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Reducing energy poverty: Characteristics of household electricity use in Vietnam☆

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ABSTRACT

Despite increased access to modern energy services being a key development priority, few studies have examined whether improved access is sufficient to facilitate universal energy use at the household level. Using micro data from Vietnam, we study how a national grid expansion is translated into households' electricity use over time. Our analysis reveals that household income is an important determinant of electricity consumption, and that this relationship is highly nonlinear with respect to income. We find a greater degree of inequality in electricity expenditure than we do in income. This finding suggests that a rapid increase in electricity access may not translate directly into increased use of electricity for low income households and could potentially increase the gap in energy use between high income and low income households. Lastly, we find that household characteristics, such as the education level of the household head, household size, as well as the type of housing (quality), are important factors that influence electricity consumption.

Introduction

The importance of energy provision for human development has been emphasized by the inclusion of universal energy access as one of the United Nations Sustainable Development Goals (SDGs). As a result of a tremendous global effort, the number of people without access to electricity has decreased from 1.1 billion people in 2015 to 840 million people in 2017 (UN, 2017, 2019). While such progress is noteworthy, welfare improvements are unlikely to occur unless households actually use the available electricity. In particular, low-income households with limited resources may postpone spending on electricity if traditional fuels or lighting sources are available, which may generate disparities in electricity use between low-and high-income households. As such, there is a limited, but growing body of micro-level evidence on the determinants of electricity use in developing countries that can be used to better understand how increased electricity access translates to electricity usage.

In upper-middle-income and high-income countries, income has been found to be an important determinant of energy consumption, among various household characteristics (Black, Stern, & Elworth, 1985; Cayla, Maizi, & Marchand, 2011; Dillman, Rosa, & Dillman, 1983; Romero-Jordán, del Río, & Peñasco, 2016). Higher levels of income removes financial constraints related to energy use and allows the purchase of appliances, which are major contributors to household energy consumption. These studies on developed countries find that households display varying electricity demand depending on the household's location in the income distribution. For example, among Spanish households, income and electricity demand display an N-shaped relationship: electricity demand increases proportionally with income from very low levels, but once the most basic electricity needs are met, the electricity demand decreases with income until households earn a sufficiently high income to begin using more electricity (Romero-Jordán et al., 2016). Cayla et al. (2011) find that the bottom 30% of households to have a flat profile for energy use with income, because they are financially constrained. They observe positive elasticity for the middle-income population only. In contrast to the microeconomic evidence on France and Spain, households in the United States are found to exhibit a rather low income elasticity of electricity consumption (Alberini, Gans, & Velez-Lopez, 2011; Kavousian,

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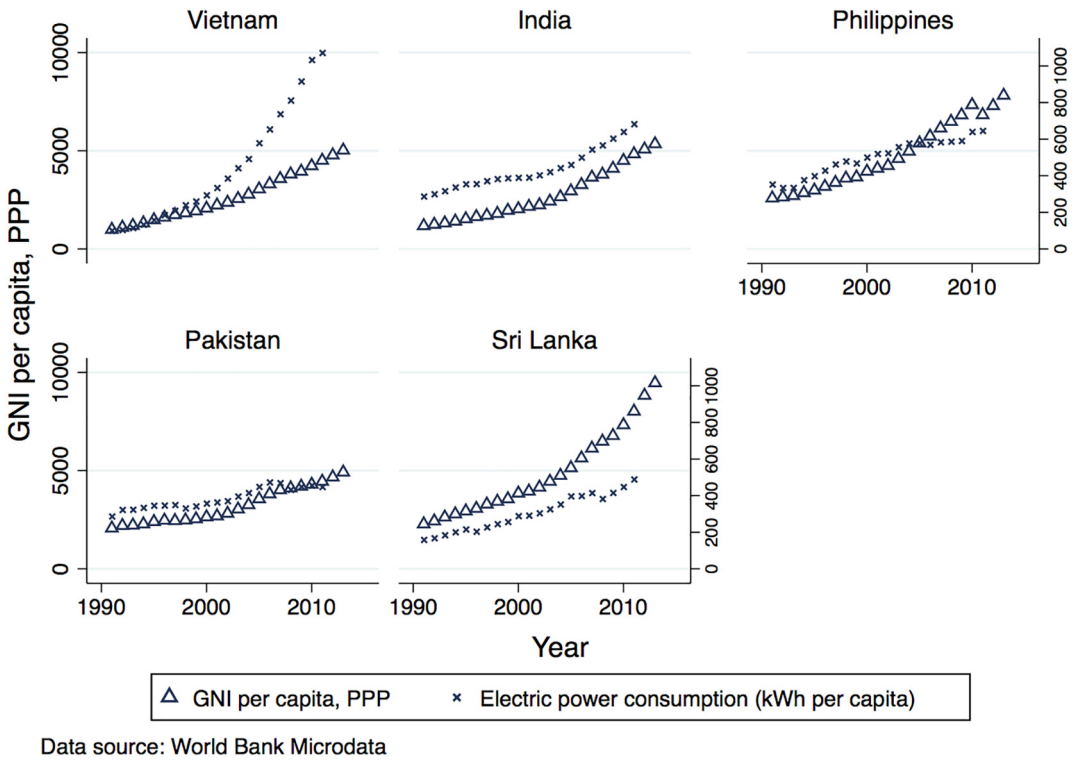

Fig. 1. Electric power consumption (kWh per capita) and GNI per capita, in PPP terms, for Vietnam, India, Philippines, Pakistan, and Sri Lanka during 1990–2014.

Rajagopal, & Fischer, 2013). Thus, in order to identify which household characteristics drive this difference, researchers use microeconomic data to discover the determinants of electricity consumption.[1]

Given the high priority of infrastructural investments in policy-making for economic development, investigating the determinants of energy use is an equally important question in a developing country setting. Because many households either lack electricity access or are recently connected to the grid, energy-use patterns observed in developing countries are likely to be different to those of developed countries. For instance, newly connected households may not yet have purchased electronic appliances, other than those for lighting, unlike developed country households. In a developing country, financial constraints are also more likely to be binding, which may preclude the benefits of the increased access from reaching the poor population. Such constraints may deepen the inequality in households' energy use. In response to this need for studies on developing countries, there is a limited, but growing body of literature on households' electricity consumption response to grid electricity provision (Alkon, Harish, & Urpelainen, 2016; Burlig & Preonas, 2016; Chakravorty, Pelli, & Marchand, 2014; Dasso Arana, Fernandez, & Ñopo, 2015; Dinkelman, 2011; Khandker, Barnes, & Samad, 2013; Lee, Miguel, & Wolfram, 2018; Louw, Conradie, Howells, & Dekenah, 2008; Urpelainen, Harish, Bayer, & Aklin, 2018).[2]

This study adds to the literature by examining the determinants of electricity consumption across the income distribution when households are newly connected to a national grid. Understanding how households use electricity has important policy implications, because electricity usage in developing countries has been found to result in various improvements in household welfare, such as increases in female labor supply (Dinkelman, 2011) and in nonagricultural income (Chakravorty et al., 2014). However, electricity grid expansion in developing countries does not necessarily guarantee that connected households are utilizing their new access to electricity, possibly owing due to financial constraints. In this case, a rapid increase in electricity access may not sufficiently reduce the productivity gap between the energy poor and non-poor. In other words, when near universal access to electricity is provided through government-led projects, society as a whole may experience welfare improvements; however, it is unclear whether households across the income distribution benefit equally.

We provide insights using a case study of Vietnam, a lower-middle-income country that underwent a large-scale rural grid expansion in a relatively short period. Thus, its centralized grid expansion provides a useful setting in which to study differential electricity consumption across households when the households are newly connected to the grid. After the establishment of Vietnam Electricity (formerly known as EVN) in 1995, the Vietnamese government actively rolled out rural electrification programs. As a result, household access to the national electricity grid increased from 14% in 1994 to 61% in 1998 (Gencer, Meier, Spencer, & Van, 2011). While reports exist on the general progress and success of Vietnam's rural electrification experience, there is little evidence on how households have used the newly provided infrastructural service (Gencer et al., 2011; Khandker et al., 2013; Tuan, 2010). We fill this gap in the literature by studying Vietnamese households' heterogeneous electricity usage at a micro-level.

Using a nationally representative household survey with a direct measure of electricity expenditure, we first examine various determinants of electricity use across the income distribution. We find that household income is a strong determinant of household electricity expenditure via a highly non-linear relationship. Furthermore, the household head's

[1] In addition to income, household size, electric heating, the presence of children in the household and the number of cooling and heating degree days have a significantly positive effect on electricity consumption (Romero-Jordán et al., 2016). Cayla et al. (2011) find that living area, the number of people in the household, the number of appliances, and the ownership of freezers and dishwashers have positive and significant relationships with general energy consumption levels. Alberini et al. (2011) find that electricity consumption increases with increases with the size of the living area; the ownership of air conditioners, dishwashers, and electrical stoves; and whether households use electricity for heating. Using smart-meter data, Kavousian et al. (2013) find that high-consumption appliances that are used intermittently, such as electric water heaters, clothes dryers, and spas, lead to greater demand for electricity at high volumes.

[2] Owing to previously low levels of electricity connection, prior studies on developing countries have focused more on the determinants of primary energy source consumption, such as charcoal and firewood (Baquié & Urpelainen, 2017; D'Agostino, Urpelainen, & Xu, 2015; Pandey & Chaubal, 2011).

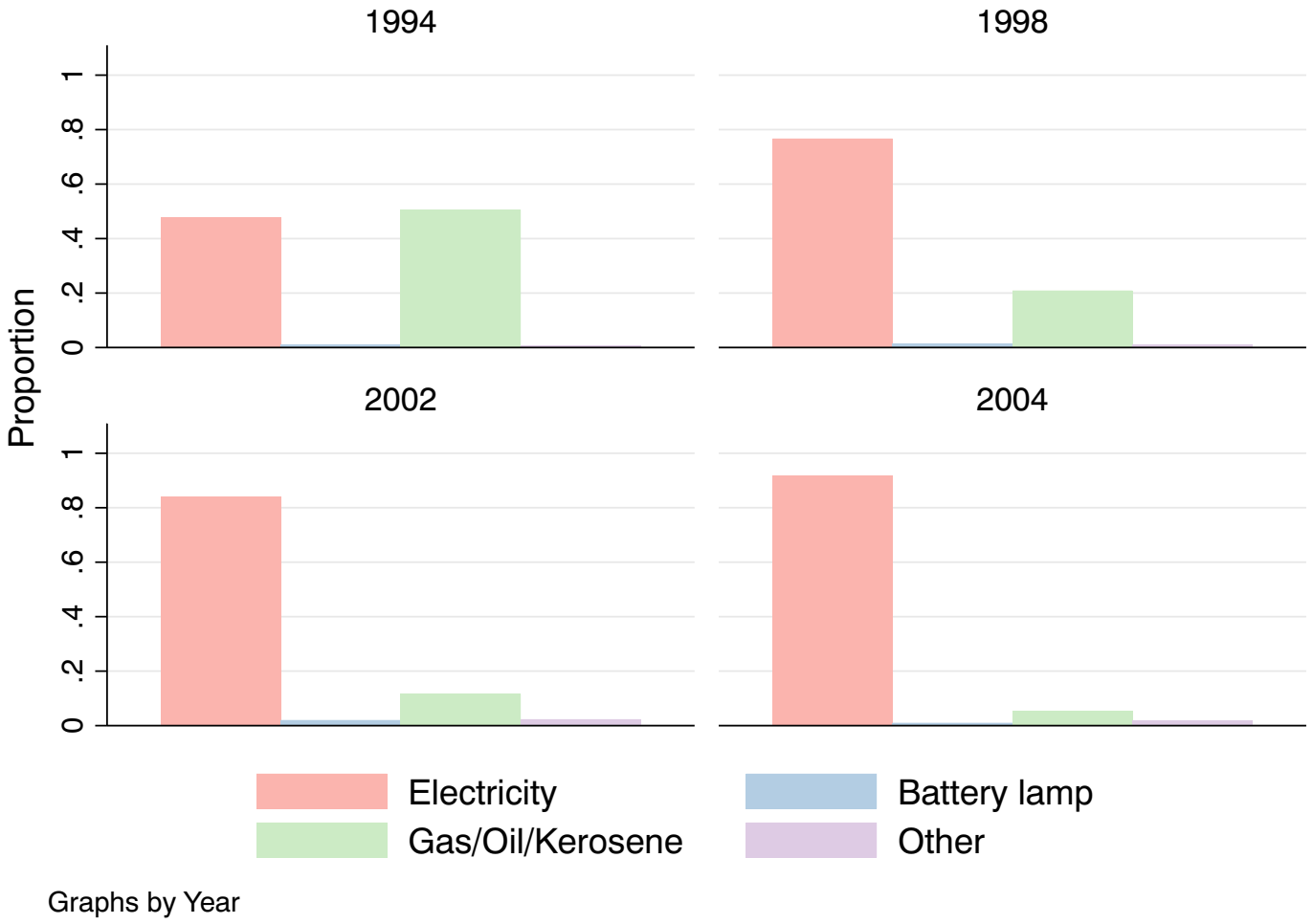

Fig. 2. Main energy source for household lighting.

education level and whether the household head is a female matter for electricity consumption. Household size and the type of housing also affect the level of expenditure on electricity.[3] Understanding determinants of household electricity spending may be relevant to assessing how the potential benefits of new energy access are distributed across households as the electricity grid is made available to the entire population.

To better understand the interplay between income and electricity use, we further analyze the disparities in household income and electricity expenditures. Compared with the weak income inequality found in Vietnam, inequality in electricity expenditure is more pronounced. Our analysis shows that the top 20% of the population in terms of income accounts for about 46% of total electricity expenditure, and the bottom 20% of the income distribution accounts for about 6%.

Despite an overall expansion in electricity access on a national level, our analysis indicates that increases in electricity spending increase may be concentrated among higher-income households. This finding suggests that if electricity use improves the welfare and productivity of households, the rapid expansion of the electricity grid may aggravate inequality through the disproportionate use of electricity across the income distribution. Such a result may partially explain the results of Lee et al. (2018) and Burlig and Preonas (2016). They find that while increased electricity access led to increased electricity usage in Kenya and India, respectively, the increased use did not result in welfare improvements in terms of improving developmental outcomes such as education, health, female employment, or meaningful investments in asset ownership. Our findings imply that this non-result may be due to the increase in electricity consumption being concentrated among higher-income households, whom are only a small proportion of the entire population that have already attained basic development needs. Moreover, because higher-income households spend more on electricity, they may be more likely to be early adopters of various electric appliances that require greater usage of electricity and, thus, experience the corresponding improvements in welfare.

The remainder of the our paper proceeds as follows. Background section provides a background on energy access in Vietnam, and Data section describes the data. Modern electricity use in Vietnam section presents the empirical approach and the results. Conclusion section concludes the paper.

Background

As low-income countries undergo economic development, electricity consumption increases rapidly in both the industrial sector and at the household level. Among the developing countries in Asia, Vietnam has experienced one of the most drastic increases in electricity consumption. Using World Bank data, Fig. 1 shows the electric power consumption (measured in kilowatt-hours per capita) for Vietnam and other lower-middle-income countries, including India, the Philippines, Pakistan, and Sri Lanka. While the countries' growth trajectories of GNI per capita in purchasing power parity terms are similar, electricity consumption has grown most drastically in Vietnam.

This steep increase in consumption, beginning in the mid-1990s, coincided with the expansion in household access to electricity through rural electrification. According to Gencer et al. (2011), early efforts for

[3] The results for these household characteristics are consistent with those usually studied in the literature; for example, see Coen-Pirani, León, and Lugauer (2010), Leahy and Lyons (2010), and Matsumoto (2016).

rural electrification in Vietnam started in the mid-1970s, primarily for irrigation purposes in rice cultivation areas, rather than for household consumption. The large-scale rural electrification by the Vietnamese government began with the *Doi Moi* (open door) reforms in 1986, although it still mainly focused on electricity transmission and distribution to support the agricultural sector. Medium-voltage distribution lines were constructed in the northern areas from the mid-1980s, increasing access to electricity for poor households from 13.9% in 1990 to around 49% in 1993.

Our data confirms these aggregate figures. In Fig. 2, we present the changes in the energy source of household lighting between 1994 and 2004. There are four categories of lighting source: electricity, battery lamp, gas/oil/kerosene, and others. In 1994, about 52% of households used electricity as the main light source, with the majority of the remaining households using gas/oil/kerosene for lighting. However, the grid expansion in the 1990s focused on connecting to the existing the medium-voltage distribution grid, rather than extending access to unelectrified rural areas (Gencer et al., 2011). As a result, many rural areas remained largely unconnected. Indeed, when we restrict the sample to rural households, the percentage of households using electricity as the main lighting source decreases to 38% in 1994.[4]

Major advancements in improving access for rural households occurred between 1994 and 1995. The construction of a super-high-voltage 500 kV transmission line connecting the northern and the southern regions of the country was completed in 1994, which was crucial for the national integration of electricity distribution (EVN, 2019).[5] In 1995, the government established Vietnam Electricity (EVN) to be in charge of electricity distribution, which was previously divided among several institutions. Coupled with a strong household demand for electricity with economic development, the public drive for the construction of low-voltage lines to connect communes and households was high. The government-led electrification projects in collaboration with the World Bank from 1995 and onward displayed their commitment to meeting this need. As a result, Vietnam experienced a dramatic increase in households' connectivity, from around 14% in 1994 to 87% of the population by 2004 (Gencer et al., 2011).

Data

As shown by the trends described in the previous section, the period from 1990 to the early 2000s one of rapid improvement in the household access rate to electricity. Thus, we use the first four waves of the household surveys conducted between 1993 and 2004 in Vietnam. The nationally representative household survey dataset was obtained from the General Statistical Office (GSO) of Vietnam. For the first two rounds of surveys, conducted in 1993 and 1998, the survey was called Viet Nam Living Standards Survey (VLSS), and households were sampled based on the 1989 census. Then, in 2002, the GSO has renamed VLSS as the Vietnam Household Living Standards Survey (VHLSS). This survey has been conducted every two years to systematically monitor changes in socioeconomic development of Vietnamese households. Sampling for the VHLSS is based on the 1999 census. The VLSS and VHLSS both ask for information on household member composition, education, employment, housing, and expenditure on food and non-food items (World Bank, 2017). Although the VHLSS questionnaires are simpler than those of the VLSS, the questionnaire design follows the standard set of questions of the World Bank's Living Standard Measurement Surveys. Thus, the responses to the VLSS and VHLSS are comparable. However, none of the households participated in both the VLSS and the VHLSS (Thu Le & Booth, 2013). Therefore, we cannot conduct a panel analysis across the two types of household surveys. Thus, to cover the period between 1993 and 2004, we pool all four waves in our analysis.

[4] Results available upon request.

[5] Previously, electricity distribution lines were operated at the regional level. Different systems in the north and south of Vietnam made the integration costly.

Table 1
Household summary statistics.

	VLSS1993	VLSS1998	VHLSS2002	VHLSS2004
Female household head	0.27	0.27	0.24	0.24
	(0.44)	(0.44)	(0.42)	(0.43)
Household head age	45.5	48.0	47.5	49.1
	(14.7)	(13.8)	(14.2)	(14.0)
Household size	4.99	4.77	4.48	4.39
	(2.19)	(1.95)	(1.77)	(1.72)
No. of children under 5	0.60	0.37	0.29	0.27
	(0.79)	(0.63)	(0.56)	(0.53)
Monthly consumption per capita[a]	300.1	570.4	600.1	635.0
	(253.4)	(496.1)	(504.4)	(484.1)
Main light source is electricity	0.49	0.78	0.86	0.93
	(0.50)	(0.41)	(0.35)	(0.26)
Pay for electricity	0.48	0.77	0.86	0.92
	(0.50)	(0.42)	(0.35)	(0.27)
Electricity expenditure[a]	46.9	74.7	59.1	73.3
	(62.5)	(110.7)	(81.7)	(90.3)
Participation in agriculture	0.60	0.50	0.55	0.64
	(0.49)	(0.50)	(0.50)	(0.48)
Rural	0.81	0.72	0.76	0.75
	(0.39)	(0.45)	(0.43)	(0.43)
Education				
No degree	0.38	0.60	0.31	0.54
	(0.49)	(0.49)	(0.46)	(0.24)
Primary school	0.25	0.07	0.24	0.29
	(0.43)	(0.25)	(0.43)	(0.45)
Lower secondary school	0.21	0.20	0.27	0.13
	(0.40)	(0.40)	(0.44)	(0.33)
Upper secondary school	0.13	0.09	0.14	0.043
	(0.34)	(0.29)	(0.35)	(0.20)
University	0.022	0.033	0.038	0.002
	(0.14)	(0.18)	(0.19)	(0.046)
House type				
Permanent house w/ private bath	0.063	0.098	0.056	0.075
	(0.24)	(0.30)	(0.23)	(0.26)
Permanent house w/ shared bath	0.10	0.066	0.10	0.12
	(0.31)	(0.25)	(0.31)	(0.33)
Semi-permanent house	0.47	0.58	0.59	0.59
	(0.50)	(0.49)	(0.49)	(0.49)
Temporary house	0.36	0.25	0.24	0.21
	(0.48)	(0.43)	(0.43)	(0.41)
Observations	4407	5656	27,049	8624

[a] In thousands of 2010 VND.

Summary statistics

Table 1 shows the summary statistics of the households variables in the VLSS and VHLSS. Females account for 27% of the household heads in 1993 and 1998, and for 24% of the households in 2002 and 2004. The age of the household head is between 45 and 50. The average household size is almost five persons per household in 1993, and decreases to about 4.4 in 2004. The number of children under five is highest in 1993 (0.60) and lowest in 2004 (0.27).

The data also reflect Vietnam's rapid economic growth during this period. The monthly consumption per capita in real terms more than doubles from 1993 to 2004, from 300,000 VND to 635,000 VND.[6] To put the numbers in perspective, the poverty line put forth by the government of Vietnam in 2005 was households with less than 200,000 VND capita per month, which was equivalent to US $150.

The next three variables show the expansion in rural electrification. Between 1993 and 2004, the share of households that used electricity as their main light source increased from 49% to 93%. Consistent with the national grid expansion policy in 1995, the greatest increase in electricity access is observed between 1993 and 1998. Alternative sources identified in the survey are battery lamps, gas, oil or kerosene lamps, resin torches and other energy sources. The next variable is a binary indicator of whether the household pays for electricity. We find that the mean

[6] Inflation-adjusted using 2010 CPI.

value of this variable is almost identical to the indicator variable for the main light source being electricity. This suggests that a household's light source switches to electricity only when the grid is connected, so that the household pays for electricity.[7] Between 1993 and 2004, monthly household electricity expenditure increased from 46,900 VND to 73,300 VND, a less than two-fold increase.

There is no obvious increasing or decreasing trend in the participation rate of household heads in agricultural activities (in most waves, about 50–64%). The majority of the households in the sample live in rural areas. The education levels of the household heads are consistently and not very high. For all four rounds, the percentage of household heads with a primary education or less is over 50%, and the corresponding proportion for tertiary education is below 1%. We also have information on the type of housing, which is a possible measure for the living standard. There are four types of housing: permanent house with private bath, permanent house with shared bath, semi-permanent house and temporary house.[8] While a permanent house with a private bath is the highest quality housing type, most households in the sample live in semi-permanent or temporary houses.

Modern electricity use in Vietnam

Determinants of electricity expenditure

In this section, we first investigate the determinants of electricity use, focusing on income. We begin our analysis with the following ordinary least squares (OLS) regression of electricity expenditure per month on household income:

$$Electricity\ expenditure_{hdt} = \alpha_0 + \beta Income_{hdt} + \gamma_1 X_{ht} + \lambda_d + \delta_t + \varepsilon_{hdt} \quad (1)$$

where $Electricity\ expenditure_{hdt}$ is the monthly electricity expenditure of household h in district d at time t. The main explanatory variable, $Income_{hdt}$, is proxied by the monthly household consumption per capita for household h in district d at time t.[9] β is the coefficient of interest. In addition, X_{ht} denotes the household covariates, including household size, household head's age and age squared, household head's education level, type of housing, whether the head is female, an indicator for rural area, and the number of household members below the age of five. We include district fixed effects λ_d to control for district-level factors that may affect electricity consumption, such as the district-level electricity tariff and electricity grid placement. Time fixed effects, captured by δ_t, are also included to control for time trends. Standard errors are clustered at the district level.

The results of the regression analysis on the determinants of household electricity expenditure are presented in Table 2. Across all specifications, we find that household income is an important determinant of household electricity expenditure. In column (1), we assume a linear relationship between income and electricity expenditure, and find that an increase in the monthly income by 1000 VND leads to 60 VND increase in electricity expenditure. Because income is one of the most direct determinants of energy spending, we relax the assumption that income has a linear effect on electricity expenditure. Column (2) assumes a quadratic function in income, and column (3) use deciles of income. In column (3), the magnitude of the coefficient estimates on

Table 2
Income deciles and electricity expenditure in 1993–2004.

	Electricity expenditure			Log Elec Exp	
	(1)	(2)	(3)	(4)	(5)
				OLS	IV
Income per capita	0.059***	0.078***			
	(0.004)	(0.004)			
Income per capita^2		−0.000***			
		(0.000)			
Income decile					
2nd			3.938***		
			(1.089)		
3rd			8.248***		
			(1.316)		
4th			13.174***		
			(1.362)		
5th			16.371***		
			(1.455)		
6th			19.695***		
			(1.544)		
7th			24.931***		
			(1.648)		
8th			31.945***		
			(1.955)		
9th			41.443***		
			(2.108)		
10th			81.434***		
			(3.341)		
Log income per capita				0.720***	0.686***
				(0.018)	(0.071)
Rural	−17.375***	−16.095***	−16.435***	−0.500***	−0.505***
	(1.816)	(1.790)	(1.837)	(0.052)	(0.021)
Household size	9.227***	9.665***	8.796***	0.149***	0.147***
	(0.684)	(0.708)	(0.616)	(0.004)	(0.006)
Household head age	−0.030	−0.154	−0.080	0.009***	0.009***
	(0.176)	(0.175)	(0.174)	(0.003)	(0.003)
HH Age^2	0.162	0.264	0.194	−0.008***	−0.009***
	(0.165)	(0.165)	(0.165)	(0.003)	(0.003)
No. of children under 5	1.866*	2.254**	2.232**	−0.000	−0.005
	(1.044)	(1.064)	(1.067)	(0.011)	(0.011)
Primary school	5.501***	4.692***	5.228***	0.191***	0.194***
	(0.827)	(0.788)	(0.828)	(0.017)	(0.017)
Lower secondary school	10.749***	9.518***	10.504***	0.297***	0.302***
	(1.034)	(0.974)	(1.003)	(0.019)	(0.020)
Upper secondary school	15.244***	12.953***	15.642***	0.365***	0.377***
	(1.593)	(1.426)	(1.431)	(0.023)	(0.028)
University	24.497***	21.636***	32.151***	0.382***	0.403***
	(3.839)	(3.635)	(4.464)	(0.028)	(0.043)
Permanent house w/ shared bath	−43.406***	−42.234***	−48.134***	−0.098***	−0.105***
	(3.324)	(3.294)	(3.950)	(0.023)	(0.022)
Semi-permanent House	−51.136***	−49.119***	−55.876***	−0.213***	−0.224***
	(3.302)	(3.265)	(4.059)	(0.020)	(0.027)
Temporary house	−60.090***	−56.636***	−64.624***	−0.632***	−0.651***
	(3.242)	(3.151)	(4.018)	(0.032)	(0.043)
Female household head	2.392**	2.372**	2.639**	−0.012	−0.010
	(1.095)	(1.078)	(1.100)	(0.014)	(0.012)
District FE	Yes	Yes	Yes	Yes	No
Wave FE	Yes	Yes	Yes	Yes	No
Adjusted R^2	0.502	0.506	0.476	0.570	0.234
Observations	40,067	40,067	40,067	40,067	39,607

Robust standard errors in parentheses.
Income and income deciles are constructed using consumption per capita of each household as a proxy variable. Numbers are inflation-adjusted using 2010 CPI.
Column 1 assumes income to be linear, while column 2 assumes income to be quadratic. Column 3 and 5 assume nonlinearity in income and column 5 uses log income to capture elasticity with respect to income.
Permanent House with Private Bath is the omitted category for housing types.
First-stage F-stat for columnn 5 is 403.70.
* $p<0.10$.
** $p<0.05$.
*** $p<0.01$.

[7] In Vietnam, the use of off-grid electricity or electricity generators is very low. In our survey data, we find that less than 2% of the households owned electricity generators in both 2002 and 2004.

[8] Permanent houses are multi-floor buildings made of brick that have flat concrete roofs. Semi-permanent houses have wooden walls and tile or tin roofs. Temporary houses are made of primitive materials, so walls are not made of brick or wood, and roofs are made with bamboo, leaves, or oil paper (Vahlne, 2017).

[9] We follow the suggestions of Deaton (1997) and Deaton and Zaidi (2002) that consumption serves as a better proxy of living standards than income in developing countries. Because income in developing countries often comes from various sources, individuals may often be confused between personal and business incomings and outgoings. This leads to a larger measurement error in income compared to that in consumption (Deaton, 1997) There is also a theoretical reason for using consumption over income. Because individuals tend to smooth consumption, current consumption may better reflect permanent income than current income, and hence serves as a better measure of the living standard.

Table 3
Quantile regression of electricity expenditure at 5, 25, 50, 75, 90% quantiles.

	5%	25%	50%	75%	90%
	(1)	(2)	(3)	(4)	(5)
Income per capita	0.023***	0.039***	0.054***	0.076***	0.102***
	(0.001)	(0.001)	(0.003)	(0.005)	(0.009)
Income per capita^2	−0.000***	−0.000***	−0.000**	−0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Rural	−9.937***	−11.069***	−12.539***	−15.593***	−20.494***
	(0.385)	(0.411)	(0.451)	(0.484)	(0.944)
Household size	2.414***	4.014***	5.042***	6.604***	8.208***
	(0.076)	(0.056)	(0.073)	(0.099)	(0.150)
Household head age	0.052	0.076**	0.099**	0.033	−0.178**
	(0.034)	(0.032)	(0.041)	(0.054)	(0.085)
Age(quadratic)	−0.077**	−0.061*	−0.041	0.046	0.273***
	(0.032)	(0.032)	(0.039)	(0.053)	(0.081)
No. of children under 5	−0.328***	−0.335***	0.252	0.790***	1.772***
	(0.126)	(0.118)	(0.170)	(0.232)	(0.263)
Primary school	3.222***	3.739***	4.380***	4.728***	4.445***
	(0.173)	(0.158)	(0.224)	(0.265)	(0.387)
Lower secondary school	5.268***	6.871***	7.637***	8.072***	8.319***
	(0.196)	(0.194)	(0.253)	(0.330)	(0.496)
Upper secondary school	6.561***	9.573***	11.136***	13.681***	15.543***
	(0.288)	(0.286)	(0.392)	(0.530)	(0.857)
University	13.170***	18.535***	20.272***	20.748***	20.378***
	(0.681)	(1.527)	(1.129)	(1.169)	(1.531)
Permanent house w/ shared bath	−6.760***	−16.557***	−24.210***	−46.197***	−73.485***
	(1.108)	(1.131)	(1.584)	(2.980)	(5.707)
Semi-permanent House	−10.249***	−21.456***	−30.536***	−54.305***	−83.579***
	(1.098)	(1.104)	(1.558)	(2.944)	(5.704)
Temporary house	−14.167***	−27.344***	−36.975***	−61.571***	−91.155***
	(1.102)	(1.109)	(1.560)	(2.940)	(5.698)
Female household head	−1.011***	−0.374**	−0.347	0.264	1.014**
	(0.188)	(0.182)	(0.213)	(0.276)	(0.398)
District FE	Yes	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes	Yes
Observations	39,928	39,928	39,928	39,928	39,928

Robust standard errors in parentheses.
Income and income deciles are constructed using consumption per capita of each household as a proxy variable. Numbers are inflation-adjusted using 2010 CPI.
* $p<0.10$.
** $p<0.05$.
*** $p<0.01$.

the income deciles increases nonlinearly, with a steep increase in the ninth and tenth deciles. The monthly electricity expenditure is 16,371 VND greater households of the fifth income decile, relative to those in the first income decile. This difference is much greater than the observed income difference. The difference in average household income between the first and the fifth income deciles is about 1520 VND, and that between the first and 10th deciles is about 6120 VND.[10] If the monthly electricity expenditure increases linearly with income, the gap between the monthly electricity expenditure of the first and 10th deciles should be approximately 64,000 VND, given the gap between the first and fifth income deciles. However, the increase in the gap is found to be much greater between households in the first and the 10th income deciles (81,434 VND). The largest incremental increase in electricity expenditure when moving up a decile occurs between the ninth and 10th income deciles (about 40,000 VND).

This finding suggests that the concern of imbalanced energy intensity that is observed between industrialized countries and developing countries may also be applicable in the context within a country, based on varying income levels (Sovacool, 2014). Although the electricity supply has been extended via the national grid, granting near universal access, and all households face the same the price of electricity, the amount spent on electricity shows a large degree of heterogeneity. Thus, beyond household income, we also analyze the effects of other variables that can influence the capabilities of households to

[10] This number is obtained by multiplying income per capita by average household size, which is four in our data.

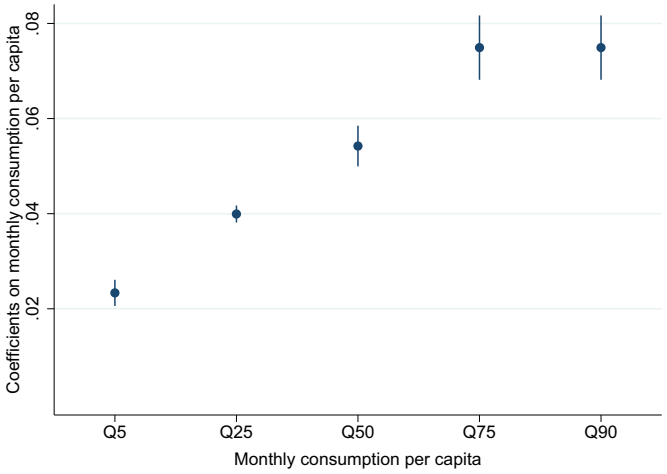

Fig. 3. Coefficient on income per capita at 5, 25, 50, 75, 90% quantiles.

consume electricity. Indeed, household characteristics do appear to affect electricity consumption, and the coefficients of the household characteristics are similar across columns (1)–(3). Since our preferred specification is column (3), with deciles of income as the main explanatory variable, we focus on column (3) in our discussion of other household controls. Households living in rural areas spent approximately 16,000 VND less on electricity. Household size is positively correlated with electricity expenditure, which also increases with the number of children below the age of five. Housing type appears to have a strong relationship with the amount of electricity expenditure. A better house type (a permanent house, which is the omitted category in the regression) is correlated with higher consumption levels of electricity compared with the other three types of housing, by between 48,000 and 64,000 VND. The coefficients on the three types of housing suggest that electricity expenditure increases with the quality of housing, and that the jump in spending is largest for permanent housing.

Several characteristics of the household head influence electricity expenditure. Households with a female household head are more likely to spend on electricity by about 2600 VND. Increases in a household head's education level are also associated with electricity expenditure. Relative to households whose household head has no education, those with heads who have completed primary education spend almost 5200 VND more on electricity expenditure. Each additional level of schooling is associated with an increase in electricity expenditure, with the largest increase for university education. On the other hand, the age of the household head is not a significant factor.

In columns (4) and (5) of Table 2, we estimate the elasticity of electricity expenditure with respect to income, using the logarithmic value of electricity expenditure as the dependent variable. In column (4), the coefficient on the log of income of 0.72 indicates that the income elasticity of electricity expenditure among Vietnamese households is relatively inelastic.[11] To deal with the potential endogeneity from using electricity expenditure as our outcome variable and household income as the explanatory variable, in column (5), we use expenditure on health as an instrumental variable to analyze the income effect on electricity use. Expenditure on health is likely to affect electricity expenditure only through its effect on the explanatory variable, income per capita. Using health expenditure as an instrument for the income variable, we find the income elasticity of electricity expenditure to be 0.686, similar to the OLS estimate in column (4).[12]

[11] Although not directly comparable, the electricity consumption elasticities (in kilowatt hours) with respect to income of Philippine households, ranged from 0.23 to 0.76 (Manalo-Macua, 2010). The electricity expenditure elasticities of UK households with respect to income, ranged from 0.046 to 0.152 (Jamasb & Meier, 2010).
[12] The first-stage F statistic is 642.23.

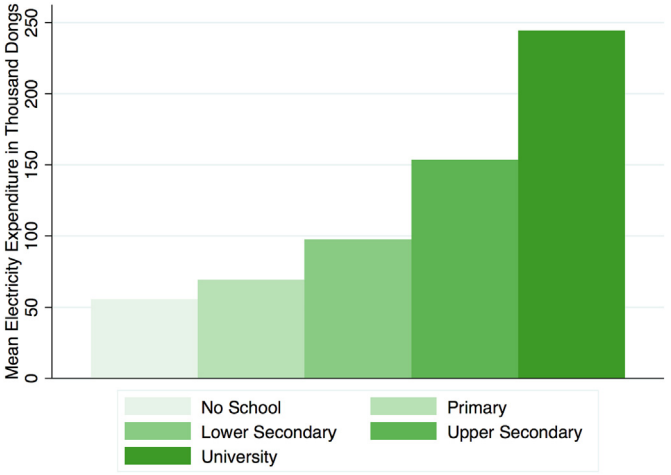

Fig. 4. Monthly mean electricity expenditure by education levels.

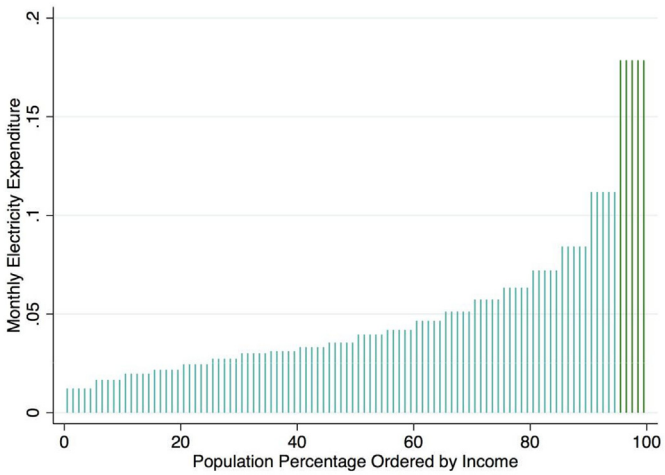

Fig. 5. Monthly electricity expenditure share by income groups. Note: Monthly electricity expenditure and income levels are analyzed in real terms.

To understand the differential effects of the determinants of electricity expenditure on the overall distribution, we also conduct a quantile regression. The results of the quantile regression of electricity expenditure on the household covariates allow us to analyze distributional relationships of the monthly income per capita and electricity expenditure for the quantiles of interest. The results of the quantile regression are reported in Table 3. Across the fifth, 25th, 50th, 75th, and 90th quantiles, the effect of the monthly income variable on household electricity consumption is consistently significant and positive. Moreover, the magnitude of the effect is greater in the upper quantiles than it is in the lower quantiles, as summarized in Fig. 3. This result is consistent with the findings of quantile regressions of electricity consumption in Taiwan (Huang, 2015) and energy consumption in the United States (Kaza, 2010). Studies in developing countries also corroborate our findings. Among rural households in India and China, only the top income decile groups switched their energy consumption from biomass and coal to electricity consumption (Pachauri & Jiang, 2008). The results of the quantile regression highlight the variation in electricity-use behavior across the income groups of the Vietnamese population. Furthermore, households in the upper tail are more sensitive, and readily consume more electricity as their income increases. At the same time, although households in the lower tail also consume more electricity with greater income, the increase is not as great as that of households in the upper tail.

Comparing disparities in income and electricity expenditure

In the previous section, we found that electricity expenditure increases nonlinearly with income, with the gradient being very steep for the top income groups. This finding suggests that despite the centralized electricity expansion policy successfully granting access to the whole population, the issue of relative energy poverty may still persist. The gap in energy use by income groups may even increase after a switch from primary energy sources to electricity, because the energy expenditures incurred from electricity use are more likely to be wider than those from primary energy sources. Therefore, at the stage of rapid expansion of electricity access, it is important to understand the energy consumption patterns across the population, and to identify the part of the population living in relative energy poverty.

One way to investigate the relative degree of energy poverty may be to compare the inequality in income and the inequality in energy consumption.[13] In terms of policy, it may be important to know whether the extent of inequality is relatively large for one or the other. If income inequality is relatively low compared to that of electricity consumption, then proper subsidies or incentives can induce energy-poor households to consume more energy. In particular, in countries such as Vietnam where a centralized electricity grid exists, there may be more room for improvement through government interventions.

In this section, we first investigate the distribution of energy expenditure across the population, and then compare the extent of inequality in income with that in electricity expenditure. In Fig. 4, we present the average electricity expenditure across completed education levels of the household head, where sizable differences are evident. While the mean monthly electricity expenditure in households whose head completed primary school is 6146 VND, that of households whose head graduated from university is about 168,507 VND per month. The gap in spending widens between upper secondary school and university degrees.

Because education level is a crude measure of a household's economic status, we directly plot the percentage share of electricity expenditure by monthly income group in Fig. 5. This figure shows that household electricity expenditure increases nonlinearly with income, and is also concentrated at higher income groups. The top 20% of the population accounts for about 46% of total electricity expenditure, and the bottom 20% accounts for about 6%. The top 5% of the population accounts for about 20% of total electricity expenditure. This graph displays a highly unequal distribution of electricity spending, which indicates that increased income

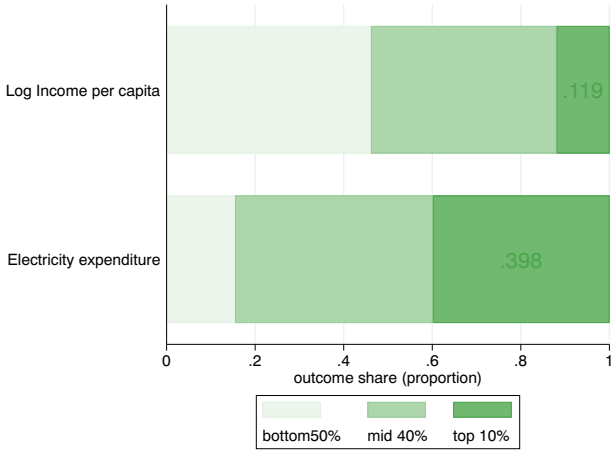

Fig. 6. Distribution of household electricity spending and income per capita. Notes: The top panel displays the proportion of monthly income per capita, proxied by monthly consumption per capita consumed by i) bottom 50% ii) middle 40% and iii) top 10% of the households in the dataset. The bottom panel displays the proportion of monthly electricity expenditure consumed by aforementioned income groups.

[13] Many researchers highlight the importance of per capita income in constructing the measure for energy poverty (Ochoa & Graizbord, 2016; Price, Brazier, & Wang, 2012).

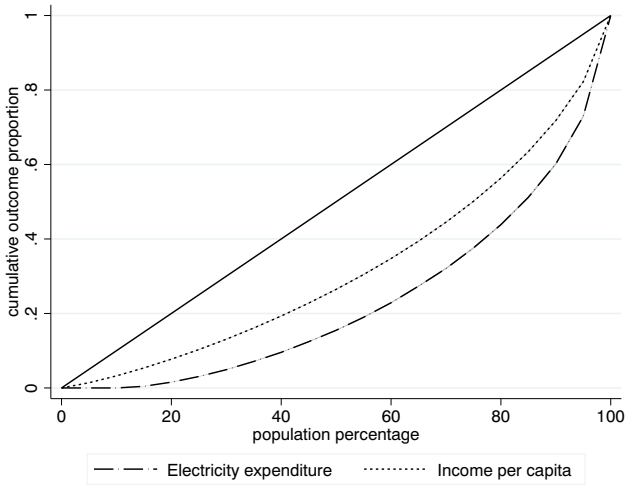

Fig. 7. Lorenz curves for electricity expenditure and income.

through development in Vietnam has not led to proportional increases in electricity usage. This finding suggests that if increases in electricity usage lead to a more efficient use of labor and, hence, increased household income, universal access to electricity may not lead to comparable improvements in productivity for low-income households.

Further analysis on the distribution of electricity expenditure and income demonstrates that the inequality in electricity expenditure is much greater than the inequality in income among households. In Fig. 6, we compare the distribution of consumption per capita versus that of electricity expenditure. The upper bar displays the income distribution proxied by consumption per capita while the lower bar corresponds to the distribution of electricity expenditure. The colored blocks denote the shares occupied by the bottom 50%, middle 40%, and top 10% of the population occupies. The top 10% of the population account for about 12% of overall consumption and about 40% of the electricity expenditure. On the other hand, the bottom 50% of the population account for approximately 46% of the overall consumption, but only about 15% of the electricity expenditure.

To graphically compare income inequality and electricity expenditure inequality, we plot the Lorenz curve for monthly electricity expenditure and monthly per capita consumption in Fig. 7. The Lorenz curve of electricity expenditure always lies below that of consumption per capita across the population distribution. This graphical illustration confirms once again that the inequality in electricity spending is more severe than that in income. This finding is consistent with a similar finding for India, where some households are found to be energy poor, even if they are not income poor (Khandker, Barnes, & Samad, 2012). This result implies that we cannot readily assume that the degree of energy inequality is the same as that of income inequality and calls for an in-depth analysis of households' use of electricity and their household characteristics.

Conclusion

This study uses rich household-level data on Vietnam to better understand the nature of increased access to modern energy in a developing country setting. Several household characteristics that are positively correlated with electricity expenditure: whether a household resides in an urban area, household size, housing type (quality), and education level of the household head. Moreover, while household income increased with state-led electrification (Son & Yoon, 2016), we found that household electricity expenditure increased nonlinearly across income deciles, indicating that electricity usage may not increase evenly, even if electricity grids are extended to connect villages. Thus, poor households may not be able to take full advantage of the newly provided residential infrastructure, which could, for example, facilitate a transition from the agricultural sector to the non-agricultural sector, even with a rapid expansion of the grid, as in Vietnam.

Moreover, our analysis indicates that the inequality in energy use is greater than that of income, suggesting that household income poverty may not always be a good indicator of energy poverty. Such inequality in electricity consumption within Vietnam across income levels resembles international inequality in electricity consumption. There is evidence that the OECD Pacific, non-OECD Europe, Latin America, and Middle East regions have experienced increasing inequalities in energy intensity, defined as the primary energy consumption per GDP (Duro & Padilla, 2011). In addition, despite the efforts of the United Nations Development Programme, there are still households that rely on woody biofuels or animal dung, and do not have access to modern forms of energy (Sovacool, 2012). Because energy poverty is pervasive in many parts of the world, this limits the scope of benefits that could further microeconomic development for the poor. Therefore, policymakers need to address the systematic barriers to improving energy access and energy usage, even when electricity grids are expanded.

There are largely two main policy directions that can alleviate the inequality in electricity spending: a price incentive and a direct subsidy to the relatively energy-poor population. If households are aware of the benefits of electricity use and have a high willingness to pay, providing different pricing tables by usage may provide a useful nudge. In developed countries, pricing has been the main tool to target consumers by their electricity use, with a focus on decreasing the energy use of the high-usage group. However, such income-level-based pricing has not been so effective for electricity conservation. For example, in the United States, neither increased-block pricing (Ito, 2014) nor a separate opt-in tariff system using dynamic pricing scheme (Borenstein, 2013) had an effect on overall electricity consumption. Furthermore, the latter system only slightly lowered the electricity bill for low-income households in the United States. On the other hand, in developing countries, the policy aim is to increase household electricity use to improve lighting conditions and to facilitate home production activities, consistent with the targets of the 7th Sustainable Development Goal. Currently, the residential electricity tariff pricing scheme in Vietnam is two-tiered; for the first 50 kWh in a month, each kWh costs 1484 VND and from 51 kWh, the rate is 1533 VND per kWh (Tuoi Tre News, 2015). Our findings suggest that this two-tiered structure is too simple or inadequate to stimulate electricity expenditure for most households in Vietnam. Therefore, policies that encourage electricity consumption in developing countries may need to be more direct, rather than only relying on the residential electricity pricing structure.

Subsidy policies to the relatively energy-poor group may complement a differential pricing scheme to increase electricity consumption. It is likely that poor households in developing countries are more credit constrained that those in developed countries are. In particular, as Cayla et al. (2011) suggests, electronic appliances explain a considerable proportion of electricity consumption, which implies that the inequality in energy consumption. Thus, the inequality in energy consumption between the high- and low-income groups may be partially explained by the lack of purchasing power for appliances among low-income households. In most cases, households in developing countries begin using electricity with relatively cheaper appliances, primarily lighting and fans. Purchases of durable appliances for productivity gains often require a lump sum payment, which is a problem that a differential pricing scheme cannot solve. In this case, subsidies or a relaxation of credit constraints may be more effective. Currently, most energy sector subsidies in developing countries are offered to provide access to renewable energy products in off-grid regions. For example, the subsidies for rooftop solar systems in India aimed to reduce the number of households that lack basic household electricity (MNRE, 2014). However, if the main objective of the increasing people's access to electricity in developing countries is to provide equal opportunities for growth and development, then policies will be needed nudge the consumers at the bottom of the economic pyramid to purchase productivity-enhancing

electric appliances at low interest rates or provide subsidies. This is left to future work.

Our finding that equal access does not immediately translate into usage may have policy implications for many developing countries with low rates of electricity access, similar to that of Vietnam before the national grid was provided throughout the country. For example, many countries in Africa still have limited access to electricity, including Burundi (7.6%), the Democratic Republic of Congo (17.1%), and Malawi (11%), according to the World Bank (2020). Some countries are following Vietnam's path of electricity expansion. Between 2000 and 2016, Sierra Leone's electricity access rate increased from 11.1% to 20%; Tanzania increased from 9.6% to 32.8%; and Cambodia increased from 16.6% to 49.8%. Our findings may also be relevant for other infrastructure expansion or public service expansion programs, including programs to increase access to clean water and sanitation, access to the internet, mobile phones, and formal financial services. Our analysis reveals a need for a carefully planned policy to encourage sufficient use of newly provided infrastructural service. Future energy research in the context of developing countries could contribute to sound policymaking by offering additional analyses on how to reduce inequalities in electricity use.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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