, i.e., the cumulative number of microhydro projects. For each sample (i.e., male vs female, all vs no-grid regions), we estimate the heterogeneous impacts of MHP by the distance from a VDC to the nearest city. All regressions control for individual characteristics (age, education, household size, and whether the household has a toilet), VDC and province-year fixed effects. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table A24: Heterogeneous Impacts on Usual Activities by Distance to a City

VARIABLES	Agriculture	Salary & Wage	Own Enterprise	Extended Economic	Household Work	Study
	(1)	(2)	(3)	(4)	(5)	(6)
A. Male, All VDCs						
Below 50km	-0.113***	0.079***	0.008*	-0.012**	0.002	0.020*
	(0.025)	(0.017)	(0.005)	(0.005)	(0.003)	(0.011)
Above 50km	-0.091**	0.043*	0.008	0.002	0.004	0.019
	(0.039)	(0.023)	(0.011)	(0.007)	(0.005)	(0.026)
Observations	2,371,140	2,371,140	2,371,140	2,371,140	2,371,140	2,371,140
B. Male, No-grid VDCs						
Below 50km	-0.054**	0.036**	0.013*	-0.011	-0.003	0.026*
	(0.025)	(0.017)	(0.006)	(0.008)	(0.005)	(0.014)
Above 50km	-0.032	0.009	0.004	0.006	-0.001	0.014
	(0.037)	(0.023)	(0.011)	(0.009)	(0.006)	(0.019)
Observations	505,062	505,062	505,062	505,062	505,062	505,062
C. Female, All VDCs						
Below 50km	-0.075***	0.020***	-0.008**	-0.027	0.035*	0.032**
	(0.028)	(0.005)	(0.003)	(0.017)	(0.018)	(0.012)
Above 50km	-0.148**	0.013*	0.003	0.043**	0.042	0.023
	(0.063)	(0.007)	(0.011)	(0.021)	(0.036)	(0.022)
Observations	2,531,500	2,531,500	2,531,500	2,531,500	2,531,500	2,531,500
D. Female, No-grid VDCs						
Below 50km	-0.034	0.010**	0.002	-0.015	0.017	0.021
	(0.037)	(0.005)	(0.004)	(0.019)	(0.028)	(0.013)
Above 50km	-0.106*	0.007	0.008	0.051**	0.026	0.012
	(0.064)	(0.005)	(0.013)	(0.024)	(0.040)	(0.019)
Observations	556,872	556,872	556,872	556,872	556,872	556,872

Notes: Each cell reports the 2SLS estimate of the coefficient for MHP, i.e., the cumulative number of microhydro projects. For each sample (i.e., male vs female, all vs no-grid regions), we estimate the heterogeneous impacts of MHP by the distance from a VDC to the nearest city. All regressions control for individual characteristics (age, education, household size, and whether the household has a toilet), VDC and province-year fixed effects. Standard errors are clustered at the district level and shown in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table A25: Impact on Employment Status - Exclude Individual Controls

	Reported employment status is:			
	Employer	Employee	Own Account Worker	Other
	(1)	(2)	(3)	(4)
A. Male, Weighted				
MHP	-0.006	0.087***	-0.087***	0.006
	(0.005)	(0.016)	(0.024)	(0.019)
B. Male, Unweighted				
MHP	-0.003	0.075***	-0.069***	-0.004
	(0.005)	(0.017)	(0.022)	(0.017)
C. Female, Weighted				
MHP	-0.011*	0.021***	-0.073**	0.062**
	(0.006)	(0.006)	(0.030)	(0.030)
D. Female, Unweighted				
MHP	-0.009	0.019***	-0.046	0.037
	(0.007)	(0.006)	(0.030)	(0.029)
Observations	7,708	7,708	7,708	7,708

Notes: For these analyses, we aggregate the individual-level census data to the VDC level by taking the mean of the outcomes. MHP is the cumulative number of microhydro plants in a VDC from the first-stage regressions. The outcome variables are responses to the individual's employment status. Employment status can be as an employer, employee, own account work (i.e., self-employed), or other, which includes unpaid family work as well as those that do not report an employment status. Panel A and C report coefficient estimates from regressions that are weighted by VDC population. Panel B and D report coefficient estimates from unweighted regressions. All regressions control for VDC and province-year fixed effects. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table A26: Impact on Usual Activities - Exclude Individual Controls

VARIABLES	Agriculture	Salary & Wage	Own Enterprise	Extended Economic	Household Work	Study
	(1)	(2)	(3)	(4)	(5)	(6)
A. Male, Weighted						
MHP	-0.122***	0.065***	0.014***	-0.010*	0.002	0.034**
	(0.025)	(0.014)	(0.005)	(0.005)	(0.003)	(0.016)
B. Male, Unweighted						
MHP	-0.094***	0.061***	0.008*	-0.007	-0.002	0.031**
	(0.022)	(0.015)	(0.004)	(0.005)	(0.003)	(0.012)
C. Female, Weighted						
MHP	-0.103***	0.012**	-0.003	-0.017	0.030*	0.055***
	(0.031)	(0.005)	(0.004)	(0.016)	(0.016)	(0.016)
D. Female, Unweighted						
MHP	-0.085**	0.016***	-0.002	-0.004	0.007	0.056***
	(0.033)	(0.005)	(0.003)	(0.014)	(0.018)	(0.014)
Observations	7,708	7,708	7,708	7,708	7,708	7,708

Notes: For these analyses, we aggregate the individual-level census data to the VDC level by taking the mean of the outcomes. MHP is the cumulative number of microhydro plants in a VDC from the first-stage regressions. The outcome variables are the individual's usual work in the past 12 months. Categories of usual work activities include: agriculture, wage or salaried work, small business activities (owning one's own enterprise), extended economic work (collecting fuel and water, preparing goods for consumption at home), household chores (cooking, cleaning, child care, etc.), and studies. Panel A and C report coefficient estimates from regressions that are weighted by VDC population. Panel B and D report coefficient estimates from unweighted regressions. All regressions control for VDC and province-year fixed effects. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table A27: MHP Capacity - First Stage

	CME Sample		Census Sample: Male		Census Sample: Female	
	kW	kWpc	kW	kWpc	kW	kWpc
	(1)	(2)	(3)	(4)	(5)	(6)
Carpet × N_t	5.367***	7.611***	1.610***	0.484***	1.617***	0.476***
	(0.960)	(1.083)	(0.257)	(0.092)	(0.261)	(0.086)
K-P F-Stats	49.44	31.24	39.21	27.78	38.33	30.50
Observations	2,241	2,241	2,371,106	2,371,106	2,531,455	2,531,455
Municipality FE	✓	✓				
VDC FE			✓	✓	✓	✓
Individual Controls			✓	✓	✓	✓
Province-Year FE	✓	✓	✓	✓	✓	✓

Notes: "kW" is the cumulative MHP capacity (in kilowatt). For the CME sample, "kWpc" is the cumulative MHP capacity per 10,000 population. For the census sample, "kWpc" is the cumulative MHP capacity per 1,000 population. "Carpet×N_t" is the interaction between: an indicator of carpet identification at the municipality/VDC level and the cumulative number of microhydro plants in Nepal in a year. Individual controls include the individual's age and education, the household size (number of people) and caste, and house amenities (toilet and water access). Standard errors are clustered at the district level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A28: Impact on Manufacturing Establishments - MHP Capacity

VARIABLES	IHS(# Manufacturing Establishments) (1)	# Establishments per 10k Population (2)
kW	0.010***	
	(0.002)	
kWpc		0.060*
		(0.032)
Outcome Baseline Mean	0.216	0.216
K-P F Stats	49.44	31.24
Observations	2,241	2,235
Municipality FE	✓	✓
Province-Year FE	✓	✓

Notes: Data is at the municipality level. "kW" is the cumulative MHP capacity (in kilowatt). "kWpc" is the cumulative MHP capacity per 10,000 population. The outcome variable in column (1) is the inverse hyperbolic sine of the number of manufacturing establishments. The outcome variable in column (2) is the number of manufacturing establishments per 10,000 population. Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Standard errors are clustered at the district level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A29: Impact on Employment Status - MHP Capacity

	Reported employment status is:			
	Employer	Employee	Own Account Worker	Other
	(1)	(2)	(3)	(4)
A. Male, kW	-0.000	0.004***	-0.003***	-0.000
	(0.000)	(0.001)	(0.001)	(0.001)
B. Male, kWpc	-0.001	0.014***	-0.012***	-0.001
	(0.001)	(0.003)	(0.004)	(0.002)
C. Female, kW	-0.000*	0.001***	-0.003**	0.002
	(0.000)	(0.000)	(0.001)	(0.001)
D. Female, kWpc	-0.002	0.004***	-0.009*	0.006
	(0.001)	(0.001)	(0.005)	(0.004)

Notes: Data is at the individual level. Each cell reports the coefficient estimate of the MHP capacity from a separate 2SLS regression. Panel A and B uses the male sample. Panel C and D uses the female sample. Panel A and C measure the capacity using the cumulative kW of microhydro plants. Panel B and D measure the capacity using the cumulative kW of microhydro plants per 1,000 population. The outcome variables are responses to the individual's employment status. Employment status can be as an employer, employee, own account work (i.e., self-employed), or other, which includes unpaid family work as well as those that do not report an employment status. All regressions control for VDC fixed effects, province-year fixed effects, and individual controls (including individual's age, the individual's education, the household size, and whether the household has a toilet). Standard errors are clustered at the district level and shown in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table A30: Impact on Usual Activities - MHP Capacity

	Own Agriculture & Farming (1)	Salary & Wage (2)	Own Enterprise (3)	Extended Economic (4)	Household Work (5)	Study (6)
A. Male, kW	-0.005***	0.003***	0.000*	-0.000*	0.000	0.001*
	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
B. Male, kWpc	-0.016***	0.010***	0.001*	-0.001*	0.000	0.003*
	(0.004)	(0.002)	(0.001)	(0.001)	(0.000)	(0.002)
C. Female, kW	-0.004***	0.001***	-0.000	-0.001	0.002**	0.001***
	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)
D. Female, kWpc	-0.013***	0.003***	-0.001	-0.002	0.005*	0.004**
	(0.005)	(0.001)	(0.001)	(0.002)	(0.003)	(0.002)

Notes: Data is at the individual level. Each cell reports the coefficient estimate of the MHP capacity from a separate 2SLS regression. Panel A and B uses the male sample. Panel C and D uses the female sample. Panel A and C measure the capacity using the cumulative kW of microhydro plants. Panel B and D measure the capacity using the cumulative kW of microhydro plants per 1,000 population. The outcome variables are the individual's usual work in the past 12 months. Categories of usual work activities include: agriculture, wage or salaried work, small business activities (owning one's own enterprise), extended economic work (collecting fuel and water, preparing goods for consumption at home), household chores (cooking, cleaning, child care, etc.), and studies. All regressions control for VDC fixed effects, province-year fixed effects, and individual controls (including individual's age, the individual's education, the household size, and whether the household has a toilet). Standard errors are clustered at the district level and shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.