Residential Electricity Efficiency and Implications for Vietnam's Clean Energy Transition

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Abstract

Vietnam's energy consumption relative to its average national income per capita is significantly higher than that of similar countries like India or China. Current energy use is not sustainable and in the future may threaten energy supply security. Of the total electricity consumption, the residential sector accounts for up to a third, making it a critical component for policy interventions. We employ a stochastic frontier model and three rounds of nationally representative household living standards surveys from 2014-2018 to measure residential electricity efficiency and its determinants in Vietnam. Our result shows that the average energy efficiency in Vietnam is approximately 75%, which is significantly less efficient than many countries of the same development status. We then discuss Vietnam's national electricity efficiency policies, and recommend major improvements which will be necessary if Vietnam wants to accelerate its long-term clean and sustainable energy prospects.

Keywords: electricity demand, electricity efficiency, energy transition, stochastic frontier, Vietnam
JEL code: D12, Q21, Q28, Q40, O13

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1 Introduction to Vietnam's Power Sector

Over the past three decades, Vietnam experienced dramatic economic growth accompanied by a ten-fold increase in energy demand. Since 1990, electricity consumption has grown 10% year-over-year, on average, except for a short period during the COVID-19 pandemic from 2020 to early 2022 when the demand increased about the same rate as economic growth (Figure 1). Meanwhile, Vietnam's economic growth rate has hovered around 5% each year. After 30 years of economic liberalization, Vietnam has become one of the most electrified countries in the world. As of 2020, all provinces, cities, and communes in Vietnam had access to national grids and government-stipulated electricity tariffs, including those living in remote areas like Con Dao Island, a small historic island in the Southern Coast with a population of 8,000. Before the 1986 economic reform (known as Doi Moi), the average per capita power consumption in Vietnam was only 70 kWh. In 2021, this figure surpassed 2,200 kWh (General Statistics Office, 2023). Some long-term projections, such as the one released by the Institute of Energy, a government-affiliated agency under the Ministry of Industry and Trade (MOIT), suggest that per capita power consumption growth will hold steady at 7% from 2024-2030 (Institute of Energy, 2021a). By 2030, per capita electricity consumption is expected to reach almost 4,000 kWh. This figure is comparable to the current consumption in Malaysia or China, despite the fact that Vietnam is significantly less developed than China or Malaysia.

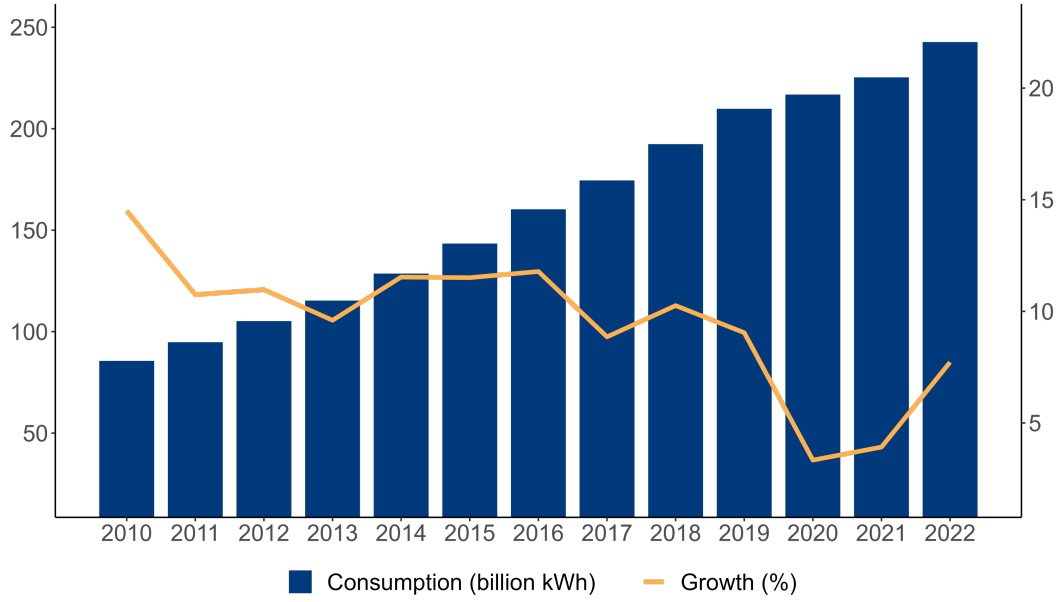


Figure 1. Commercial electricity demand and growth rate in Vietnam

Data source: For 2009, Tu-Nguyen (2010). From 2010–2020, Institute of Energy (2021a). For 2021, Nguyen (2022). For 2022, Nguyen (2023)

The Vietnamese government has made supply expansion in the power sector a key

priority. In fact, from 2010 to 2022, the country's total installed capacity increased more than three-fold, from approximately 21 GW in 2010 to nearly 78 GW in 2022 (Figure 2). By the total generation capacity, Vietnam's current power system is even larger than the Australian system and those of many regional countries. For example, the installation capacity of Australia in 2021 was 58 GW (AEMO, 2021), while Thailand has only 49 GW in 2023 (Timmons, 2023). By 2030, Vietnam must invest USD77.6 billion, of which USD71.7 billion for power generation assets and USD5.9 billion for transmission grids (Hoang Ha, 2023).

Electricity generation in Vietnam falls into 6 main categories: hydropower, coal, gas, solar, wind, and other including imports from Lao PDR and China (Figure 3). Until recently, hydropower and thermal power plants (coal and gas) accounted for over 85% of total energy production in 2022. Hydropower represents around one-third of both capacity and generation in Vietnam. When we think about growth, however, there is little room to expand hydropower. Almost all domestic hydropower potential has been utilized. In fact, looking into the future, hydropower capacity could decrease in the face of global warming. If hot and dry periods increase, causing extended droughts and lower overall water levels, then it would be difficult for the hydropower system to run at full capacity.

While there may not be room for the hydropower sector to grow, Vietnam remains dependent on coal-fired power plants to maintain a stable and reliable base load supply. However, domestic supply of coal and gas has also been depleted. Vietnam has become a net coal importer since 2015. In the last five years, wind and solar capacity have expanded substantially due to favorable government policies. Looking forward, the country is exploring new energy alternatives such as liquefied natural gas (LNG) and off-shore wind. These alternatives could help Vietnam meet the commitments it has made to reach net zero emissions by 2050.

The economy of Vietnam is noticeably inefficient in terms of energy consumption. One indicator of this is electricity elasticity, presented as the growth rate of electricity consumption relative to the growth rate of the Gross Domestic Product (GDP). Vietnam's electricity elasticity, despite experiencing a downward trend recently, is considerably higher than many other countries. It is higher than China and India, whereas China is more urban and more industrial, while India has a similar GDP per capita as Vietnam (Figure 4). Another indicator of this is the electricity intensity of the economy, which is the amount of electricity needed to produce one unit (USD1000) of economic output. The electricity intensity of Vietnam is higher than China, Korea, and Japan (Figure 5). This is especially interesting when you consider that the average winter temperatures, and thus the average need to heat one's home, is much higher in these countries compared to Vietnam. In effect, Vietnam uses a lot more electricity to produce one unit of economic output, and that amount is growing much more quickly than elsewhere. Without

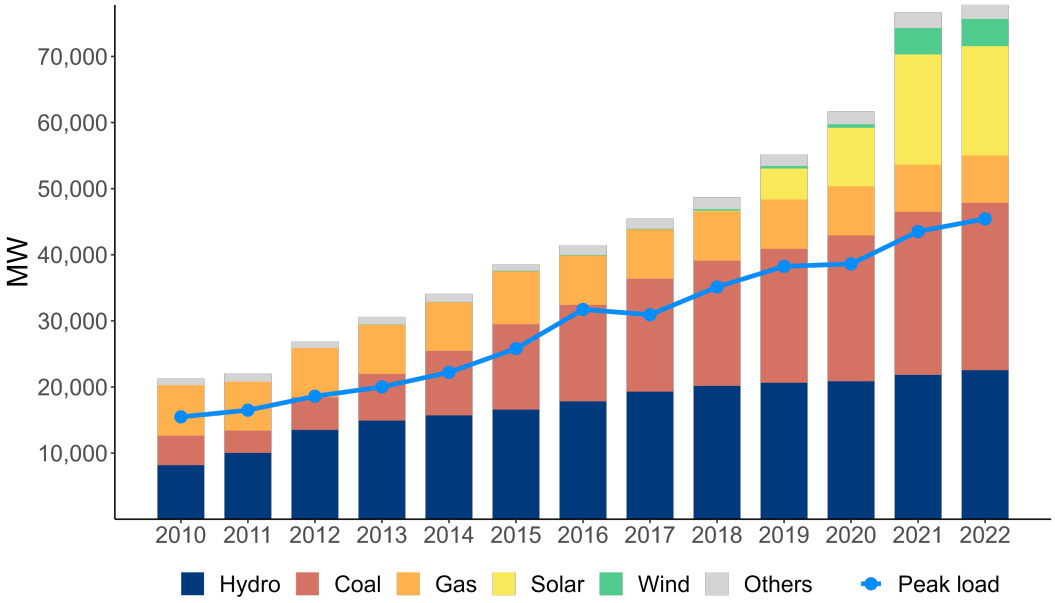


Figure 2. Installed capacity by power sources and the peak load

Data source: For peak load: 2010–2014, Institute of Energy (2015); 2015–2020, Institute of Energy (2021b); 2021, Nguyen (2023). For installed capacity: 2010, Institute of Energy (2020); 2011, EVN (2012); 2012, EVN (2013); 2013, EVN (2014); 2014, EVN (2015); 2015–2020, Institute of Energy (2021b); 2021, Luong-Bang (2022) and Nguyen (2022); 2022, Le-Van (2023)

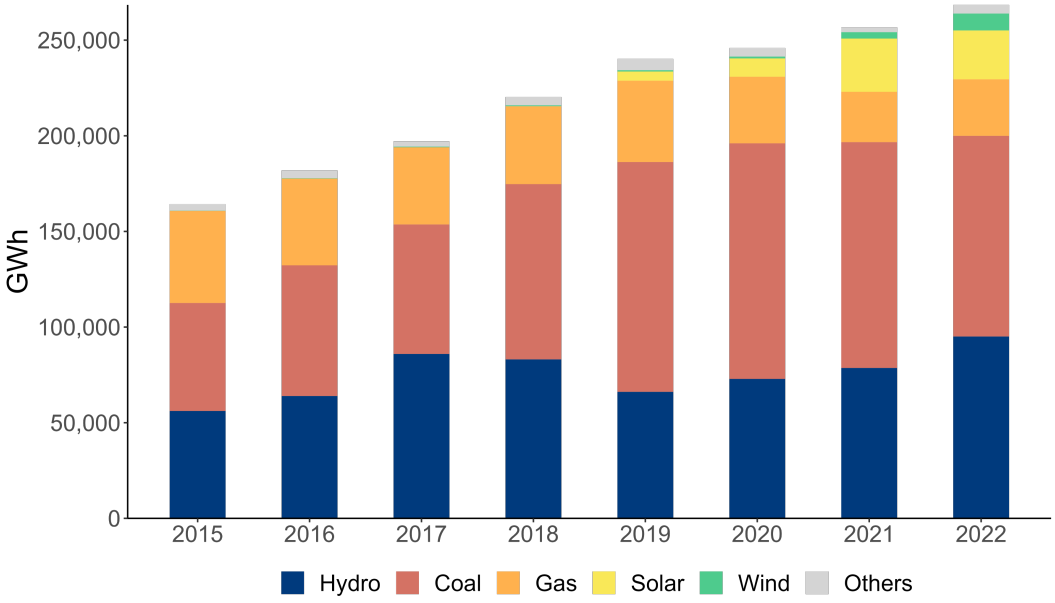


Figure 3. Power generation by sources from 2015 – 2022

Data source: 2015–2020, Institute of Energy (2021b). 2021, Nguyen (2022). 2022, Nguyen (2023)

interventions, this trend is expected to persist over time.

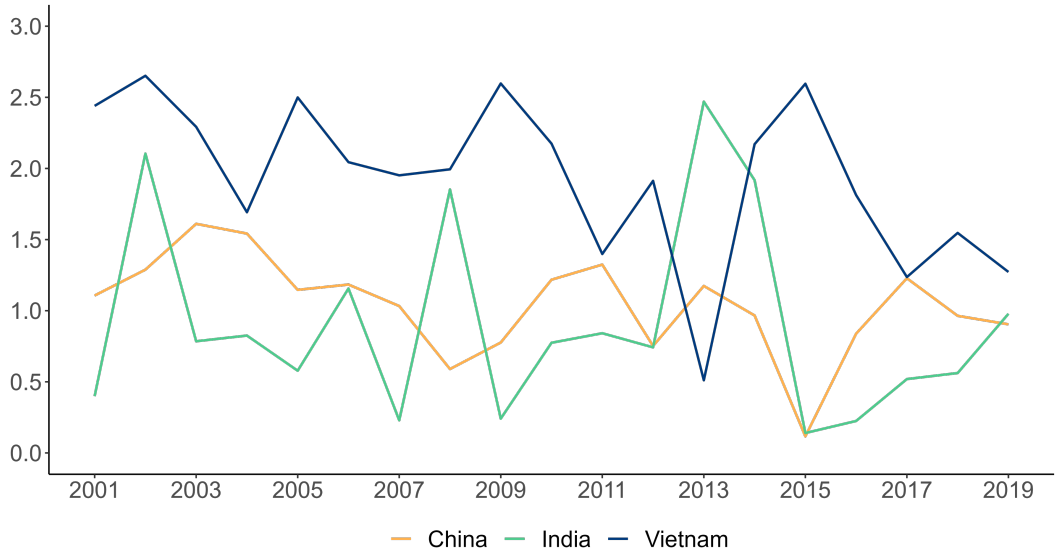


Figure 4. Electricity elasticity of some selected countries

Data source: Authors' calculations from U.S. Energy Information Administration (n.d.) and World Bank (n.d.b)

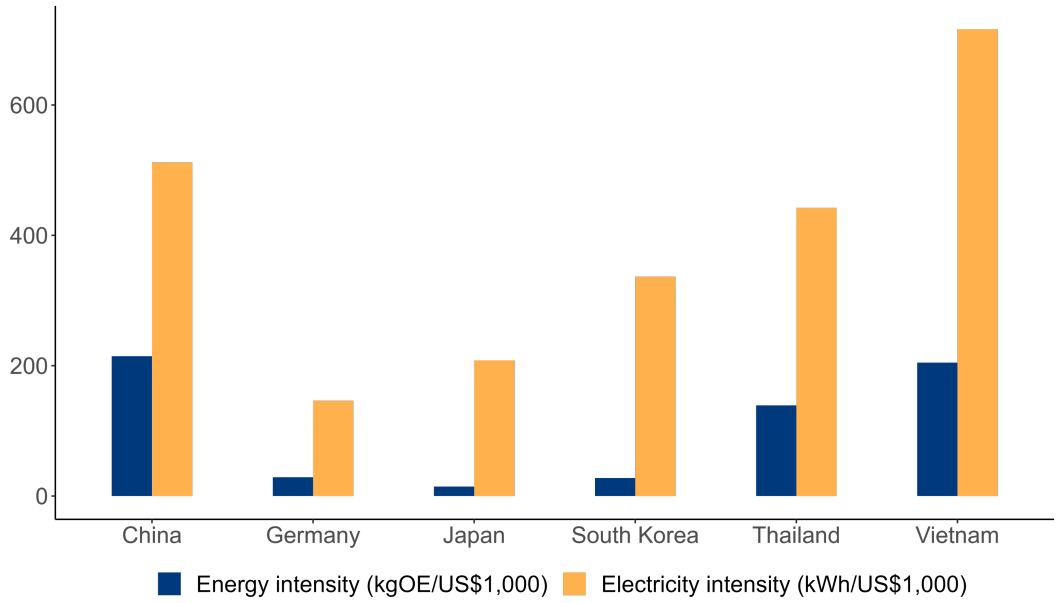


Figure 5. Energy and electricity intensity of some selected countries in 2021

Data source: Authors' calculations from U.S. Energy Information Administration (n.d.) and World Bank (n.d.a)

The high electricity intensity indicates a serious structural problem within the Vietnamese economy. Vietnam's government has prioritized the industrial sector, particularly energy-intensive industries such as cement, steel, fertilizer, and construction, to drive

economic growth. As a result, the industrial sector has gradually become the largest electricity user accounting for over 54% of the total electricity demand from 2015 to 2020 (Figure 6). Yet, this sector contributed only around 36% of the GDP. On the other hand, the commerce and services sector accounted for only 5% of the total electricity demand but contributed more than 42% of the GDP (World Bank, 2023). Demand from the residential sector has grown rapidly, which is likely correlated with the drastic nationwide improvement in household income and living standards over the past three decades. For example, refrigerator ownership has become almost universal and over half of households use air conditioners in big cities (Figure 7). Looking forward, researchers expect Vietnam will experience higher overall temperatures and more heat waves, which will increase the demand for energy for cooling and ventilation and put a strain on the current power grid.

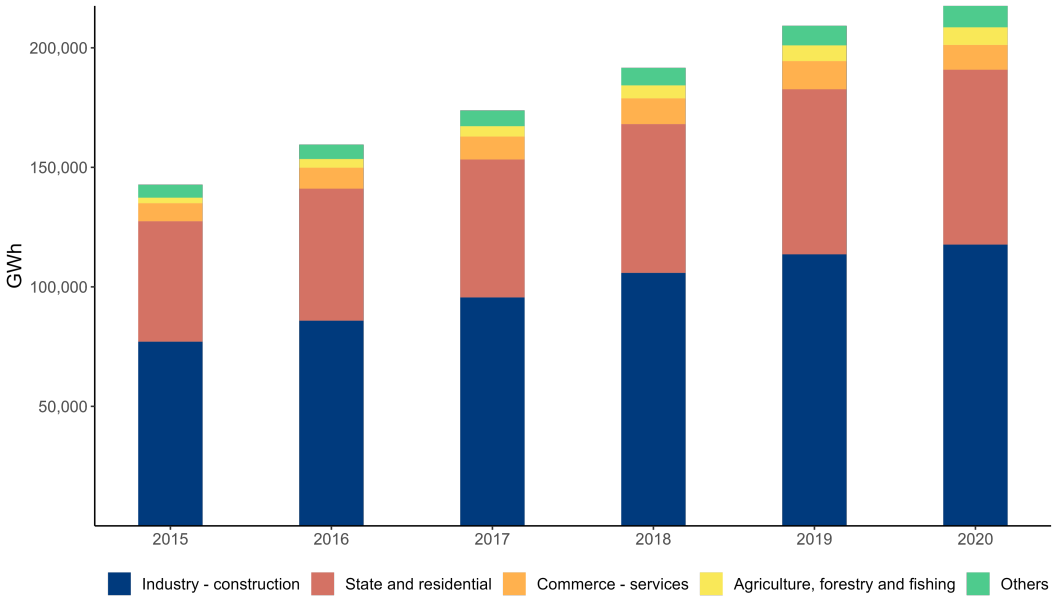


Figure 6. Electricity consumption by sectors from 2015 - 2020

Data source: Authors' calculations from Institute of Energy (2021b)

The high electricity intensity in Vietnam relative to its regional peers signifies the need for bold actions. Understandably, for most countries of the same development status as Vietnam, there are significant obstacles for improving energy efficiency due to lack of clear policy frameworks, enforcement, and financial mechanisms for investment in energy-efficient technology and conservation efforts (Vietnam Business Forum, 2016). Vietnam faces these issues and more. An additional obstacle to improving energy efficiency in Vietnam is the low retail price of electricity which disincentivizes private investment in energy conservation. Even though the retail price of electricity has been repeatedly raised over time, the real price (adjusting for the depreciation of the Vietnam Dong against the US Dollar) has decreased. Vietnam has much lower electricity prices than its

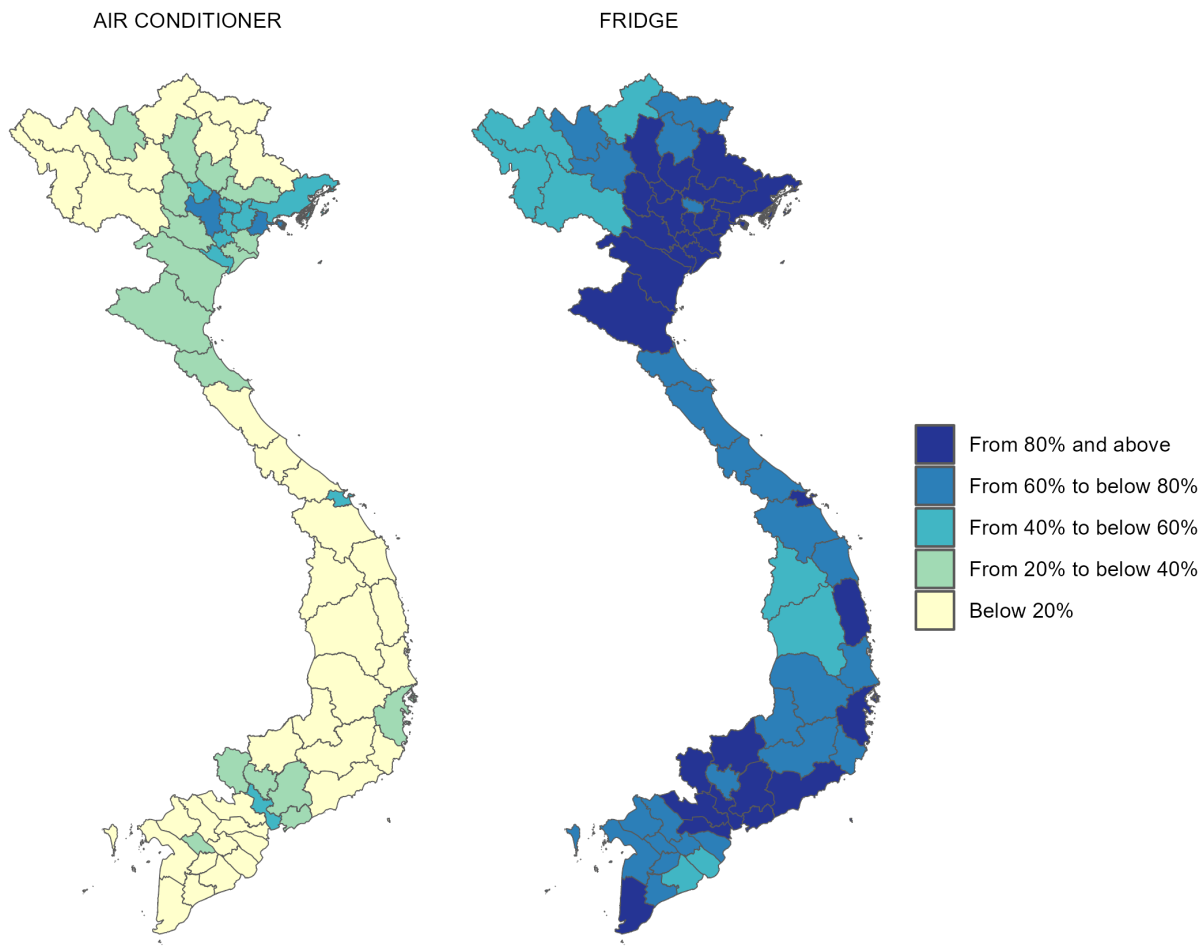


Figure 7. Share of equipment ownership based on Vietnam's Population and Housing Census 2019

neighbors(Dapice et al., 2022).

Many countries have passed regulations requiring electricity users to upgrade or replace their equipment to meet certain energy efficiency specifications. Improved building designs and better materials can greatly reduce electricity used for lighting, cooling and ventilation. However, improvements can also be made by educating the public. Some actions cost very little effort such as knowledge transfers and behavior changes. Educating the public about the benefit of energy savings would also help build support for private sector investment. Unfortunately, there is a dearth of studies on electricity efficiency, particularly pertaining to households which account for a third of the total electricity

demand in Vietnam. To the best of our knowledge, no previous studies have investigated the electricity efficiency of the residential sector in Vietnam.

We aim to make two contributions to the existing literature. We provide a first estimate of the residential electricity efficiency in Vietnam. We show that the level of efficiency is lower relative to many countries of the same low-middle income development status, and is significantly lower than developed countries. Our study identifies household's electrical equipment and their ages as key drivers of the electricity demand and efficiency. Second, we review energy efficiency and conservation efforts in Vietnam, focusing on policy and institutional arrangements and the barriers that have arisen from domestic energy policy priorities. Our findings could help policymakers implement more effective and targeted actions, which will be vital to accelerating the transition to clean energy in Vietnam.

The rest of this paper is structured as follows. Section 2 describes our econometric approach to estimate residential electricity efficiency. We review our data sources in section 3. Section 4 presents our empirical findings. Section 5 concludes with policy implications.

2 Econometric modelling

2.1 Residential electricity demand

We start with the market equilibrium for electricity demand in the presence of increasing block-rate (IBR) pricing. The demand for electricity is affected by consumption behaviors, the availability of substitutes for electricity by other fuels, the stock of appliances, and possible replacements of electric equipment in the long term. Subsistence uses such as lighting and basic entertainment are expected to be less responsive to price, while consumption for luxury purposes such as air-conditioning tends to be more responsive to price. Household income is a major determinant of demand as electricity is considered a normal good in most situations. A higher income often results in more consumption. In addition, a higher income could allow ownership of more power-intensive electric appliances which further raise consumption. Therefore, the residential electricity demand could be modeled as a function of electricity price, disposable income, price and availability of substitutes for electricity, and other explanatory variables that control for demographic and housing characteristics (Olmstead, 2009; Filippini et al., 2014; Wiesmann et al., 2011; Phu, 2020; Nguyen, 2019).

Meanwhile, the supply of electricity is more complicated. In many countries including Vietnam, retail electricity price is strictly regulated, most often through increasing block-rate pricing that costs more per unit as consumption increases. The government sets a low

price for the first 50kWh to increase accessibility for the majority of the population. The price increases at higher consumption levels, reaching the highest level of VND 2,587 per kWh for consumption exceeding 400kWh per month for urban residents in 2017. The price tariff was most recently adjusted in late 2023 by raising each block rate yet keeping the six blocks unchanged. Due to IBR pricing, we have two potential equilibria corresponding to the average price (AP) and the marginal price (MP). Nevertheless, the literature about electricity demand produces no consensus on consumers responding to the average or the marginal price (Shin, 1985; Ito, 2014).

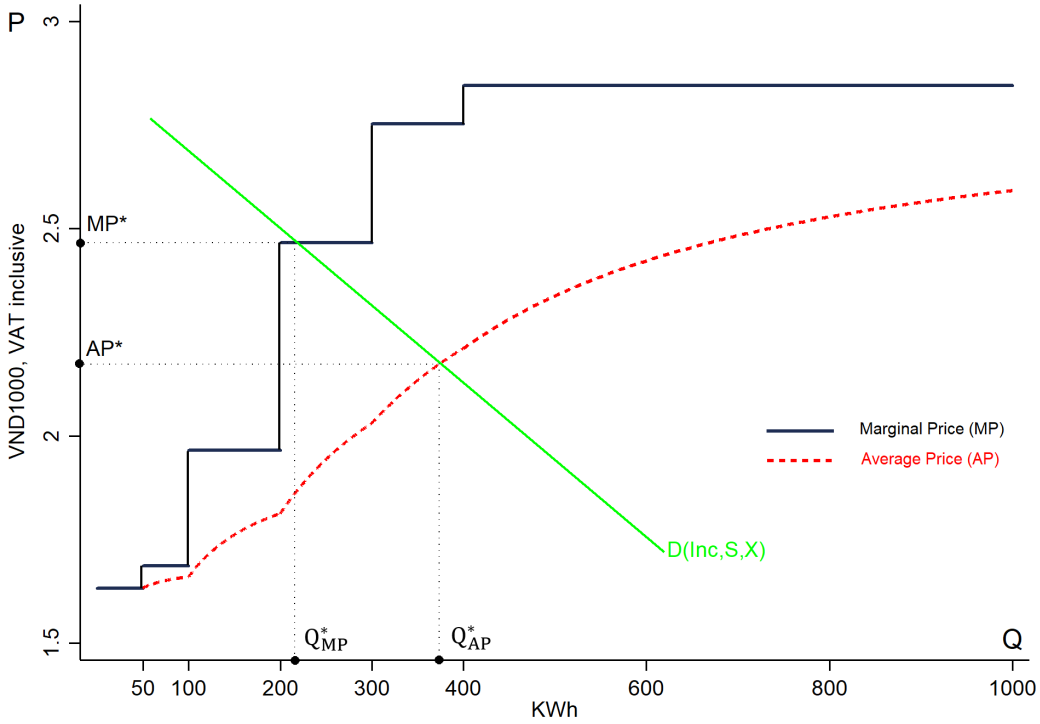


Figure 8. Market equilibrium with increasing block-rate pricing

Source: Authors' illustration

Using mathematical notations,

$$\begin{cases} Demand: & Q = f(P, Y, S, X) \\ Supply: & P = g(Q) \end{cases} \tag{1}$$

with Q being the average monthly electricity consumption in kilowatt-hours (kWh). The explanatory variables are: price of electricity (P); household's disposable income (Y); price of substitute energy (S); and the vector of other control variables (X) including asset ownership, housing characteristics, and regional effects such as climatic conditions that may affect the electricity demand.

As both price and quantity demanded are simultaneously determined, an ordinary

least squares (OLS) estimation of the demand function, taking price as given, will suffer from simultaneity bias. Most studies focusing on price elasticity of demand resort to two-stage least squares with instrumental variables to overcome price endogeneity. For example, Phu (2020) estimated the structural demand equation using two-stage least squares instrumenting the endogenous price by a set of unique instruments representing an antiquate household's registration system and concluded that the demand is almost unitarily price elastic in Vietnam. Boogen et al. (2021) using marginal peak and off-peak prices and local average prices as instrumental variables also found a relatively large price elasticity of -0.7 in the short- and medium-run in Switzerland and argue that pricing policy can be used to reduce electricity consumption.

In this study, our interest is to estimate the power consumption at equilibrium. Therefore, we have made use of a reduced-form solution of the structural equations system by substituting the price equation into the demand equation, then implicitly solving for the equilibrium quantity Q^*. As both the supply and demand are monotonic in price, there is a unique equilibrium quantity expressed as follows:

$$Q^* = h(Y, S, X) \tag{2}$$

Note that in the reduced-form equation of the quantity demanded at equilibrium, there is no longer an endogenous price, thus it could be estimated by the traditional least-squares method. This demand function is usually assumed a double-log form, which is a dominant specification with a strong theoretical underpinning (Plourde and Ryan, 1985):

$$lnQ_i = \beta_0 + \beta_1 \times lnY_i + \beta_2 \times lnS_i + \sum_j X_i^j \times \beta_j + v_i \tag{3}$$

The double-log demand function allows for a straightforward explanation of β_1 and β_2 as the reduced-form parameters of income elasticity, and cross-price elasticity of demand, respectively. It is important to note that the electricity demand is estimated for specific time frames. For example, in the short term, the stock of appliances is fixed, which limits the ability of users to change consumption behaviors. In the long term, users can upgrade or replace capital equipment.

In this model, the dependent variable is the amount of electricity consumption. Explanatory variables include household income and expenditure on other fuels in log form. Household demographic variables include the number of people in the house and the education level (in years of schooling) of the household's head. Electric equipment ownership and house size are important determinants of the electricity demand, particularly in the short term. We also include a set of variables such as the rural/urban area indicator to control for location effects, and the average land surface temperature of the neighbor-

hood to control for micro-climatic effects, which could affect heating or cooling equipment usage.

2.2 Residential electricity demand in the presence of efficiency effects

To study the efficiency effects of residential electricity demand, we apply a stochastic frontier concept to the electricity demand function (3). The stochastic frontier is used to measure differences between energy use best practices and predicted energy use (Filippini and Hunt, 2012). As explained in Boyd (2008), the engineering models represent best practice technologies, while statistical models represent the average practice. Answering the question "How close is observed performance from the best practice?" would provide useful information for energy management and goal setting. Figure 9 explains the concept of efficiency and how inefficiency may arise in the cost minimization problem. The demand for electricity is a derived demand from the stock of electrical appliances (Hartman, 1979). Households either maximize the utility or minimize the cost of electric consumption like cooking, lighting, or air-conditioning. Households achieve this goal by selecting a portfolio of electric appliances and electricity consumption. As in traditional production theory, a firm chooses the optimal level of inputs K and L to maximize profit or minimize the cost of inputs.

If households are fully efficient, the optimal combination of capital good and electrical input is at point E_1, which is the tangent of the utility isoquant and the budget set B_1. This corresponds to the optimal capital stock K_1 and electricity input Q_1. This combination implies both technical efficiency (no waste of inputs) and allocative efficiency (inputs are used in the most appropriate proportion). This equilibrium is expected in the long-term when all inputs are allowed to change.

However, when the capital stock of appliances is fixed at K_2, as would be expected in the short term, the optimal equilibrium is E_2, corresponding to power consumption Q_2 and budget set B_2. The budget set B_2 is larger than B_1, indicating a loss of allocative efficiency, which is a consequence of household choices being restricted by the capital stock of electric appliances in the short-term. The long-term and short-term effects are influenced by the duration over which a household can replace capital goods. In the short-term, the stock of capital goods is fixed, thus households are only allowed to change the level of variable inputs, i.e. how much electricity to use. In the long-term, a household can change both the stock of appliances as well as the intensity of usage. It is important to note that there is no clear definition of the short-term or the long-term. Office equipment is replaced every three to five years, while household appliances may last longer. Equipment used in heavy industries can last much longer than those in light industries or the service

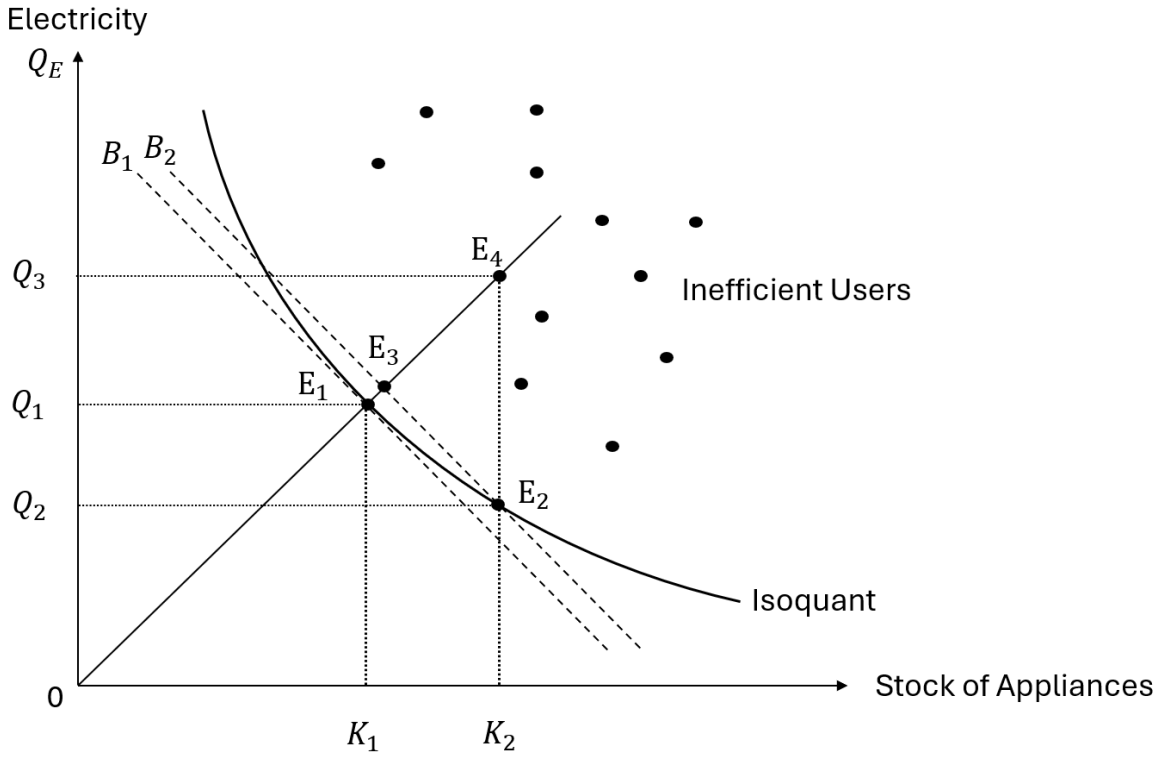


Figure 9. Radial and non-radial measure of efficiency effects

Source: Authors' illustration

sector (Hartman, 1979).

Not all households are technically efficient. For example, points above the isoquant such as E_4 are inefficient because the household uses more of both inputs (capital and electricity). Household inefficiency can further be explained in terms of radial and non-radial measures. If households are free to choose their levels of capital stocks and electricity consumption, then radial inefficiency is measured as the distance between $E_1 and E_4$. However, if the capital stock is fixed at K_2, the non-radial (or single-input) inefficiency is the distance between $E_2 and E_4$. Regarding electricity consumption, the radial inefficiency is Q_1Q_3, while the non-radial inefficiency, Q_2Q_3, will always be more inefficient.

The inefficiency effect can be introduced in the demand function by adding an error term u with a truncated or half-normal distribution, following the classical framework in Lovell and Kumbhakar (2000) and Coelli et al. (2005):

$$lnQ_i = \beta_0 + \beta_1 \times lnY_i + \beta_2 \times lnS_i + \sum_j X^j{}_i \times \beta_j + \underbrace{u_i + v_i}_{\text{composite errors}} \tag{4}$$

with $u_i \overset{\text{iid}}{\sim} N^+(0, \sigma_u^2)$ and $v_i \overset{\text{iid}}{\sim} N(0, \sigma_v^2)$.

The technical efficiency can be expressed as:

$$TE_i = e^{-u_i} \tag{5}$$

Because u is non-negative, the technical efficiency is always between $[0 - 1]$. The demand function is fully efficient when $u = 0$, which occurs along the isoquant. The further the distance to the isoquant, the larger the u, and the more inefficient the demand is. The presence of inefficiency could be tested by decomposing the composite errors $(u_i + v_i)$. If the efficiency component u is large, as denoted by the relative size of $\lambda = \frac{\sigma_u}{\sigma_v}$, then the efficiency effect is present and should be accounted for.

Regarding the specification of the demand frontier and efficiency, there are two approaches, one including the determinants of efficiency on the frontier such as Boogen (2017), and the other explicitly modeling the efficiency in the second state of the model such as Andor et al. (2021). This leads to discussion about which factors affect the demand frontier, and which factors are determinants of technical inefficiency. In our model, we include household income and substitutes as the main determinants of the reduced-form demand equation. Other control variables are household characteristics including demographics (such as the number of persons and education level of the household's head) and the physical environment (such as the house size and the average temperature). We also control for the stock of appliances in the demand frontier because our measure of inefficiency is non-radial. This approach is suitable for short-term analyses when the stock of appliances is fixed. Long-term analyses could allow the stock of appliances to change, such as Dubin and McFadden (1984), which jointly estimate the demand for appliances and the demand for electricity by appliances. The determinants of inefficiency should only be related to equipment quality or consumption behaviors. We do not include socio-economic factors or the gender of a household's head as determinants of inefficiency because these have no theoretical foundation.

3 Data sources and description

3.1 Data sources

The Vietnam Household Living Standard Survey (VHLSS) is conducted bi-annually by the General Statistics Office (GSO) of Vietnam. This survey is designed to investigate household economic status in Vietnam by collecting a wide range of information with regard to household demographics, incomes and expenses, access to healthcare, education background, ownership of durable goods, housing, and social assistance. The VHLSS has a rotating panel design at the enumeration areas. In each round, a half of the sample of

the households from the previous round are re-surveyed; while the remaining households are replaced with new households (see Figure 10 for demonstration). This unique design allows us to construct a longitudinal dataset. To identify duplicated households, the survey asks whether a household was interviewed in the last round. If the answer is "yes", identification information such as the province, district, ward, enumeration area, and household code are provided.

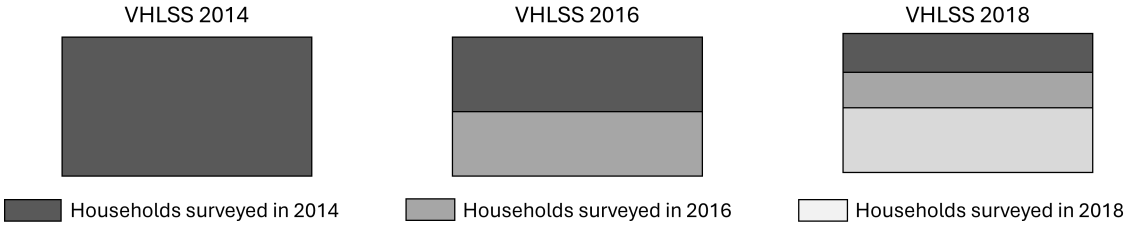


Figure 10. Illustration of the rotating panel design in VHLSS

We use data from three consecutive rounds of surveys: 2014, 2016, and 2018. Before 2014, the information on electricity consumption was not sufficient for analysis. In 2012, of 23,235 households interviewed, only 4,478 households, or 19.27% of the total, reported their electricity consumption. We also exclude the 2020 and 2022 surveys as they were collected during the coronavirus pandemic. During this period, the Vietnamese government subsidized electricity bills to help the population cope with adverse economic impacts. We restrict the study sample to households living in their own houses and using the national power grid because these households pay the official block-rate tariff. This group accounts for approximately 96% of the total sample. We exclude tenant households because their electricity prices are decided by their landlords, which are often higher than the highest block of the government-stipulated price (World Bank Group and Vietnam Academy of Social Sciences, 2016). The final data set includes 11,077 total observations from 1,787 households in the 2014-2016 panel, 1,689 in the 2016-2018 panel, and 1,375 in all three surveys (Figure 11).

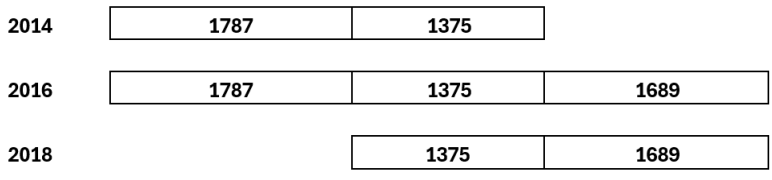


Figure 11. Household samples after cleaning

3.2 Variables descriptions

Electricity consumption

The dependent variable is the electricity consumption in kilowatt-hours used in the last month of the survey. We focus on households staying in their own houses and paying the official block-rate tariff. As a result, the consumption quantity could be extrapolated from the monthly electricity bills using Eq. (6). Under the block-rate scheme, the marginal prices increase at higher consumption levels. The residential retail tariff has been updated over time in Table 1.

$$\text{Electricity bill} = \begin{cases} P_1 Q & 0 \leq Q \leq Q_1 \\ P_1 Q_1 + P_2(Q - Q_1) & Q_1 < Q \leq Q_2 \\ P_1 Q_1 + P2Q2 + P_3(Q - Q_2) & \text{if } Q_2 < Q \leq Q_3 \\ ... & Q_{k-1} < Q \leq Q_k \\ P_1 Q_1 + P_2 Q_2 + ... + P_{K-1}(Q - Q_{K-2}) & Q_{K-1} < Q \leq Q_K \\ P_1 Q_1 + P_2 Q_2 + ... + P_K(Q - Q_{K-1}) & Q > Q_K \end{cases} \tag{6}$$

Table 1. Electricity tariff (VND per kWh), subject to value-added tax (VAT)

Interval	**2014**		**2016**	**2018**
	Before June 1	From June 1		
0 - 50 (poor households only)	993			
0 - 50 (remaining households)	1,418	1,388	1,484	1,549
51 - 100	1,418	1,433	1,533	1,600
101 - 150	1,622	1,660	1,786	1,858
151 - 200	2,044	1,660	1,786	1,858
201 - 300	2,210	2,082	2,242	2,340
301 - 400	2,361	2,324	2,503	2,615
401 and above	2,420	2,399	2,587	2,701

The official exchange rate is USD/VND = 22,719 by the end of 2017

Household income

Household income is the average monthly income from all sources including both wages and non-wage income that may come from sources like agriculture, forestry, fishery, household business, social support and transfers.

Substitutes of electricity

The most popular substitutes for electricity are liquefied petroleum gas (LPG) and coal used for cooking, respectively. Some households may use firewood or biomass; however, they are not widely used even in rural Vietnam nowadays. Lighting is exclusively

powered by grid electricity. Ideally, we would use the price of electricity substitutes. Unfortunately, the prices of these sources are unavailable in the survey data. Given that their demand is often inelastic (Espey, 1998; Labandeira et al., 2017), we can approximate price as expenditure. We do not consider gasoline or diesel used in transportation as substitutes for electricity because electric transportation is negligible in Vietnam at the moment.

Household appliances

We focus on seven common electric appliances, including the number of personal computers, refrigerators, washing machines, air conditioners, electric fans, water heaters, and electric stoves. We assume that the demand for electricity is determined by the stock of appliances. Meanwhile, efficiency is affected by equipment quality, which could be proxied by equipment age. We do not have information on equipment brands or specifications.

Temperature

We expect that the environment, particularly the ambient land surface temperature, may significantly affect electricity demand for air-conditioning and ventilation in summer or heating in winter. Vietnam has a tropical hot-humid climate, so there is limited demand for space heating. Air-conditioning is exclusively powered by grid electricity. We extract temperature data from the Moderate Resolution Imaging Spectroradiometer (MODIS) attached to the Terra satellite. This sensor captures the land surface temperature in Vietnam at the $1km \times 1km$ resolution every eight days. We average the temperature over the quarter of the interview at the district level (Figure 12). Some studies have made use of the Heating Degree Days (HDD) or Cooling Degree Days (CDD), which could be derived from temperature variations between the maximum and minimum temperatures. However, the MODIS data is insufficient to estimate HDD or CDD units.

Control variables

We control for a wide range of variables, including a dummy variable indicating if the area is rural/urban, the house size, the number of household members, and the year of schooling of a household's head. We include a time index to control for the Underling Energy Demand Trend (UEDT) as in Filippini and Hunt (2012). The model includes the months of the year to account for seasonal consumption patterns such as extended national holidays on power consumption like the effect of the Lunar New Year, which falls in the first quarter of the year.

The descriptions of variables and summary statistics are provided in Table 3.

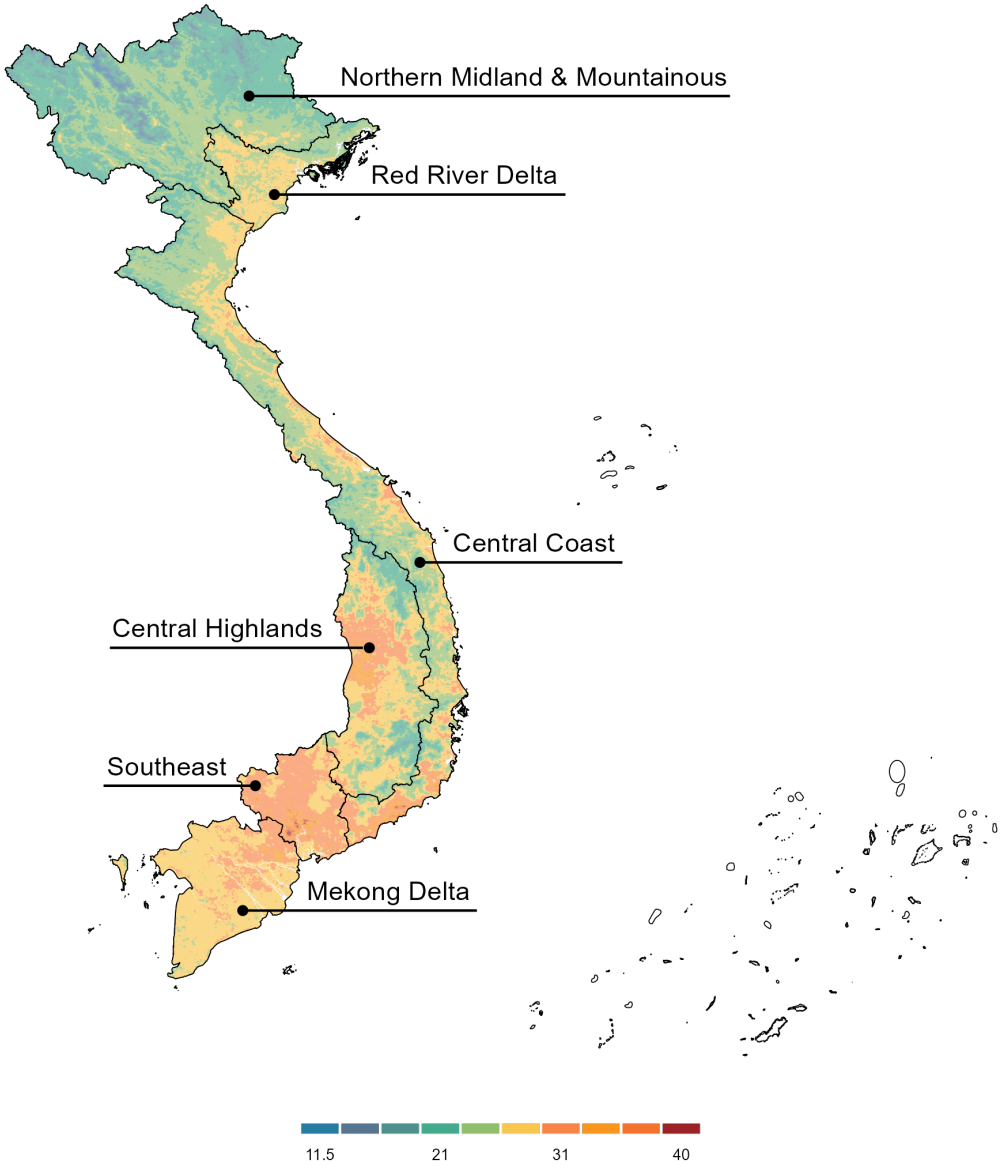


Figure 12. The mean temperature pattern in Q4-2018 as derived from MODIS data and deliniations of six socio-economic and climatic regions in Vietnam.

4 Empirical findings

We present two sets of results according to various specifications to ensure the robustness of the results. The first set corresponds to the simplest application using a pooled model in the spirit of Aigner et al. (1977). Many models have been developed to estimate stochastic frontiers in the presence of panel data such as Pitt and Lee (1981) and Greene (2005). Here, we present a second set of results from four different models including the traditional fixed effects and random effects estimation, and the time-invariant and time-varying efficiency models. The latter two models represent different assumptions on

the efficiency terms. One assumes an invariant efficiency term across the time dimension, u_i. The time-varying efficiency model allows for the efficiency term to change over time (Battese and Coelli, 1992).

The results of pooled regressions are shown in Table 4, corresponding to least squares and stochastic frontier estimations. To estimate the determinants of the efficiency term, a third model was estimated using a truncated normal distribution(Kumbhakar et al., 2021). As expected, all the estimated parameters are positive and statistically significant. The elasticity of income is 0.13, indicating that electricity demand increases with a household's total income. It is consistent with the existing literature that electricity is a normal good (for example, see Silk and Joutz (1997), Ziramba (2008), Okajima and Okajima (2013) or Phu (2020)). The elasticity of substitution is 0.06, suggesting that LPG used for cooking is a substitute for electricity, however the degree of substitutability is limited.[1]

An increase in certain attributes, like house size and number of people per house, raises the electricity demand frontier. People with more education tend to earn more, which in turn increases their electricity consumption. It can also be that they need more power for productive activities such as lighting or computer usage. Urban households tend to consume more power than people in rural areas. In addition, electricity consumption increases in hotter weather. The magnitude of the impact is significant. For each 1 Celsius degree increase in the average temperature, the demand for electricity increases by about 2.8%. This result is consistent with Phu (2021) which finds that national electricity demand increases non-linearly by 1.4% up to 3.5% or 7.7% for each one-degree increase in the average temperature from the 30^oC, 35^oC and 38^oC baselines, respectively. Increased ownership of electric equipment, particularly relating to fridges, washing machines, air conditioners, and electric stoves, comes with significantly more power consumption.

[1]It is important to note that these parameters are reduced-form elasticity of income and elasticity of substitution. To make a comparison with the underlying structural parameters, we rely on a closed-form solution of a system of demand-supply equation. Following Wooldridge (2015), assuming the demand-supply system is specified in a simple linear form as follow:

$$\begin{cases} Demand: & Q = \beta_0 + \beta_1 P + \beta_2 Y + \beta_3 S \\ Supply: & P = \gamma Q \end{cases}$$

where γ is the slope of the residential electricity supply curve.

Moving P from the supply equation to the demand equation and rearranging the terms, we have a reduced-form equation of the equilibrium quantity:

$$Q = \frac{\beta_0}{1-\gamma\beta_1} + \frac{\beta_2}{1-\gamma\beta_1} Y + \frac{\beta_3}{1-\gamma\beta_1} S$$

Therefore, the reduced-form parameters of income $\frac{\beta_2}{1-\gamma\beta_1}$ and substitutes $\frac{\beta_3}{1-\gamma\beta_1}$ are in fact the structural parameters β_2 and β_3 being re-scaled by $1-\gamma\beta_1$. Phu (2020) showed that the structural parameters $\beta_1 \approx -1$, $\beta_2 = 0.3$, and $\beta_3 = 0.06$ using Vietnam's Household Registration Survey data. We realize that our estimates of the reduced-form parameters of income and substitutes are not far from the structural parameters derived in Phu (2020).

Sakah et al. (2019) share the same finding that housing characteristics such as the floor size and the number of lighting features and electric equipment in the house, raise overall energy consumption. We also find that there is an increasing trend in electricity consumption over time in all models.

To verify our results, we estimate separate models for each of the six socio-economic and climatic regions (Figure 12), and for the urban or rural areas in Table 5 and 6. The estimates are generally consistent across the models. Fridges, air conditioners, washing machines, and electric stoves have a strong influence on electricity demand. Water heaters have a greater impact on power consumption in regions with a cold climate such as the Northern midland and mountainous area. Electric fans affect power consumption more in rural areas than in urban areas, whereas the effect from air conditioning is the opposite.

To test the presence of technical efficiency effects in equation (4), under which $H_0 : \sigma_u^2 = 0$ against the alternative $H_1 : \sigma_u^2 > 0$, a generalized one-sided LR test was conducted. We reject the null hypothesis of no efficiency effect at the 1% significance level for all models, confirming the need for a stochastic frontier modeling approach. We compare the importance of the efficiency terms u relative to the idiosyncratic errors v, $\lambda = \frac{\sigma_u}{\sigma_v} = 1.33$ (Table 4). This indicates that the efficiency effect is large and even dominates the random variations. If we did not reject the null, the stochastic frontier would reduce to an OLS model with normal errors.

To make the optimal use of repeated observations of the VHLSS data, we present a second set of estimations in Table 7 for the balanced panel and Table 8 for the full panel. Due to the overlapping sample design of the survey, the panel is rather limited despite having a large cross section in each survey. We use panel data to address potential omitted factors that could cause biases in the cross-sectional models. Unobserved household characteristics such as operational knowledge of electric equipment that correlates with both the dependent variable (electricity demand) and the explanatory variables (income, substitutes, or other explanatory variables) could bias the estimated coefficients. If unobserved characteristics remain constant between consecutive rounds of surveys, then they could be addressed by a fixed effects estimator. We observe that the panel estimation using random effects and stochastic frontiers is largely similar to the pooled regressions. Meanwhile, the fixed effects estimation deviates in magnitude slightly from other models, yet the signs of all coefficients are consistent. This is not unexpected because fixed effects estimator using within transformation suffers from losses of data variations, especially relating to household's equipment ownership which are only upgraded or replaced in the long-term. We also confirm that the efficiency effects u is significant relative to the instantaneous error term v.

Estimated electricity efficiencies

Across different models, the technical efficiency of electricity consumption averages 75%. The distribution of estimated efficiency is shown in Figure 13. This rate is lower than many countries of the same development status (Table 2). Regional differences are stark, with the highest efficiency in the Red River Delta, the most prosperous region in Vietnam, while households in the Northern midland and mountainous region (the poorest regions) suffer from the lowest efficiency. We also find that electricity efficiency is higher in urban areas than it is in rural areas. Like Otsuka (2017), we find that urbanization and spatial development may improve energy efficiency; however, it contradicts Yu and Guo (2016), which finds that rural households are generally electricity efficient.

Table 2. Residential electricity efficiency in selected countries

Authors	**Country**	**Efficiency**
Boogen (2017)	Switzerland	0.80
Andor et al. (2021)	Germany	0.83
Yu and Guo (2016)	China (rural)	0.93
Weyman-Jones et al. (2015)	Portugal	0.97
Otsuka (2017)	Japan	0.77
Twerefou and Abeney (2020)	Ghana	0.63
This study	**Vietnam**	**0.75**

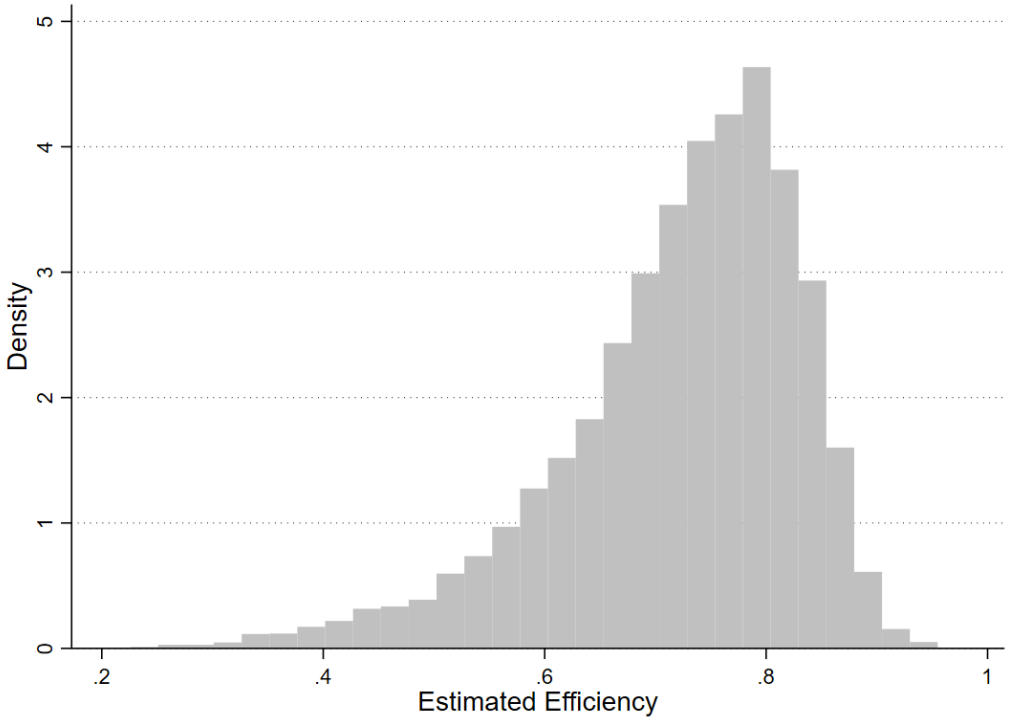


Figure 13. Estimated residential electricity efficiency

Determinants of electricity inefficiency

We attempt to estimate the determinants of inefficiency of the demand frontier (4). Supposing that the inefficiency function is modeled as:

$$u_i = \theta_0 + \sum_j \theta^j Z_i^j + \eta_i \tag{7}$$

where u_i is the technical inefficiency terms derived from a truncated-normal stochastic frontier and Z_i^j is the list of explanatory variables with regards to inefficiency. We use equipment age as a proxy for equipment quality as we expect that electric equipment become less efficient over time. The availability of new and better replacements may also make aging equipment less efficient than newer equipment. Admittedly, many other factors may affect electricity efficiency such as operational behaviors or operating condition. However, this information is normally not collected in most household surveys. Both the frontier and the efficiency models are estimated using a single-step model (Kumbhakar et al., 1991; Reifschneider and Stevenson, 1991).

The results are displayed in last two columns of Table 4. Note that a positive coefficient indicates more inefficiency because $TE_i = e^{-u_i}$. Technical efficiency is highest when the inefficiency term u is as close to zero as possible. Our result suggests that older equipment, particularly relating to fridges, air conditioners, and electric fans, adversely affects electric efficiency. The estimated parameters of other equipment are statistically insignificant. In our data, the average age of fridges, air conditioners, and electric fans is about 5.7, 4.2, and 6.4 years old. On the high end, we see that some equipment is as old as 25 years (far longer than the equipment's intended useful life in most cases). This finding suggests that replacing old fridges, air conditioners, and electric fans with newer, more efficient ones could be a way for households to significantly cut electricity use. Policies targeting replacement may have a significant long-term impact on household energy efficiency in Vietnam.

5 Discussion and policy implications

Our results indicate that the energy saving potential in Vietnam is at least 25% of the total residential demand. Considering that the residential electricity demand accounts for a third of the country's total electricity production, improving electricity efficiency could reduce investment needs in expanding generation capacity significantly. The Government of Vietnam has recognized the important role of energy efficiency and issued its first decree on energy efficiency and conservation (EE&C) in 2003. From that milestone, many regulations and national programs related to EE&C have been approved and implemented, including the Law on Economical and Efficient Use of Energy, which was passed by the

National Assembly in 2010. Three national energy efficiency programs (VNEEP) successively raise the targets for efficiency goals (Figure 14). These regulatory frameworks promote energy efficiency activities in all sectors of the economy through regulations, standards, and incentives. They also stipulate the rights and obligations of regulatory entities, businesses and households, and individuals in using and conserving energy. With regards to residential usage, VNEEP programs promote the use of high-performance electrical equipment, encourage users to replace outdated devices, and offer incentives such as tax exemptions, land use incentives, and preferential loans from domestic banks. In the construction sector, the Ministry of Construction has formulated technical standards on building design, including standards on what wall, ceiling and floor materials should be used to conserve energy needed for air-conditioning, ventilation and lighting.

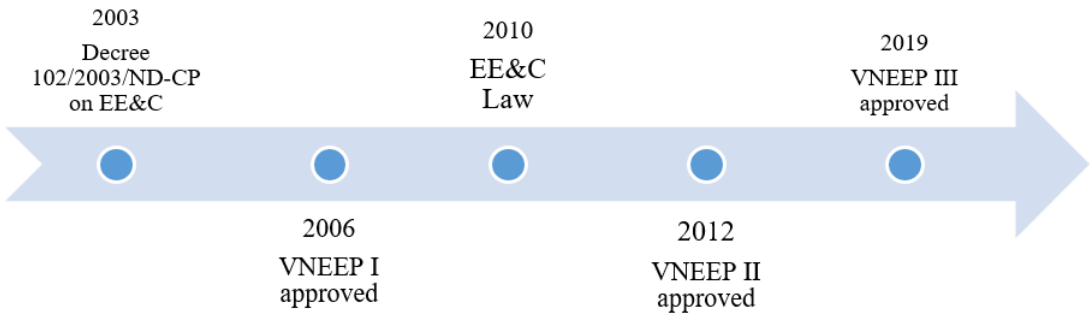


Figure 14. The timeline of major legal documents for energy efficiency and conservation in Vietnam

Source: Authors' summary

Some programs have been considered successful such as the energy efficiency labeling program. First rolled out in 2008, equipment labeling was voluntary except for light bulbs and electric kettles. In 2013, the list of labeling mandatory equipment was expanded, including common household appliances such as air conditioners, washing machines, rice cookers, electric fans, and televisions. LED bulbs and water heaters were later added in 2017. Apart from the labeling program, the government has prohibited manufacturing and importing appliances whose energy efficiency is lower than stipulated minimum energy performance standards. Items that cannot be imported are things like incandescent light bulbs with a capacity greater than 60 watts. Because electricity consumption for lighting is quite high in Vietnam, accounting for up to a third of the total power consumption[2], much can be achieved with the transition to modern lighting equipment such as LED light bulbs. Vietnam has also succeeded in installing nearly 100,000 home solar panel systems, with a total capacity of over 9 GW, accounted for nearly 15% of generation

[2]https://tietkiemnangluong.com.vn/tin-tuc/pho-bien-kien-thuc/t21279/35-dien-nang-tieu-thu-phuc-vu-chieu-sang.html (Power consumption for lighting in Vietnam)

capacity in 2021. This success is attributed to the particularly attractive feed-in-tariff of 8.38 US cent/kWh. Rooftop solar photovoltaic (PV) panels could contribute to lowering peak electricity demand at noon and feeding excess power back to the grid. Another low-cost option is replacing electric heaters with solar water heaters. A survey by the Institute of Energy shows that a family of four persons will consume an average of about 1.8 – 2.5 kWh/day to produce and use hot water, which accounts for about one-fifth of a household's daily electricity demand (DEA, 2017).

Going forward, we highlight several major issues underlying the low efficiency of the power sector in general, and of the residential sector in particular, and potential policy recommendations.

First, as retail price affects consumption behavior and the economics of energy saving investments, a price reform is needed to unlock the potential of energy efficiency. The current average retail electricity price is about 8.2 US cent/kWh in Vietnam as of November 2023. It is among the lowest in Southeast Asia and the world. The average price (in cent/kWh) is about 10 in Malaysia, 30 in the Philippines, 11 in Indonesia, and 12 in Thailand, and is much higher in developed countries such as Singapore (20) (Dapice et al., 2022). The Vietnamese government has rationalized low electricity pricing as a social policy. Inadvertently, this reduces the incentive for electricity users to invest in more energy-efficient appliances. The low retail price is the consequence of direct and indirect government interventions to subsidize power generation. In fact, Electricity Vietnam, the state utility provider, has set the average retail price lower than the average cost of production which rose to approximately 8.6 US cent/kWh in2023 due to high fossil fuel prices and low hydropower outputs. As a consequence of rising energy consumption and high energy prices, subsidies have become a major financial burden on the government. The International Energy Agency (IEA) calculated that in 2012 implicit subsidies in various forms, mostly to State-owned enterprises in energy production and electricity generation, amounted to USD2.86bn out of the total fossil fuel consumption subsidy of USD3.45bn (UNDP, 2014). In order to remove government subsidies, the minimum price charged to consumers by EVN must be set to at least the actual cost of generation. Phu (2020) finds a high price elasticity of residential electricity demand in Vietnam relative to that in other comparable developing countries such as China or India. This opens up the potential for using pricing instruments to regulate electricity use behaviors. Demand response programs using time-of-use (TOU) pricing could be trialed. Currently, this type of policy is only applied to industrial electricity pricing in Vietnam.

Second, our results show that replacing old and obsolete equipment with more efficient equipment could enhance efficiency. According to Young (2008), equipment replacement cycles vary: some last very long such as fridges, which can be used for more than 20 years, while others, like dishwashers, are replaced more frequently. Replacement cycles

are affected by socio-economic factors such as income. Zou and Mishra (2020) note that subsidies for rural households may encourage them to purchase energy-efficient appliances. Additionally, a lack of knowledge regarding energy labels may impact the rate at which consumers switch to more efficient appliances (Mills and Schleich, 2010). Thus, targeted policies aiming at earlier replacement could enhance efficiency. Particularly for countries with estimated low efficiency, policy measures could be through incentives for rural appliance markets (Twerefou and Abeney, 2020). Because our estimate of efficiency is non-radial (the stock of appliances is fixed), radial efficiency could be much higher when households are allowed to upgrade old and less efficient equipment in the long-term. A similar result based on non-radial sub-vector input distance function suggests a much higher saving of up to 25% in the residential electricity demand in Switzerland (Boogen, 2017). This potential saving is much higher than the bottom-up engineering calculation of only 15%. Dapice et al. (2022) suggest that higher efficiency could be achieved by inducing energy users to respond to higher energy prices and invest in energy savings, particularly if preferential credit is available, while raising efficiency standards and providing information to accelerate the response of both industry and building construction and retrofitting. Some sectors might even see much high higher efficiency. For example, the cement industry could see a potential savings of up to 50% (GIZ, figures on energy intensity of this sector). However, a majority of Vietnamese electricity users are small households or home businesses with limited resources to incur large upfront investments. Therefore, having access to low-cost capital is crucial for the transition.

Third, understanding the property of the electricity demand frontier and determinants of efficiency is only the first step toward developing optimal policies to raise efficiency. The implementations of various efficiency improvements in Vietnam have been largely ineffective due to lack of coordination among key stakeholders as well as weak enforcement. Table 9 shows the institutional arrangement regulating energy efficiency in Vietnam. MOIT is tasked with state management of the energy sector. Its role is to provide guidance for energy users to develop and implement efficiency and conservation action plans. However, Ministry of Natural Resources and the Environment (MONRE) and its Department of Climate Change (DCC) are tasked with the leading role in designing national climate policy and the emissions pathway incorporating all economic development policies and international commitments. As the energy sector plays the most critical role in any emissions reduction pathway, MONRE should be given an equal role with MOIT in designing and implementing EE&C policy. Yet, this isn't the case. This leads to the invariable conflict of priorities. The role of MONRE has become largely symbolic. Most technical regulations and investment decisions rest on cost-benefit analysis with minimal concerns for the environment. We recommend that future EE&C programs focus on close coordination among relevant ministries and stakeholders in the energy sector.

6 Limitations

Our result does not take into account the rebound effect. Effectively, the conventional stochastic modeling approach assumes zero rebound effect (Orea et al., 2014). Admittedly, including the rebound effect could lead to higher energy intensity even with more efficiency gains in the future. Zhou et al. (2022) concluded that accounting for rebound effects reduces energy savings to only 37.7% of the predicted value in Chinese manufacturing. Adha et al. (2021) arrived at the same conclusion with Indonesian households, with increased energy consumption in the long-term. Our result represents short-term estimates with the capital stock of household appliances fixed. Other studies such as Zheng et al. (2024) detect a trend in lowering efficiency over time. This happens to be correlated with lower efficiency among higher-income households. It may be that households may choose comfort over energy savings, particularly those that are considered wealthy households (Bakaloglou and Charlier, 2021). McNeil and Letschert (2005) found increased ownership of electric appliances with rising income and urbanization, which results in increased power consumption.

In addition, when taking conservation goals into account, the choice is between extending or reusing the product life of electric equipment or new products that consume less energy. The trade-off is between resource conservation in the production phase and energy consumption during the consumption phase. Truttmann and Rechberger (2006) argued that reusing older equipment, even less inefficient ones, is still better than replacing them with newer ones, in resource conservation of materials and energy. Research focusing on the consumption phase often concludes that the benefit of better efficiency standards outweighs the cost Meyers et al. (2003) without taking into account the production aspect. Solving these questions will need a more comprehensive a life-cycle analysis in the future.

Declarations

The authors declare no conflict of interest. No funding was used to conduct this study.

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Table 3. Variables description and summary statistics

Variable	Description	N	Mean	SD	Min	Max
Electricity consumption *(kWh)*	Electricity consumption in the most recent month	11,077	156.043	106.034	6.553	1,846.135
Household income *(thousand VND)*	Household income in the most recent month	11,077	18,517	30,509	2,227	1,096,946
Price of substitutes *(thousand VND)*	A approximation of costs of substitutes	11,077	161.896	133.184	4	4,650
House size *(m^2)*	Total living area	11,077	91.933	55.563	10	1,000
Number of members *(persons)*	Number of household members	11,077	3.943	1.495	1	13
Head's years of education *(years)*	Years of education the head has obtained	11,077	7.590	4.525	0	22
Temperature *(℃)*	Temperature of the ward in the most recent month	11,077	30.018	3.740	18.062	42.810
Area	Whether a household lives in rural or urban area *(reference: rural)*					
Urban		11,077	0.321	0.467	0	1
Number of appliances	Number of appliances a household owns					
Personal computer		11,077	0.261	0.506	0	8
Fridge		11,077	0.799	0.438	0	4
Air conditioner		11,077	0.255	0.589	0	6
Washing machine		11,077	0.400	0.500	0	5
Fan		11,077	2.155	1.367	0	13
Water heater		11,077	0.342	0.529	0	5
Electric stove		11,077	0.950	0.389	0	4
Year	The difference between the year in which the interview was taken and 2014	11,077	1.982	1.500	0	4
Enumeration month	The month in which the interview was taken *(reference: March)*					
June		11,077	0.134	0.340	0	1
July		11,077	0.001	0.023	0	1

September		11,077	0.432	0.495	0	1
October		11,077	0.002	0.046	0	1
December		11,077	0.284	0.451	0	1
Appliance age	The average age of a type of appliance†					
Personal computer		2,600	4.589	2.878	0	24
Fridge		8,691	5.712	3.561	0	25
Air conditioner		2,142	4.202	3.009	0	18
Washing machine		4,388	5.334	3.342	0	22
Fan		10,371	6.429	3.895	0	34
Water heater		3,531	5.550	3.546	0	24
Electric stove		9,999	5.522	3.642	0	35

† Equipment age is zero if the equipment was purchased in the same year of the survey.

Table 4. Electricity demand frontier with pooled regression

	OLS		Frontier			
			Half-normal		Truncated normal	
	Coeff.	SE	Coeff.	SE	Coeff.	SE
Demand function						
Income	0.133***	0.007	0.132***	0.006	0.134***	0.006
Substitutes	0.062***	0.008	0.067***	0.007	0.061***	0.007
House size	0.074***	0.009	0.074***	0.008	0.071***	0.008
No. of members	0.139***	0.012	0.133***	0.011	0.144***	0.011
Education	0.005***	0.001	0.005***	0.001	0.005***	0.001
Temperature	0.028***	0.001	0.027***	0.001	0.027***	0.001
Area						
Urban	0.105***	0.009	0.102***	0.010	0.097***	0.010
No. of appliances						
PC	0.039***	0.009	0.040***	0.009	0.033**	0.013
Fridge	0.488***	0.013	0.462***	0.011	0.449***	0.012
AC	0.132***	0.008	0.141***	0.008	0.111***	0.011
Washing machine	0.139***	0.010	0.136***	0.010	0.135***	0.013
Fan	0.033***	0.003	0.029***	0.003	0.032***	0.003
Water heater	0.092***	0.009	0.092***	0.009	0.090***	0.013
Electric stove	0.117***	0.013	0.104***	0.011	0.118***	0.011
Year	0.011**	0.003	0.011**	0.003	0.009**	0.003
Enumeration month						
June	-0.038*	0.017	-0.039*	0.017	-0.032	0.017
July	0.208	0.119	0.174	0.164	0.202	0.168
September	-0.021	0.013	-0.021	0.013	-0.013	0.013
October	-0.088	0.050	-0.13	0.085	-0.080	0.086
December	0.029*	0.013	0.023	0.013	0.035**	0.013
Constant	1.139***	0.080	1.563***	0.076	0.967	28.520
Inefficiency determinants						
Appliance age						
PC					0.001	0.003
Fridge					0.010***	0.001
AC					0.011***	0.003
Washing machine					-0.002	0.002
Fan					0.002*	0.001

Water heater			-0.001	0.002
Electric stove			0.000	0.001
Constant			0.206	28.524
σ_v		0.320	0.407	
σ_u		0.426	0.032	
λ		1.333	0.08	
LR-test ($\sigma_u^2 = 0$)		160		
Obs	11,077	11,077	11,077	
Average efficiency		**0.72**	**0.77**	

$^{***}p < 0.01,\ ^{**}p < 0.05,\ ^{*}p < 0.1$

Table 5. Electricity demand frontiers by regions

	(1)		(2)		(3)		(4)		(5)		(6)	
	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE
Income	0.172***	0.019	0.088***	0.011	0.143***	0.014	0.110***	0.026	0.092***	0.018	0.100***	0.013
Substitutes	-0.006	0.018	0.112***	0.015	0.091***	0.015	0.072*	0.029	0.113***	0.023	0.075***	0.016
House size	0.071**	0.024	0.111***	0.013	0.112***	0.018	0.171***	0.033	0.080***	0.024	0.064**	0.019
No. of members	0.078**	0.028	0.237***	0.019	0.132***	0.021	0.083	0.043	0.204***	0.029	0.183***	0.023
Education	0.013***	0.003	0.007***	0.002	0.001	0.002	0.006	0.004	-0.002	0.002	0.004*	0.002
Temperature	0.037***	0.006	0.031***	0.004	0.031***	0.003	0.029***	0.008	0.024***	0.004	0.011	0.006
Area												
Urban	0.114***	0.028	0.086***	0.019	0.096***	0.020	0.069	0.036	0.124***	0.028	0.135***	0.021
No. of appliances												
PC	0.068*	0.028	0.053**	0.017	0.048**	0.018	0.074*	0.033	0.077***	0.021	0.048*	0.022
Fridge	0.540***	0.027	0.243***	0.021	0.504***	0.021	0.394***	0.039	0.329***	0.038	0.515***	0.021
AC	0.090***	0.026	0.092***	0.013	0.164***	0.022	0.147*	0.058	0.158***	0.019	0.167***	0.020
Washing machine	0.112***	0.03	0.114***	0.018	0.124***	0.022	0.078*	0.038	0.128***	0.025	0.151***	0.024
Fan	0.029**	0.009	0.006	0.005	0.020**	0.007	0.006	0.012	0.011	0.008	0.030***	0.008
Water heater	0.148***	0.028	0.083***	0.015	0.048*	0.023	-0.014	0.034	0.060*	0.026	0.063	0.037
Electric stove	0.149***	0.024	-0.004	0.018	0.050*	0.024	0.087*	0.037	0.068	0.040	0.058*	0.025
Year	0.008	0.009	0.019**	0.006	0.015*	0.007	0.005	0.012	0.010	0.009	0.022**	0.007
Enumeration month												
June	-0.172**	0.054	-0.105**	0.040	-0.057	0.037	0.066	0.062	-0.065	0.045	0.061	0.036
July											0.197	0.164
September	-0.153**	0.049	-0.099**	0.037	-0.032	0.029	0.060	0.049	-0.023	0.032	0.066**	0.025

October									-0.299	0.359	-0.025	0.088
December	-0.029	0.035	-0.040	0.026	0.069**	0.026	0.135*	0.058	-0.020	0.035	0.087**	0.028
Constant	1.284***	0.239	1.797***	0.154	0.983***	0.171	1.299***	0.358	1.995***	0.239	2.152***	0.226
σ_v	0.298		0.299		0.330		0.298		0.278		0.317	
σ_u	0.520		0.313		0.357		0.432		0.399		0.407	
λ	1,747		1.048		1.083		1.447		1.435		1.282	
LR-test ($\sigma_u^2 = 0$)	49.04		12.72		14.32		14.36		23.61		28.91	
Obs	1,717		2,606		2,548		702		1,237		2,267	
Average efficiency	**0.68**		**0.78**		**0.76**		**0.72**		**0.74**		**0.73**	

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

Six regions: (1) Northern Midland and Mountainous, (2) Red River Delta , (3) North Central Coast and Central Coast, (4) Central Highlands, (5) Southeast, and (6) Mekong Delta

Table 6. Electricity demand frontiers by areas

	Rural		**Urban**	
	Coeff.	SE	Coeff.	SE
Income	0.132***	0.008	0.111***	0.011
Substitutes	0.040***	0.009	0.150***	0.013
House size	0.076***	0.011	0.076***	0.013
No. of members	0.121***	0.013	0.164***	0.017
Education	0.005***	0.001	0.006***	0.002
Temperature	0.028***	0.002	0.024***	0.002
No. of appliances				
PC	0.041**	0.014	0.051***	0.012
Fridge	0.474***	0.012	0.357***	0.021
AC	0.139***	0.014	0.164***	0.010
Washing machine	0.134***	0.013	0.136***	0.016
Fan	0.039***	0.004	0.011*	0.005
Water heater	0.121***	0.013	0.051***	0.013
Electric stove	0.123***	0.013	0.037*	0.018
Year	0.016***	0.004	0.003	0.006
Enumeration month				
June	-0.045*	0.021	-0.040	0.028
July	0.024	0.205	0.375	0.261
September	-0.011	0.016	-0.042*	0.021
October	-0.090	0.091	-0.178	0.261
December	0.038*	0.016	-0.009	0.021
Constant	1.601***	0.098	1.658***	0.126
σ_v	0.324		0.317	
σ_u	0.445		0.329	
λ	1.374		1.037	
LR-test ($\sigma_u^2 = 0$)	110		20.16	
Obs	7,525		3,552	
Average efficiency	**0.71**		**0.77**	

$^{***}p < 0.01,\ ^{**}p < 0.05,\ ^{*}p < 0.1$

Table 7. Electricity demand frontier with balanced panel data

	FE		**RE**		**TI**		**TVD**	
	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE
Income	0.076***	0.015	0.116***	0.011	0.108***	0.011	0.106***	0.011
Substitutes	0.061***	0.013	0.054***	0.012	0.069***	0.011	0.066***	0.011
House size	0.065***	0.019	0.084***	0.014	0.081***	0.014	0.082***	0.014
No. of members	0.218***	0.028	0.162***	0.019	0.163***	0.019	0.169***	0.019
Education	0.001	0.003	0.008***	0.002	0.007***	0.002	0.007***	0.002
Temperature	0.011***	0.003	0.018***	0.002	0.017***	0.002	0.017**	0.002
Area								
Urban	0.235	0.216	0.171***	0.021	0.147***	0.020	0.140***	0.019
No. of appliances								
PC	0.049*	0.019	0.046**	0.015	0.046**	0.015	0.043**	0.015
Fridge	0.246***	0.020	0.395***	0.017	0.364***	0.017	0.354***	0.017
AC	0.064***	0.017	0.121***	0.014	0.130***	0.013	0.133***	0.013
Washing machine	0.061**	0.021	0.135***	0.017	0.133***	0.016	0.135***	0.016
Fan	0.013*	0.006	0.025***	0.005	0.020***	0.005	0.019***	0.005
Water heater	0.020	0.020	0.076***	0.016	0.081***	0.015	0.084***	0.015
Electric stove	0.032	0.018	0.074***	0.016	0.054**	0.016	0.046**	0.017
Year	0.025	0.017	0.004	0.017	0.005	0.016	-0.019	0.017
Enumeration month								
June	0.065	0.038	0.029	0.036	0.035	0.035	0.046	0.035
July	0.152	0.162	0.213	0.151	0.137	0.149	0.153	0.144
September	0.017	0.037	-0.018	0.036	-0.016	0.035	-0.021	0.034
October	-0.180	0.096	-0.182*	0.090	-0.222*	0.087	-0.241**	0.089
Constant	2.467***	0.187	1.688***	0.130	2.099***	0.127	2.179***	0.127
σ_v	0.304		0.304		0.313		0.311	
σ_u	0.379		0.246		0.624		0.560	
λ	1.247		0.809		1.993		1.802	
Obs	4,125		4,125		4,125		4,125	
Average efficiency					**0.75**		**0.78**	

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

FE: Fixed effects, RE: Random effects, TI: Time-invariant, TVD: Time-varying decay model.

TI model assumes $u_{it} = u_i$.

TVD model assumes $u_{it} = exp\{-\eta(t - T_i)\}u_i$.

Table 8. Electricity demand frontier with panel data for full sample

	FE		**RE**		**TI**		**TVD**	
	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE
Income	0.068***	0.01	0.131***	0.007	0.125***	0.007	0.124***	0.007
Substitutes	0.051***	0.009	0.057***	0.007	0.071***	0.007	0.071***	0.007
House size	0.079***	0.013	0.086***	0.009	0.079***	0.009	0.080***	0.009
No. of members	0.192***	0.019	0.140***	0.012	0.135***	0.011	0.137***	0.011
Education	0.001	0.002	0.007***	0.001	0.006***	0.001	0.006***	0.001
Temperature	0.015***	0.002	0.025***	0.001	0.024***	0.001	0.024***	0.001
Area								
Urban	0.203	0.178	0.133***	0.012	0.115***	0.011	0.112***	0.011
No. of appliances								
PC	0.041**	0.013	0.045***	0.010	0.046***	0.009	0.046***	0.009
Fridge	0.249***	0.014	0.418***	0.011	0.388***	0.011	0.384***	0.011
AC	0.066***	0.012	0.120***	0.009	0.133***	0.008	0.134***	0.008
Washing machine	0.049***	0.014	0.125***	0.011	0.126***	0.010	0.127***	0.010
Fan	0.015***	0.004	0.031***	0.003	0.025***	0.003	0.025***	0.003
Water heater	0.033*	0.014	0.083***	0.010	0.086***	0.009	0.086***	0.009
Electric stove	0.038**	0.013	0.093***	0.010	0.077***	0.010	0.075***	0.010
Year	0.041***	0.012	0.017***	0.004	0.016***	0.003	0.007	0.004
Enumeration month								
June	0.018	0.027	-0.035*	0.015	-0.027	0.015	-0.028	0.015
July	0.149	0.161	0.204	0.149	0.126	0.150	0.128	0.147
September	0.036	0.027	-0.014	0.012	-0.014	0.011	-0.013	0.011
October	-0.124	0.087	-0.14	0.077	-0.187*	0.076	-0.188*	0.078
December	0.043	0.049	0.027*	0.014	0.019	0.013	0.020	0.013
Constant	2.404***	0.139	1.272***	0.079	1.688***	0.078	1.716***	0.078
σ_v	0.307		0.308		0.324		0.324	
σ_u	0.409		0.261		0.668		0.667	
λ	1.329		0.847		2.061		2.061	
Obs	11,077		11,077		11,077		11,077	
Average efficiency					**0.76**		**0.77**	

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

FE: Fixed effects, RE: Random effects, TI: Time-invariant, TVD: Time-varying decay

Table 9. Stakeholders of energy efficiency and conservation in Vietnam

Stakeholders	**Role**
Ministry of Industry and Trade (MOIT)	- Coordinating with other ministries to developing policies, standards and regulations for energy end-use equipment - Providing technical advice, develop and review activities related to training, certification system for energy auditors and energy managers in the building sector
Ministry of Natural Resources and the Environment (MONRE)	Unclear roles
Ministry of Construction (MOC)	In charge of EE&C in the construction sector
Ministry of Finance (MOF)	Development of incentives/penalty schemes and mechanism to support EE&C
Ministry of Science and Technology (MOST)	Developing policies and providing technical advice on EE standards for energy intensive appliances and equipment in buildings, construction materials and provision of technology transfer
Ministry of Planning and Investment (MPI)	In charge of EE&C in industrial parks
Ministry of Agriculture and Rural Development (MARD)	In charge of EE&C in the agricultural sector
Ministry of Transport (MOT)	In charge of EE&C in the transport sector
Other Ministries (Education and Training; Labor, War Invalids, and Social Affairs)	In charge of EE&C in corresponding sectors including training and knowledge dissemination
Provincial Committees	Through DOIT, implementing and monitoring EE&C compliance
Electricity Vietnam (EVN)	Implementation and evaluation of energy efficiency in production and distribution, and demand-side management
Major energy users	Implement EE&C in accordance with the approved roadmap
Other stakeholders (academia, EE&C associations, energy conservation centers...)	Capacity building, information dissemination, research and development

Source: Authors compiled from Vietnam's National Assembly (2010)