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The link between electricity prices and carbon emissions: Exploring the urban-rural energy demand in the Philippines

Veronica I. Castillo-Dida[1]*

[1]*Department of Economics, College of Economics and Management, University of the Philippines Los Baños, College, Laguna, Philippines*

ABSTRACT. Transitioning to cleaner energy may cause some volatility in electricity prices. This price volatility prompts households to consider alternative fuels like LPG, kerosene, charcoal, and fuelwood alongside electricity, especially when the price of electricity increases. With varying carbon intensity of each type of fuel households use, changes in household fuel composition may affect carbon emissions. This study seeks to answer how changes in residential electricity prices influence carbon emissions from energy consumption in urban and rural households. Through analyzing cross-price elasticities, this study aims to uncover how electricity price changes impact households' carbon emissions from energy use by looking at the price elasticities. The results showed that the estimated price-elasticities from the QUAIDS model reveal that amidst price volatility, rural households would still be more dependent on using the least CO_2-intensive energy alternative and more exposed to indoor pollution from burning fuelwood. Results also showed that compared to rural households, urban households are more consistent in contributing to higher CO_2 emissions amidst the possible electricity price changes. Although the price responsiveness is generally inelastic, summing up the contribution of each household would have a considerable effect on a national level.

Keywords: cross-price elasticities, household fuels, carbon intensity, QUAIDS

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*Email: vicastillo@up.edu.ph

INTRODUCTION

The rapid increase of anthropogenic activities contributing to greenhouse gas (*e.g.*, carbon, methane, sulfur dioxide) emissions is driving the worsening climate change trajectory. Thus, there is a serious need to speed up efforts to reduce greenhouse gas (GHG) emissions. Global efforts to mitigate climate change focus on reducing the reliance on fossil fuels and speeding up the innovation in renewable energy. The most recent Conference of the Parties (COP28) to the UN Framework Convention on Climate Change calls for tripling the renewable energy capacity and phasing out of unabated coal power[1].

In the Philippines, the National Renewable Energy Program (NREP) aims to increase the use of indigenous renewable energy resources for up to 35% of the country's installed power capacity by 2030.

[1] *https://www.cop28.com/en/global-renewables-and-energy-efficiency-pledge*

To accelerate the utilization and commercialization of renewable energy (RE) sources, its legal foundation was laid down in 2008 by implementing the Renewable Energy Act (RA 9513). The incentives that the government is imposing to fast-track innovations in the RE could lead to a temporary increase in electricity prices, particularly in the initial phases, as the sector transitions to cleaner energy. This includes imposing taxes, subsidies, and feed-in-tariff (FiT). For example, FiT offers fixed payments to renewable energy generators rate and is being funded by adding a FiT-Allowance rate to the end-users' electricity bills. The shift towards renewable energy sources may bring about fluctuations in electricity prices. While introducing FIT mandates is anticipated to lower wholesale prices by boosting the availability of renewables, it will also drive up-regulated retail rates as utilities seek to cover the associated costs (Ravago & Roumasset, 2016).

The volatility of electricity prices is affecting the retail consumers, particularly the households. Households may switch and combine alternative household fuel[2] types like liquefied petroleum gas (LPG), kerosene, charcoal, and fuelwood to meet their needs when electricity becomes too expensive. These alternatives serve as substitutes for certain uses. However, they may not replace all electricity needs, and households may use these alternative and more traditional energy types. It is even more difficult for energy-poor households to substitute the least advanced fuel (fuelwood) amidst electricity price increases (Castillo *et al*., 2024). This so-called energy stacking behavior is particularly being observed in the Philippines. Moreover, urban and rural households consume various energy inputs (Seriño, 2014; Bayudan-Dacuycuy & Dacuycuy, 2018; Castillo *et al*., 2024).

The price of household fuels is a driving factor in household energy demand. In the Philippines, the need to adapt to fluctuations in energy prices induces households to use combinations of various fuels such as LPG, kerosene, charcoal, and fuelwood, along with electricity, as the price of electricity changes (Bayudan-Dacuycuy & Dacuycuy, 2018). As households exhibit energy-stacking behavior and alter their composition of household fuel use, their impact on greenhouse gas emissions and pollution varies. The extraction, transportation, processing, and burning of household fuels such as electricity, LPG, kerosene, charcoal, and fuelwood are sources of carbon emissions from household energy use. Collecting wood for cooking and heating also plays a role in global warming, causing deforestation and changes in land use. On the other hand, burning solid fuels indoors releases harmful particulate matter harmful to health (Aberilla *et al*., 2020). Although renewable energy policies are intended to reduce the carbon emissions from using electricity nationally, the reallocation of the household's composition of household fuel also affects their contribution to carbon emissions and indoor pollution.

In light of the above discussions, this study aims to answer the question, "How do changes in residential electricity prices explain the varying carbon emissions in urban and rural households?" By analyzing the cross-price elasticities, this study would like to shed light on how changes in electricity prices may affect households' contribution to carbon emissions from energy use.

The shift drives carbon emission reduction in the Philippines to a less carbon-intensive energy source (Seriño, 2014). Economy-wide models highlighted that carbon tax is an effective policy to reduce emissions in the energy sector (Corong, 2007; Seriño, 2014; Cabalu *et al*., 2015a; Pradesha *et al*., 2019). The energy market equilibrium model of (Mondal *et al*., 2018) also supported that both carbon tax and renewables subsidy are effective economic instruments in reducing emissions in the energy sector. Furthermore, increasing RE shares in the electricity generation sector is expected to reduce emissions (Pradesha *et al*., 2019). At the household level, the change in the use of energy inputs with varying carbon intensities affects the amount of household carbon emission (Renner *et al*., 2019). However, carbon emission studies are focused on the economy-wide scale rather than

2 *The terms 'household fuel', 'household energy', 'energy inputs', and 'residential energy commodities' are interchangeably being used in the literature.*

the micro-level household carbon emission. Most energy emissions studies in the Philippines are macro simulations (Corong, 2007; Cabalu *et al.*, 2015; Mondal *et al.*, 2018; Pradesha *et al.*, 2019). To date, there has been very limited knowledge of how household responsiveness to energy prices affects emissions from household energy consumption.

Switching to another less modern and less efficient energy type due to an increase in electricity price may increase the use of a more emission-intensive fuel alternative. From the results of the study by Aberilla *et al.*, (2020), which compares the global warming potential of the four common alternatives to electricity[3] (LPG, kerosene, charcoal, and fuelwood), charcoal has the highest impact among these four at 225 g CO_2 equivalent/MJ. This is due to the carbonization process. Kerosene and LPG have lower impacts at 179 g CO_2 eq./MJ and 160 g CO_2 eq./MJ, partly due to the combustion emissions of CO_2. Fuelwood has the least impactful option for this metric at 70 g CO_2 eq./MJ.

The choice and use of energy inputs also vary across households with different characteristics. These include socioeconomic characteristics (*e.g.*, income, urbanity, education, the industry of work, practices for energy services, among other things), dwelling characteristics (*e.g.*, house-built material, size, and appliances), and geographical characteristics (White & Reiss, 2005; Shi *et al.*, 2012; Pashardes *et al.*, 2014; Charlier & Kahouli, 2019; Pacudan & Hamdan, 2019). The strength of micro-level models is anchored on accommodating the heterogeneity of household responsiveness to changes in the price of electricity. The advantages of using demand estimation *vis-a-vis* macro-simulation particularly favor how energy policies will be designed to account for the differences in consumption behavior of households depending on their socioeconomic characteristics and other relevant household and non-household determinants.

3 *Currently, electricity has the highest GWP at 502 g CO2 eq./ MJ, mainly due to the use of fossil fuels Aberilla et al., 2020. Thus, increasing RE shares is expected to reduce its contribution to the potential for global warming .*

METHODOLOGY

The framework used to model the household energy demand and its carbon emissions is mainly adopted from Castillo *et al.*, (2024). This was the basis for how price elasticities explain the variations in carbon emissions from household energy use.

Household energy demand and its carbon emissions

It is important to highlight that energy demand is treated as an input to producing energy services. Mathematically, this can be represented by:

$$Q_i = Q\left(E_i, L_i, K_i, C_i F_{i,}\right) \qquad (Eq.1)$$

where Q_{it} is the household *i*'s consumption of energy services (*i.e.*, cooking, lighting, etc.).

The direct demand for energy services can also be interpreted as the final consumption of cooked food or illumination (Spreng & Pachauri, 2003). The five possible energy inputs considered in this study included electricity, $E_{it,}$ gas fuel LPG, L_{it}, liquid fuel kerosene, K_{it}, and traditional biomass such as charcoal, C_t, and fuelwood $F_{it.}$

This means that household i at time t with a vector of socioeconomic characteristics, θ_{it}, receives utility from consuming Q and other goods z_{it}. Hence, utility at time t for household *i* is:

$$U_{it} = U\left(Q\left(E_{it}, L_{it}, K_{it}, C_{it} F_{it,}\right), z_{it}, \theta_{it}\right) \quad (Eq.2)$$

At each time t, the household faces the following income constraint, which is determined by the prices of the energy input $E_{it}, L_{it}, K_{it}, C_{it}, F_{it}$. Good z is assumed to be numeraire. This energy budget constraint, which includes the energy budget for this five-energy input model, can be written as:

$$Y_{it} \geq p_t^e E_{it} + p_t^l L_{it} + p_t^k K_{it} + p_t^c C_{it} + p_t^f F_{it} + z_{it} \qquad (Eq.3)$$

Here, Y_{it} is the household income at time t, p_t^e is the price of electricity, and p_t^l is the price of LPG, p_t^k is for kerosene, p_t^c for charcoal, and p_t^f for fuelwood.

The cost minimization problem above mirrors the utility maximization problem that can be derived from equations 1 and 2. The income and price elasticities were derived using the Slutsky equation, which connects the Marshallian demand to Hicksian demand. It is also crucial to note that the income and price elasticities must satisfy the following constraints: (i) the household's demand for all the goods and services should not exceed its budgetary constraints and is consistent with the Walrasian demand principle, (ii) demand is consistent to changes in relative prices, (iii) demand decreases when prices rise, and (iv) the compensated cross-price elasticities are symmetric and reciprocals (Deaton & Muellbauer, 1980).

In environmental economics, the law of thermodynamics underscores that certain resource inputs, like energy, are lost in the consumption and production process. This process produces waste, such as carbon emissions (Ayres, 1998). Thus, energy consumption always produces some level of emissions. An effective strategy for cutting emissions in household energy use is to decrease reliance on emission-intensive fuels. The possible substitution and stacking of energy inputs (*e.g.*, electricity, liquid fuels, and biomass) implies the shares of each energy input. The carbon emissions associated with household energy consumption vary depending on the composition of household energy inputs.

One measure to reduce emissions in the energy sector is to reduce emission-intensive sources and increase clean, renewable energy sources. The potential substitution and stacking of energy inputs influence the proportion of energy inputs utilized, impacting the carbon emissions from household energy expenditures. The basis of carbon dioxide emission is the global warming potential, as shown by the study by Aberilla *et al*. (2020).

Sources of data

The main cross-section data used in this study was obtained from the 2018 Family Income and Expenditure Survey (FIES). This is the first and only FIES before the COVID-19 pandemic that collected at least 140,000 households, accounting for a response rate of 92.5%. After removing the outliers in total energy spending per capita, the total sample used is 147,212 household respondents from the initial 147,717.

The regional electricity prices and the quantity of energy consumed for LPG, kerosene, and charcoal were obtained from the most recent Household Energy Consumption Survey, the 2011 HECS. A total of 20,591 responding households were included in the survey, which accounted for a 91.6% response rate. The 2018 regional price estimates of energy prices were derived from the 2011 HECS. These were complemented by the monthly regional consumer price index of each household energy type published by the Philippine Statistics Authority.

Household energy demand estimation using QUAIDS

Several energy consumption studies have used the Quadratic Almost Ideal Demand System (QUAIDS) model. It looked into the responsiveness of the household energy consumption of various fuel types as the price of energy changes (Rasyid & Kristina, 2021; Kutortse, 2022; Liu *et al*., 2022). Using the QUAIDS model can reflect the non-linearity of Engel curves and depict a more realistic consumer demand behavior (Korir *et al*., 2020). It also captures the interdependence among various energy commodities when prices change (Okonkwo, 2021).

The censored (QUAIDS) from (Castillo *et al*., 2024) was adopted to calculate how electricity price affects the household energy expenditure shares of the five household energy types: electricity, LPG, kerosene, charcoal, and fuelwood. The factors used to estimate the household expenditure shares were the total energy expenditure per household, the average regional price of each energy, IMR_n is the inverse mills ratio of a given fuel combination[4] derived from the multinomial probit model, and the household demographic attributes. The household demographic attributes included family size and dummy variables that determined whether the household was in a rural area and mainly dependent on an agricultural source of income, with both household heads working, owning electric appliances, and some description of the house-built materials where the household resides.

The QUAIDS was empirically implemented using the heteroscedastic robust variance quaids Stata program of Poi (2012). Note that the charcoal expenditure share was initially dropped since the adding-up condition leads to a singular covariance matrix of the residuals. The charcoal parameters of the dropped equation were automatically recovered from the adding-up restriction through this Stata program. The post-estimation tools of the quaids Stata Program estimated the compensated and uncompensated cross-price elasticities.

RESULTS AND DISCUSSION

Fuel consumption shares of urban and rural households

Figure 1 shows the average fuel consumption shares of urban and rural households in the Philippines. Expectedly, on average, urban households will have higher energy consumption shares allotted to electricity than their rural counterparts. This could be because of several factors, such as access and the need for more cooling. Based on the data, the percentage of households who owned air conditioning units is more than twice that in urban areas compared to rural areas. Urban households also have higher consumption shares of LPG.

On the other hand, rural households have higher consumption shares allocated to fuelwood and charcoal, on average. This supports the fact that fuelwood is a staple in rural households, with the second highest percentage of shares being 33%, next to electricity at 42%.

4 *The fuel combinations include the following: (1) Electricity and LPG, (2) Electricity, LPG, kerosene charcoal, wood, (3) Electricity, kerosene, charcoal, wood, and (4) LPG, kerosene, charcoal, wood.*

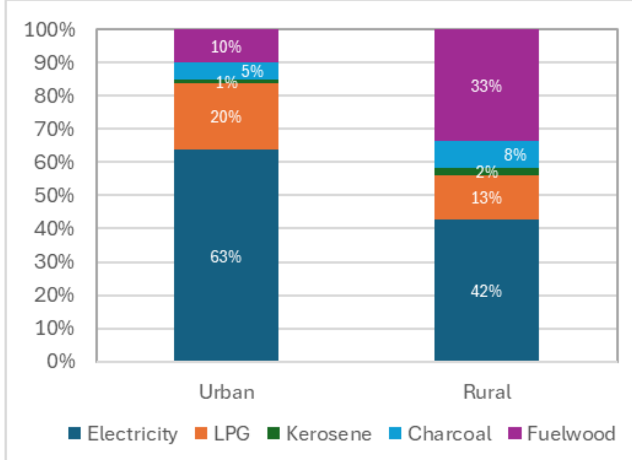

Figure 1. Mean consumption shares and price energy inputs of urban and rural households.

Price elasticities on fuel consumption of urban and rural households

The changes in the price of electricity resulting from renewable energy policies, such as feed-in-tariff or taxes, may affect the composition of energy inputs due to households' energy stacking behavior. It is acknowledged that other households may not be using all four energy alternatives to electricity (*e.g.*, LPG, kerosene, charcoal, and fuelwood). Thus, the analysis focuses on the typical responsiveness to electricity price changes of an average household.

Based on **Table 1**, the own-price elasticity of electricity demand is negative and is consistent with a downward-sloping demand curve. The uncompensated cross-price elasticities of charcoal, kerosene, and LPG are also negative, suggesting they are not complements. The compensated cross-price elasticity of LPG is positive, which implies a gross substitute for electricity. This means that, on average, the combined changes in the purchasing power and relative substitutability would result in an increased electricity prices and decreased shares of charcoal, kerosene, and LPG. However, if households were given a corresponding income to compensate for the reduced purchasing power, they would prefer to substitute LPG once the price of electricity increases. For fuelwood consumption, both the compensated and uncompensated elasticities of rural and urban households are positive,

Table 1. Price elasticities of energy inputs to changes in the electricity price.

	Electricity	Charcoal	Kerosene	LPG	Fuelwood
	Uncompensated elasticities				
Urban	-0.8737	-1.0208	-2.9533	-0.1721	0.4670
Rural	-0.7726	-0.7619	-0.8974	-0.5076	0.1601
	Compensated elasticities				
Urban	-0.1197	-0.7910	-2.7517	0.4779	0.5671
Rural	-0.2765	-0.4900	-0.8703	0.0429	0.5161

indicating that households would choose to substitute fuelwood given an increase in the price of electricity. The subsequent analysis will focus on the uncompensated elasticities to also account for the change in the purchasing power brought about by the change in the electricity price.

Acknowledging the differences in the energy spending behavior of households based on urbanity, the estimated elasticities from the censored QUAIDS model were estimated both for rural and urban households. **Table 1** presents the energy demand elasticities of urban and rural households to changes in electricity prices. Before discussing the differences in the magnitude of the price-responsiveness of urban and rural households, it is crucial to take note of the practical implication of the magnitude of cross-price elasticities derived from the QUAIDS model. This means that when the electricity price increases and the cross-price elasticity is negative and relatively large, an increase in the price of electricity (which will thus decrease the electricity demand) will significantly decrease the consumption shares of that specific energy alternative to electricity. Assuming the cross-price elasticity is positive and relatively small, an increase in the price of electricity will compel households to substitute other energy sources for electricity, but the change in the consumption share will not be that large.

Based on the uncompensated cross-price elasticities in **Table 1**, when electricity prices decrease, urban households tend to complement electricity use by increasing their shares of charcoal and kerosene, which are relatively larger than their rural household counterparts. For LPG, compared to urban households, rural households tend to give up larger shares of LPG consumption when electricity prices increase. The opposite is true for fuelwood.

Given an increase in the price of electricity, urban households tend to be more responsive to increasing the shares of fuelwood than rural households. This means it is easier for urban households to respond to changes in electricity prices and reduce their consumption shares of fuelwood when electricity prices increase and increase their consumption shares when electricity prices decrease. However, rural households' fuelwood consumption is more fixed than urban households. This could be because rural households are already used to fuelwood, their second major energy input, and are more accustomed to using it. Meanwhile, for urban households, it constitutes less than ⅓ of the shares of rural households' fuelwood consumption.

It can also be observed in **Table 1** that the uncompensated elasticities concerning the electricity price of almost all the energy inputs (except for charcoal and kerosene for urban) have a value of less than 1. This suggests that they are inelastic due to changes in electricity prices. This further supports that electricity is an inelastic goodand shows that changes in electricity prices will not induce a big change in the energy consumption of each household. However, summing up the contribution of each household would have a considerable effect on the national level.

Effect of changes in electricity price on carbon emissions from household fuel consumption

Possible changes in electricity prices due to emission reduction policies in the energy sector may alter the composition shares of household fuel use, including electricity, LPG, kerosene, charcoal, and fuelwood. These changes in the composition of household fuel due to changes in electricity prices also impact household energy use emissions.

Each energy input has a corresponding contribution to emissions, which can also be measured regarding their global warming potential. According to the study of Aberilla *et al*., (2020), charcoal has the second highest CO_2 equivalent per megajoule of energy next to electricity. This is followed by kerosene and LPG. Fuelwood has the lowest contribution of CO_2 equivalent per megajoule of energy use.

Emission reduction policies in the energy sector (*e.g.*, shifting to renewabl`e energy and decreasing the reliance on fossil fuels) are expected to reduce carbon emissions from electricity. Thus, the ensuing discussions focus on how changes in electricity prices affect the changes in carbon emission from the consumption of other energy alternatives such as charcoal, kerosene, LPG, and fuelwood.

To account for the purchasing power changes, the succeeding analysis focuses on the uncompensated elasticities. Comparing the magnitude of change in the most-carbon emission-intensive energy alternative (charcoal) and the least-carbon emission-intensive energy input (fuelwood) for rural and urban households will also have an implication not only on the contribution to global warming potential but also on the health impact of indoor pollution.

As electricity prices increase, urban households decrease their consumption of the most emission-intensive charcoal even more than rural households. Also, they are switching to increasing the consumption shares of the least CO_2-intensive energy alternative, fuelwood. Despite changes in electricity prices, rural households would still be more dependent on using the least CO_2-intensive energy alternative, fuelwood. This shows the more consistent exposure of rural households to indoor pollution from burning fuelwood, which may also pose some health risks. On the other hand, urban households respond less in terms of their LPG consumption shares as electricity price changes compared to their rural counterpart. This is consistent with their relative dependence on LPG, as urban households have higher LPG shares than rural households. Given that LPG has higher global warming potential than fuelwood, it can be concluded that urban households are more consistent in contributing to higher CO_2 emissions amidst the possible electricity price changes.

CONCLUSIONS AND RECOMMENDATIONS

The results support the need to analyze how the interdependence of various energy inputs to electricity prices may affect the contribution of rural and urban households' use of energy to carbon emissions. Although the emission from electricity is expected to be reduced as the country transitions to renewable energy, the possible changes in the composition of household fuel due to possible electricity price changes must also be acknowledged. The results showed that, except for LPG, it is easier for urban households than rural households to change the consumption shares of other energy alternatives as a response to changes in electricity prices. When electricity prices change, rural households are still more dependent on using the least CO_2-intensive energy alternative and are more exposed to indoor pollution from burning fuelwood. Results also revealed that urban households contribute more consistently to higher CO_2 emissions amidst the possible electricity price changes. To strengthen the findings on the contribution of household energy use to carbon emission, further studies are recommended to relate the energy consumption shares to actual energy efficiency units.

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