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Determinants and Consequences of Electrification in India: A Cross Sectional Analysis of Socioeconomic Inequities

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Abstract

This study examines the effects of village-level electrification on socioeconomic welfare in rural India, with a focus on inequities in access and outcomes. Electrification is widely regarded as a catalyst for development, improving productivity, educational attainment, and income. However, the distribution of these benefits remains uneven. Using cross-sectional data from the Socioeconomic High Resolution Urban Geographic (SHRUG) dataset, this paper investigates the relationship between eelctricity access and estimated monthly consumption per capita, a proxy for welfare.

The analysis employs multiple linear regression to control for factors such as income, poverty rates, gender composition, and land ownership. Results indicate that access to domestic electricity increases estimated monthly consumption by 1.6%, highlighting its positive impact on welfare. However, access to commercial electricity shows no significant effect, underscoring the limited role of electrification in non-agricultural sectors. The findings reveal that higher-income villages are more likely to benefit from electrification, exacerbating existing socioeconomic inequities.

This study contributes to the growing body of literature by offering village-level insights into the determinants and consequences of electrification. Policymakers must address distributional disparities and prioritize targeted strategies-such as integrating gender empowerment and poverty alleviation programs- to ensure equitable access and masximize the developmental benefits of rural electrification.

Introduction

Access to electricity is widely recognized as a cornerstone of socioeconomic development. Electrification enhances productivity, improves education outcomes, and increases income, making it a critical tool for poverty reduction in developing countries. Despite significant global progress, nearly one billion people still lack access to electricity, with rural areas in developing nations experiencing the greatest inequities (Burlig and Preonas 2024). India provides a compelling case for examining the impacts of rural electrification: Between 2000 and 2016, India contributed to 80% of global gains in household grid connections, underscoring its efforts to expand energy infrastructure to underserved areas.

However, the benefits of electrification are not distributed evenly. Existing research revals discrepancies in welfare outcomes based on population size, socioeconomic status, and local conditions. For instance, Burlig and Preonas (2024) find that smaller villages often experience limited or even negative welfare impacts from electrification, while larger villages see significant gains. Similarly, Khandker et al. (2012) show that higher-income households benefit more from electrification, as they are better positioned to leverage new energy resources for productivity and consumption. These findings raise important questions about the determinants of electrification and its role in addressing socioeconomic inequities at the village level.

This study seeks to explore two central questions: 1) What are the determinants of access to electrification for rural villages in India? 2) To what extent does electrification improve welfare, as measured by estimated monthly consumption per capita?

Using the Socioeconomic High Resolution Urban Geographic (SHRUG) dataset, this paper conducts a cross-sectional analysis at the village level to examine the relationship between electrification and welfare. While much of the existing research focuses on household-level impacts using datasets like the IHDS, this study offers a unique perspective by using data aggregated at the village level. The results aim to provide insights into the inequities of access and inform targeted policy interventions for inclusive development.

The paper proceeds as follows: Section 2 reviews relevant literature, highlighting findings on the impacts of electrification and factors influencing its distribution. Section 3 outlines the theoretical framework and hypothesis. Section 4 describes the methodology, including the data and regression model used. Section 5 presents the results, and section 6 discusses their implications. Finally, section 7 concludes with policy recommendations and directions for future research.

Literature Review

Electrification is widely regarded as a driver of economic development. Several studies demonstrate its positive effects on education, labor markets, and income.

Khandker et al. (2012) finds that electrification increases weekly study time for children by 1 hour, boosts women's employment hours by 17%, and raises per capita income by 38.6%. This highlights how electricity can alleviate household labor, particularly for women, freeing up time for income-generating activities.

Rathi and Vermaak (2018) provide evidence that electrification improves rural labor market outcomes with a gendered lens: women's labor participation increases due to reduced time spent on fuel collection and domestic chores, while men's participation shows slight declines.

Burlig and Preonas (2024) find that smaller villages experience negative welfare effects after gaining electricity access, in contrast to larger villages where welfare nearly triples. This raises questions about the scalability and equity of eledctrification programs in India. Sedai et al. (2021) emphasizes that marginalized communities derive fewer benefits from electrification compared to dominant groups, underscoring how social structures influence outcomes.

In Khandker et al. (2012) researchers argue that the impact of electrification across income and expenditure vary with higher income households receiving more benefits from electrification. In their study Khandker et al. (2012) say that it can be argued income and expenditure don't depend on proportion of households with electricity, rather, it depends on household size and age composition of the household.

In Sedai et al. (2021) researchers examine the probability of electrification and the effect of electrification for marginalized communities compared to dominant communities using the IHDS II data set. They find that marginalized communities benefit less from electrification than dominant communities.

Researchers in Rathi and Vermaak (2018) examine the impacts of rural electrification on labor market outcomes through a gendered lens. The study finds that on average when rural Indian communities receive access to electricity, women are more likely to work at least 240 hours, and men are less likely to work. The study argues this is because access to electricity frees up time by reducing time spent collecting fuel and making household tasks more efficient. In Rathi and Vermaak (2018) argues the extent that electrification improves the labor force depends on supporting policies, labor absorption capacity and willingness to participate in income generating activities which may be related to local norms. The Rathi and Vermaak (2018) study concludes that policy makers should consider local social and political structures, gender roles, and labor absorptive capacity to realize benefits of rural electrification programs. Singh (2016) and Auerbach (2019) provide evidence showing that social, cultural and political structures have important effects on development.

Theory and Hypothesis

Examining how electricity access shapes the overall economic landscape of impoverished villages is highly relevant for developing countries seeking to expand

their energy infrastructure and improve living standards. India presents an instructive setting to investigate questions related to economic outcomes.

In 1947, 1500 villages in India had access to electricity. India contributed to 80% of global gains in new household grid connections between 2000 and 2016 (Burlig and Preonas 2024). Since 1951 India has implemented at least ten major initiatives aimed at increasing electrification (Rathi and Vermaak 2018). Among the most notable include the Rajiv Gandhi Grameen Vidyutikaran Yojna (RGGVY) from 2005-2011, which had a target of achieving 100 percent rural electrification, and the Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) which succeeded the RGGVY program and is focused on providing more consistent power supply to rural areas of India.

Existing research, such as Thomas et al. (2020), suggests a positive association between electrification and total household expenditure using the latter as a proxy for disposable income. This paper attempts to examine this effect.

This study contributes to the literature by examining these relationships at the village level. Using the Socioeconomic High-resolution Rural-Urban Geographic (SHRUG) dataset which includes data from the 2011 Indian population census and the Socio-Economic and Caste Census (SECC), the study adopts a cross sectional analysis that focuses on village level variation in electrification and socioeconomic indicators. This approach allows the paper to capture how initial conditions such as education levels, land assets, and housing quality may shape the likelihood of electrification and the magnitude of its economic benefits.

Based on the existing literature, this paper derives to hypothesis:

Hypothesis 1: Villages that have access to electricity will exhibit higher average per capita consumption levels than villages without access. This reflects the expected productivity gains, increased labor market participation, and reduced opportunity costs associated with traditional fuel use.

Hypothesis 2: Villages with relatively stronger socioeconomic foundations such as higher levels of education, better housing conditions, and greater land assets will be both more likely to have access to electricity and more effectively translate that access into higher consumption levels. The initial socioeconomic environment influences the probability of electrification and the extent of its positive impact.

Methodology

This study employs a cross-sectional analysis to investigate the relationship between village-level electrification and welfare outcomes, measured by estimated monthly consumption per capita. The analysis utilizes data from the SHRUG dataset. The SHRUG dataset aggregates household level data into village level metrics, providing a robust framework for analyzing socioeconomic outcomes at the village scale.

The unit of analysis for this study is the village, aggregated from household level data. This approach allows for identification of collective welfare impacts of electrification, complementing prior household level studies. Village level analysis is particularly relevant for policy formulation, as rural electrification programs are often implemented at this scale.

Using a multiple linear regression we are able to simulate a ceterus peribus effect, holding other factors fixed. By controlling for factors such as the proportion of the household that had an income of at least 5,000 Rs, hours of electricity the village has in the summer, rate of poverty in the village, proportion of the population that is female, proportion of the population that is female and in poverty, proportion of people in the village that own land, the analysis controls for factors that may affect consumption.

The various types of electricity access signify if a village had access to electricity for that sector. According to 2011 population census documentation, if 10% of households were electrified, the variable for domestic access to electricity was coded as a 1. If the village had access to electricity for agriculture, the electricity for agriculture variable was coded as a 1. If the village had access to electricity for commercial purposes, the variable for commercial electricity was coded as a 1. The SECC records earnings for the highest earning member of the household in three bins, 0 to 4,999 rupees, 5,000 to 9,999 rupees, and 10,000 or more rupees. According to Asher and Novosad (2019) 85% of households report being in the lowest bin. This analysis used the 5,000 to 9,999 rupee bin to estimate the impact for lowest and highest earners.

Data

Shrug is an open source repository of Indian village-level datasets Asher et al. (2021) . The data set includes population census data from 2001 and 2011, and Socioeconomic and Caste Census (SECC) data from 2011. Researchers Asher et al. (2021) create a measure of estimated consumption per capita and estimated poverty level. To create the variables Asher et al. (2021) use data from the Indian Human Development Survey (IHDS-II) and combine it with data from the SECC. They regress household consumption from the IHDS data set with SECC data that includes household level enumeration of assets. The IHDS consumption expenditures are based on 47 questions about household consumption. The total average total expenditure per household is used as a measure of each household's economic level. They include variables for consumption of food items such as rice, wheat, sugar and meat. The consumption metric also includes average amount spent on fuel and kerosene. The monthly consumption variable is based on household level consumption aggregated up to the village level to construct estimated consumption per capita and estimated poverty level.

Estimated consumption per capita is the outcome of interest for exploring the welfare impacts of electrification. It can be assumed that people who gain electricity will have better welfare outcomes and will consume more. If consumption

increases for villages that have electricity, having electricity is a significant indicator for development.

The Popoulation Census of India collects data about India's population on a decennial interval. In Vasudha Foundation (2013) it is estimated that 34,887 villages are yet to be electrified. The population census Census 2011 - concepts & definitions used in town and village amenities (2023) includes dummy variables for whether there is access to electricity for agriculture use, commercial use, and domestic use. If 10% of households in a village have electricity, it is coded as a 1 (Vasudha Foundation 2013). The data includes a dummy variable that indicates if all 3 sectors have access to electricity.

In India the population census is collected by the Registrar General. Enumerators are sent to visit every household across the country (Government of India n.d.). Information about each individual is gathered using a questionnaire and captures demographic information.

The SECC is conducted in the same way in a survey conducted by India's Ministry of Rural Development. The SECC aims to document the socioeconomic status of all households in urban and rural areas. The survey documents the material of the walls and roof individuals are living in, demographic information, education level, disabilities, caste status, and ownership of assets such as cell phones, motor vehicles, and land.

The survey data used for this analysis was collected in 2011, at the end of the RGGVY program. The program started its initiative towards 100% electrification in 2004 and villages that were selected for electrification in the first wave received funding between 2005 and 2008 (Burlig and Preonas 2024). Villages that were selected in the second wave received funding between 2008 and 2011 (Burlig and Preonas 2024).

Descriptive Statistics

Table 1 shows descriptive statistics for the covariates. There were 57% of villages in rural areas in 2011 that had electricity for domestic, agriculture, and commercial purposes, 90% of villages had electricity for at least 10% of households.

According to the data, 210,286 villages do not have electricity access for all three documented sectors, and 274,344 villages have electricity for all three sectors.

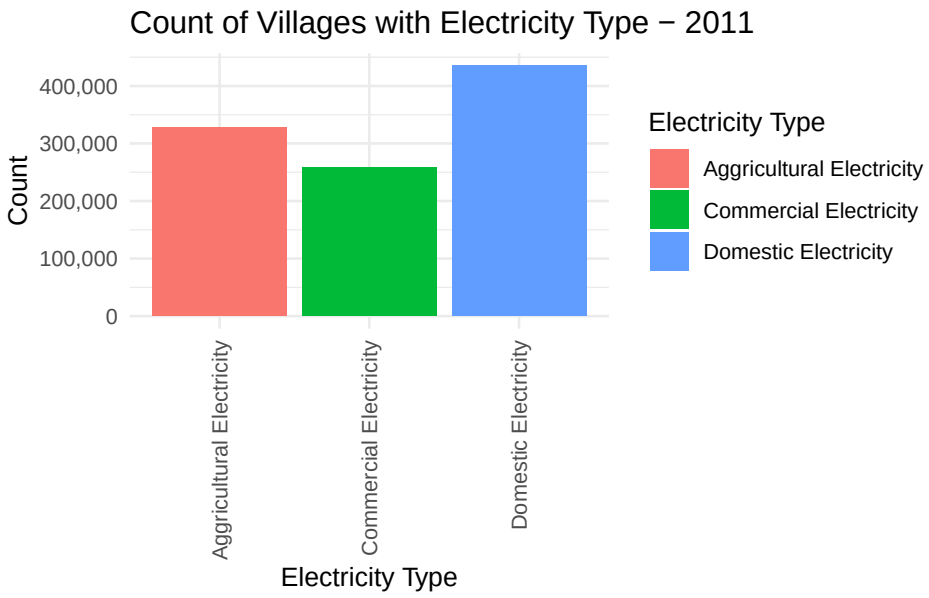
The bar graph below shows the raw data for access to power for each sector as they are coded for each village. Access to domestic electricity is the highest with 90% of villages being coded as having domestic electricity access, however it is unclear what percentage of households in these villages have access to electricity.

Table 1: Summary Statistics

Statistic	Mean	St. Dev.	Min	Max
Electricity Access - All	0.57	0.50	0	1
Electricity - Domestic	0.90	0.30	0	1
Electricity - Agg	0.68	0.47	0	1
Electricity - Commercial	0.53	0.50	0	1
HH Income - 5k	0.24	0.23	0.00	1.00
Summer Power (Hours)	6.94	7.72	0.00	24.00
Poverty	0.35	0.22	0.00	1.00
Proportion Female	718.32	978.90	0	192,721
Proportion Own Land	0.54	0.29	0.00	1.00

Table 2: Count of Villages with access in all 3 sectors

Electricity Access	Count
All sectors - No	210286
All sectors - Yes	274344



The map below shows estimated average monthly consumption per capita for sub districts in India that are classified as rural in the data set. Yellow areas represent sub districts that have an estimated monthly consumption of 10,000 INR or below, green is 20,000 or below, dark green is 30,000 or below, blue is 40,000 or below, and purple is 40,000 or more.

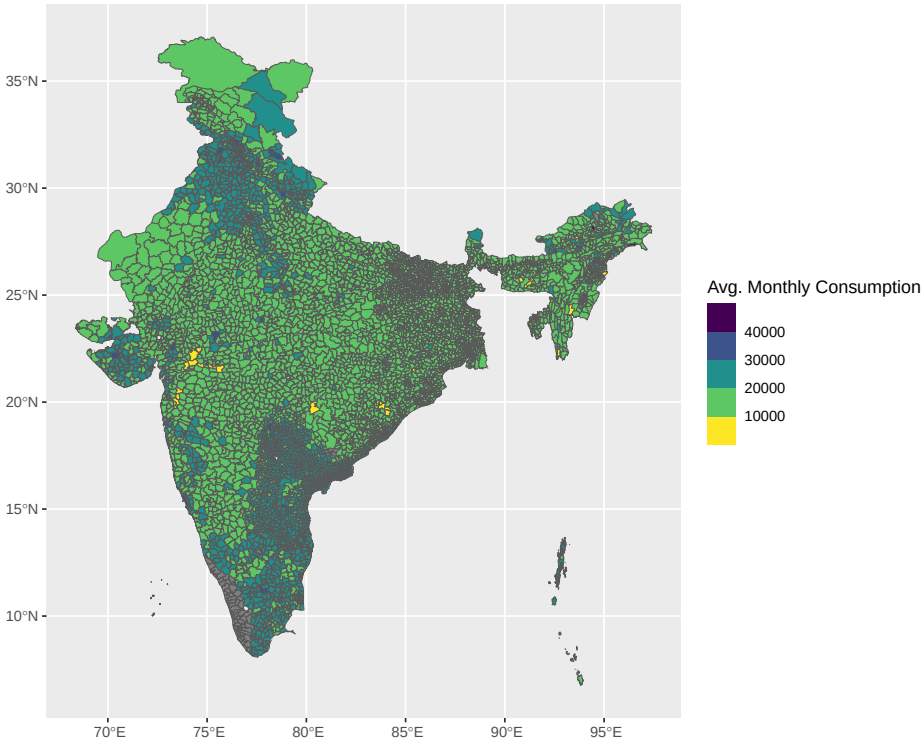


Fig. 1: This map shows estimated average consumption per capita at the sub district level in INR.

The map below shows a breakdown of sub districts by whether villages in the sub district have access to power in all 3 sectors. Over 75% of villages in sub districts that are yellow had all 3 types of power in 2011, a sub district that is green had between 50% and 75% of villages that had all 3 types of electricity, a sub district that is blue has between 25% and 50% of villages that had access to all types of electricity, and a sub district that is purple had less than 25% of villages that had access to all 3 kinds of electricity.

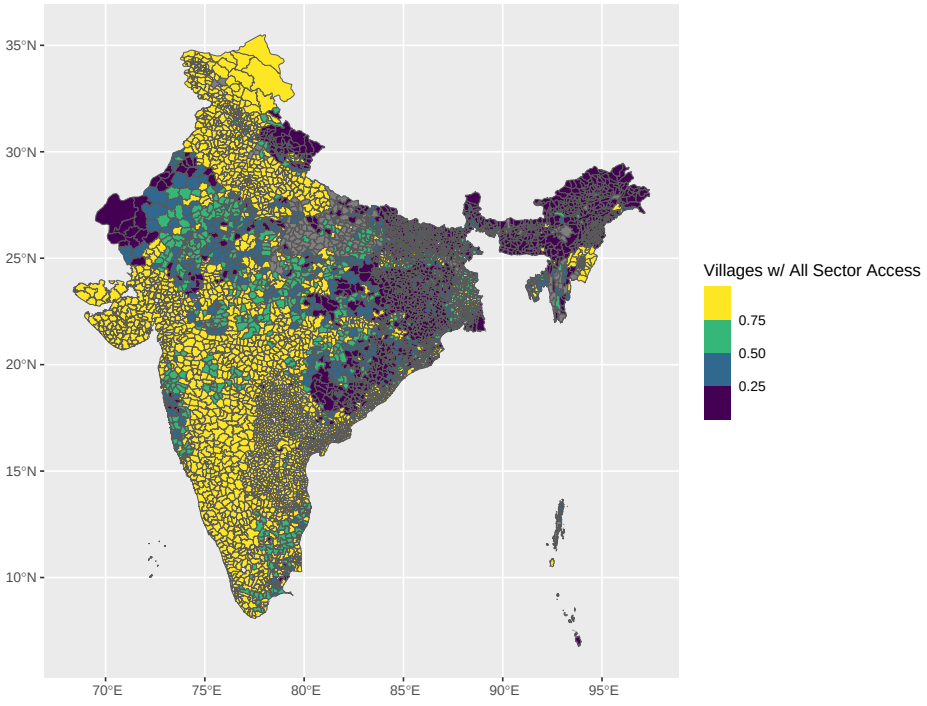


Fig. 2: This map shows the average percentage of villages in each subdistrict that had access to electricity in all 3 sectors

Model

The model used to explore the welfare impacts of electrification is as follows.

$$(log)Y_i = \beta_0 + \beta_1 AccesstoElectricity + \beta_2 Income5k + \beta_3 RateofPoverty + \beta_4 ProportionofFemaleinVillage + \beta_3\beta_4 RateofPovertyxProportionFemale + \beta_5 OwnLand + u$$

In this model Y_i is the outcome of interest, log of estimated monthly consumption. A log linear model also reduces the impacts of possible heterogeneity. The main independent variable β_1 is access to electricity. The covariate β_2 is share of households that the income of the highest earning member is greater than 5k Rs. β_3 is the estimated rate of poverty in the village. β_4 is proportion of the population that is female, $\beta_3 x \beta_4$ is an interaction term between rate of poverty in the village and proportion that is female, and β_5 is share of households that

own land. The error term u contains unexplained variance in the model.

Results

When the primary independent variable is access to electricity in all three sectors, consumption decreases by 2.6%. This result is shown in Table 3. This is likely a result of the dummy variable for the commercial sector. Since this data is based on the SECC census for rural populations, commercial access to electricity is arguably ineffective at increasing the welfare of a population. Rathi and Vermaak (2018) estimated 64% of employment in rural areas is agriculture. The covariants measuring if the household head made more than 5,000 Rs, hours of electricity in the summer, poverty rate, proportion of a population that is female, and the proportion of the population that owns land were centered in the models by subtracting each value from the average value.

Table 3: Regression Results

	Dependent variable:
	Consumption Per Capita
Electricity Access	0.026^{***}
	(0.0004)
HH Income - 5k	0.148^{***}
	(0.001)
Poverty	-1.221^{***}
	(0.001)
Proportion Female	-0.00001^{***}
	(0.00000)
Proportion Female x Poverty	-0.00002^{***}
	(0.00000)
Proportion Own Land	-0.055^{***}
	(0.001)
Constant	9.686^{***}
	(0.0003)
Observations	484,630
R^2	0.824
Adjusted R^2	0.824
Residual Std. Error	0.131 (df = 484623)
F Statistic	$377{,}557.900^{***}$ (df = 6; 484623)
Note:	*p<0.1; **p<0.05; ***p<0.01

The results in Table 4 show that consumption increases when villages have access to domestic electricity. If households have access to electricity, there is a 3.2% increase to estimated monthly consumption per capita. There is a

15% increase in estimated monthly consumption per capita if the highest earner in a household makes at least 5,000 Rs. Consumption decreases by 5.8% as the proportion of the population in the village that owns land increases. This result is unexpected. Possible explanations for this may include differences in expectations when households are wealthier. In the US, the expectation is that households that earn more money have higher expenditures. In India, it is possible that this is not the case. It is also possible that the argument posed by Khandker et al. (2012) that consumption is based on the size and makeup of a household explains this outcome. Consumption also decreases by 122% for every unit increase in a village's poverty rate. All of the coefficients in the model are statistically significant lower than the 1% level.

Table 4: Regression Results

	Dependent variable:
	Consumption Per Capita
Electricity Access - Domestic	0.032^{***}
	(0.001)
HH Income - 5k	0.150^{***}
	(0.001)
Poverty	-1.227^{***}
	(0.001)
Proportion Female	-0.00001^{***}
	(0.00000)
Proportion Female x Poverty	-0.00002^{***}
	(0.00000)
Proportion Own Land	-0.058^{***}
	(0.001)
Constant	9.673^{***}
	(0.001)
Observations	484,630
R^2	0.823
Adjusted R^2	0.823
Residual Std. Error	0.132 (df = 484623)
F Statistic	$375{,}677.700^{***}$ (df = 6; 484623)
Note:	*p<0.1; **p<0.05; ***p<0.01

To test How the regression performed with different types of electricity access each type of electricity access was inserted into the model as the primary independent variable. Table 5 displays the results of these models. All variables indicating access to electricity had a positive and statistically significant impact on average consumption per capita except for the commercial electricity access variable.

Table 5: Regression Models

	Dependent variable:		
	log(Consumption Per Capita)		
	(1)	(2)	(3)
Commercial Sector	-0.007^{***}		
	(0.001)		
Domestic		0.016^{***}	
		(0.001)	
Aggriculture			0.010^{***}
			(0.0005)
Electricity Access	0.147^{***}	0.149^{***}	0.148^{***}
	(0.001)	(0.001)	(0.001)
HH Income - 5k	0.003^{***}	0.002^{***}	0.002^{***}
	(0.00003)	(0.00003)	(0.00003)
Summer Power (Hours)	-1.210^{***}	-1.207^{***}	-1.208^{***}
	(0.001)	(0.001)	(0.001)
Poverty	-0.00001^{***}	-0.00001^{***}	-0.00001^{***}
	(0.00000)	(0.00000)	(0.00000)
Proportion Female	-0.00002^{***}	-0.00002^{***}	-0.00002^{***}
	(0.00000)	(0.00000)	(0.00000)
Proportion Female x Poverty	-0.055^{***}	-0.054^{***}	-0.053^{***}
	(0.001)	(0.001)	(0.001)
Constant	9.705^{***}	9.686^{***}	9.695^{***}
	(0.0003)	(0.001)	(0.0004)
R^2	0.826	0.826	0.826
Adjusted R^2	0.826	0.826	0.826
Note:			*p<0.1; **p<0.05; ***p<0.01

Discussion

The results of the linear regression model show that on average welfare for villages in India increased as a result of having access to electricity for domestic purposes.

Limitations to this analysis include possible overestimation due to model selection and choice of method. A preferable method would have used an instrumental variables or fixed effects regression model. Previous research on the impact of electrification outline that electrification is not randomized, therefore there may be unaccounted endogeneity in the model. Rathi and Vermaak (2018) outlines three ways that access to electricity may be endogenous to labor market outcomes. Sedai et al. (2021) asserts that consumption and distribution of electricity are endogenous. A cross sectional analysis is limited in its ability to make claims about the direction of the effect.

The second limitation of the analysis in this paper is that the scope is not narrow enough to make substantive claims about the effect of electrification. If the study was done with a more limited focus, such as the impact of electrification for previously un-electrified villages, there would be potential to make more substantial claims. Burlig and Preonas (2024)'s cites that by 2011, the RGGVY had connected 17.5 million households and connected 1 in 5 previously un-electrified households. A study similar to the one by Burlig and Preonas (2024) that examines the data using panel data and narrowing the scope to include homes that were previously un-electrified has greater policy implications for developing countries.

A necessary assumption for MLR is that the error term is not correlated with the explanatory variables. In this case It is possible that there is omitted variable bias, with unmeasured factors in the error term having high correlation with the predictors.

Future studies would benefit from combining the ideas of development research. Existing work has examined the impact of electrification in both directions and explored various causal mechanisms for benefits that result from electrification. It would be interesting to examine these effects across various political structures and areas. Singh (2016) points to Kerala's development indicators as an outlier compared to the development indicators of surrounding states. The study points to linguistic sub-nationalism as a causal factor in Kerala's development. Studies that seek to examine what factors have the greatest positive effect on development should include variables that account for variation in development such as sub-national solidarity.

Conclusion

This study examined the determinants of electrification in rural India using cross-sectional data from the SHRUG dataset. The finding reveal significant socioeconomic inequities in access to electricity, with higher-income households

more likely to benefit. While access to domestic electricity positively impacts welfare by increasing estimated monthly consumption, the results highlight that commercial electrification alone has limited utility in improving rural well being.

The analysis underscores the importance of targeted policies to address disparities in electrification. Programs must consider challenges such as poverty, gender and land distribution, to ensure equitable access to energy infrastructure. These finding align with previous research that stresses the interplay of social and economic factors in determining development outcomes. However, they also suggest that rural electrification policies need greater integration with broader development strategies, such as gender empowerment and income distribution.

This study has limitations, such as the reliance on cross-sectional data and the potential for unobserved confounders influencing results. Future research should employ longitudinal methods to better isolate causal relationships. Exploring the role of political, cultural, and institutional factors in shaping access to electricity could provide richer insights into how development policies can be optimized.

By shedding light on the inequities in electrification, this paper contributes to a growing body of literature emphasizng the need for inclusive energy policies in developing countries. Policymakers must prioritize marginalized communities to ensure that electrification serves as a catalyst for sustainable development.

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