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Energy Poverty and Carbon Emissions: The State of Luzon, Philippines

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The prevalence of energy poverty on a global scale has been a longstanding concern, particularly in developing countries. In the Philippines, 1.6 million households had no access to electricity in 2020, owing to high power costs at around 0.20 $/kWh, the most expensive in the ASEAN region. While the energy poverty in the Philippines is apparent, energy consumption and carbon emission levels are assessed only on the national level in the past due to limited data. This study assessed the possible relationship between household energy consumption and emission levels with income by using data from the Family Income and Expenditure Survey (FIES) Report, which holds information on a household's income, energy expenses, and other relevant socioeconomic indicators. Additionally, Gini coefficients for energy consumption and carbon emissions are calculated to investigate the distribution of energy use within the population and assess which income group contributes the highest emissions. The Gini coefficient for electricity at 0.40 indicates greater consumption and emission inequity due to income disparity when compared with the 0.20 coefficient for non-electricity carbon emission. This indicates a direct relationship between income and electricity reliance. The non-electricity emission of 1.32 t CO_{2e} per capita in comparison with electricity emission of 0.17 t CO_{2e} per capita shows that poor households contribute higher overall emissions due to the inability to rely on electricity. Findings from this study can be used by policymakers to pursue a targeted approach with consideration of income in creating energy regulations.

1. Introduction

An important factor in the development of a society is its ability to provide energy security to its people. Historical data have shown that energy and economic growth are interconnected; increased electricity consumption and access translates to higher Gross Domestic Product (GDP) (Zhang and Ren, 2011). Despite this, ensuring energy equity among households from a global standpoint has been a longstanding concern. Many families around the world still struggle to acquire energy-intensive services, including, but not limited to, cooking food, providing adequate lighting in their houses, and availing transport infrastructures. This energy inequity can lead to and compound numerous problems involving health, social activities, and education, among many others.
One adverse effect of energy inequity is increased carbon emissions. Studies have shown that while advanced economies have generally maintained their levels of energy-related CO_2 emissions, less-developed economies have seen a significant surge in their emission contributions (IEA, 2020). The higher emission from developed countries is due to the higher energy consumption despite having less consumption per capita. This could indicate that poor countries have inadequate energy infrastructure and clean energy access for their population. The Philippines recorded an impressive 5.8 % GDP growth in 2015 (NEDA, 2016). In recent years, the country's economy continues to grow while its energy consumption also sees a steady increase (PSA, 2016). Nevertheless, energy poverty in the country still prevails, especially in low-income households. While the electrification rate reached a remarkable 90 % in 2016, 2.4 million Filipinos were still left without electricity access in the same year (DOE, 2016a). Add to that, the cost of electricity in the country continues to rise, reaching an average of 0.20 $/kWh, significantly higher than in other ASEAN countries (UN ESCAP, 2021). Numerous policies, such as the Renewable Energy Act (2008) and Energy Efficiency and Conservation Act (2018) were put in place to improve the Philippines' energy situation. However, experts note that poor

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implementation and inconsistencies hinder this progress. Records show that while the Philippines had a consistently low emission share compared to other countries in the past decades, this contribution has been steadily increasing. In 2015, the share was approximately 1 metric t/cap of CO_2 emissions, rising to 1.2 metric t in 2020 (Climate Watch, 2023). Previous studies have not looked into the effect of household income on the increasing use of non-electrical forms of energy and how it affects efficiency and overall greenhouse gas emissions in the Philippines. This paper presents a novel methodology to capture household energy and emission behaviors by using the household’s energy expenses from the Family Income Expenditure Survey (FIES) Report conducted by the Philippine Statistics Authority (PSA) every 3 y. FIES lists the income level of households in the country, as well as their expenditure for various energy sources (PSA, 2017). These expenses shall be converted to energy consumption and corresponding carbon emissions in order to determine the prevailing energy equity. As such, this study will help determine which income group has the highest per capita emissions in Luzon. Due to the volume of the data, as well as the availability of public records, only Luzon shall be covered in this study.

2. Literature review

Various researchers have studied the relationship between several factors and energy poverty using diverse approaches. Rodriguez-Alvarez et al. (2021) assessed the energy statistics from 2005 to 2018 of 30 European countries in order to provide insights into their energy situation. The study proposed a model that measures a country’s energy poverty by assessing country-specific factors such as income levels, energy costs, and energy intensity, among others. The researchers concluded that providing financial aid to marginalized sectors, reducing the cost of energy, as well as improving energy efficiency are key factors in alleviating energy poverty in these countries. In another study by Dong et al. (2021), the effects of transitioning to low-carbon technologies in alleviating energy poverty in China were assessed using a novel causality-in-quantiles method. The research found that transitioning to low-carbon technologies and addressing issues on energy cost and availability, cleanliness of energy use, and energy management also improve the country’s energy situation. Uzar (2020) looked into the effects of income disparity on renewable energy consumption in 43 developing and developed countries starting from 2000 within a 15 y period, concluding that consumption of energy from renewable resources can be significantly improved by reducing income inequality. Zhao et al. (2021) have researched the connection between energy poverty and the sharp rise in carbon emissions, investigating the spatiotemporal aspects of energy poverty in China using a novel comprehensive evaluation index to assess the existing poverty in 30 provinces in the region; by using the system-generalized method of moments (GMM) method, the impact of energy poverty on CO_2 emissions was also assessed and re-estimated. From existing data from 2002 up to 2017, the authors found that energy poverty caused the growth acceleration of carbon emissions in the region. Pan et al. (2021) looked at how such poverty affected people's health, employing Oster's bound analysis approach and GMM estimation using a large panel of data from 175 nations from 2000 to 2018. The study's findings showed a negative correlation between energy poverty and public health. Over a 27 y period beginning in 1990, Banerjee et al. (2021) looked at how energy poverty influenced health and education in 50 developing nations. To examine whether levels of poverty and income per capita have an impact on developmental outcomes, the researchers developed an overall energy development index. The findings indicated that in terms of developmental outcomes, access to electricity had a more significant impact than energy usage. Higher energy indices, according to the researchers, are linked with reduced newborn mortality rates. They came to the conclusion that reduced rates of energy poverty result in better health and educational results. Transitioning to renewable energy resources can also affect the cost of generating electricity.

3. Methodology

Energy equity in the Philippines is measured only by the electrification rate, as well as energy consumption and emissions per GDP capita on the national level. While these may provide an overview of the prevailing energy situation, they cannot fully capture the distribution of energy and emissions within the population. The Gini coefficient shall be used as an additional parameter in assessing energy equity as it uses a numerical value to describe resource distribution based on income. Determining the coefficients for energy resources and assessing the values in relation to existing metrics will greatly help policymakers in improving energy regulations within the region. The study utilizes the FIES Report from 2015. Electricity is classified as indirect fuel, while LPG, kerosene, and biomass resources are considered direct fuels. Figure 1 shows the block diagram describing the process flow to assess energy equity in the Luzon region.

3.1 Indirect fuel consumption (Electricity)

The Philippines currently has 143 power suppliers, including 22 private distribution companies and 121 electric cooperatives (DOE, 2018). Calculating the electricity consumption of households using only one historical average price point is not advisable due to the wide variety of government-required subsidies and taxes paid depending on the electricity consumption range. The monthly price point per energy unit for a specific usage range can be calculated by utilising the unbundled rates provided by different electricity providers within regions (FOI, 2021a). Assuming that a household's monthly consumption remains constant annually, it is important to ascertain in which consumption range a household's electricity expenditure falls based on the unbundled rates in order to compute the household's usage. The authors present Eq.(1) to compute the annual household electricity consumption based on the expenses and corresponding electricity costs per range.

$$AEC_e = 12 \cdot \frac{E_a - Rate_{kwh} + f(E_T)}{Rate_{hh} + f}\ kWh/household \quad (1)$$

Where AEC_e is the annual electricity consumption per household in kWh/household; E_a is the annual electricity expense per household in PhP/household; $Rate_{kwh}$ is the partial annual rate per energy unit, PhP/kWh/household; $Rate_{hh}$ is the partial annual rate per household in PhP/household; f is the energy tax factor; and E_t is energy tax consumption bracket. Should a household's expense not fall within any specified range in the unbundled rates, interpolation between ranges may be done to estimate annual electricity consumption.

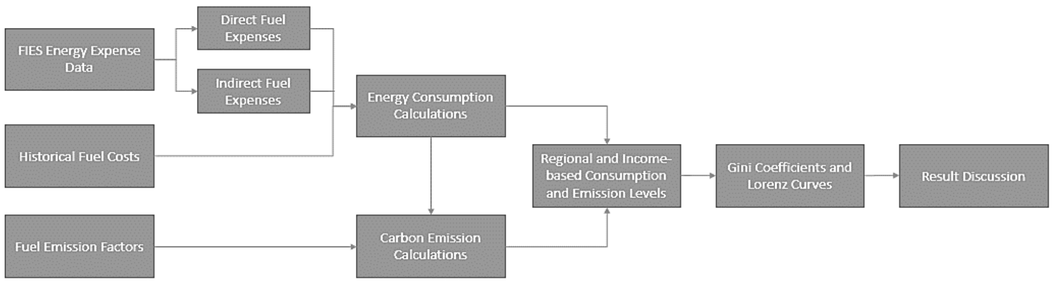

Figure 1: Energy equity assessment process flow block diagram

3.2 Direct fuel consumption (LPG, kerosene, fuelwood, and charcoal)

Expenses made for direct fuel types can be converted to energy consumption by dividing them by their corresponding historical fuel costs and then multiplying the results by the corresponding heating values. Historical LPG (FOI, 2019) and kerosene (FOI, 2021b) costs in NCR were requested through the FOI website, while the prices for the other Luzon regions were from the DOE website for kerosene (DOE, 2015a) and LPG (DOE, 2015b). Annual Forestry Statistics publishes the historical costs of fuelwood and charcoal per cu. m and sack (DENR, 2017). The authors shall determine their per mass equivalent using the methodology in the Wood Fuel Survey (FAO UN, 1983). Eq.(2) is used for the conversion of direct fuel expenses to energy consumption

$$AEC_f = \frac{E_f}{C_f} \times HV_f\ kWh/household \quad (2)$$

Where AEC is energy consumption of a household for specific fuel type in kWh/household; E is the expense of a household for specific fuel type f in PhP/household; C is the price per unit of specific fuel type in PhP/unit fuel; CV is the calorific value of specific fuel type in kWh/unit fuel; and f is the type of direct fuel.

3.3 Carbon emissions

Emissions are determined by multiplying the calculated energy consumption to their corresponding fuel emission factors. The Intergovernmental Panel on Climate Change (IPCC, 1996) published a list of emission factors for different fuel types including the ones listed in FIES, except for electricity since it is an indirect fuel. To define the corresponding emission factor of electricity, the power generation mix in that specific year shall be determined (DOE, 2016b). All emission factors used in the mix are from the mentioned IPCC document except for the geothermal energy which is from data published by DiPippo (2012), and for biomass which is from Environmental Protection Agency (EPA, 2014). Eq.(3) is used to calculate a household's annual emissions.

$$ACE_{e,f} = \sum ef_{e,f} \cdot AEC_{e,f} \quad (3)$$

Where ACE is the respective annual carbon emissions for electricity e, and direct fuel type f; ef is the corresponding CO_{2e} emission factor for said energy resources.

3.4 Gini Coefficient and Lorenz Curve

Jacobson et al. (2005), used the Gini Coefficient and Lorenz Curve concepts to quantify the energy distribution and evaluate the energy poverty in Kenya, El Salvador, Thailand, the United States, and Norway. The Lorenz curve is a ranked distribution on the graph's abscissa of the cumulative proportion of the population represented in the 2015 FIES, while the cumulative percentage of resource use is distributed on the y-axis of the graph. The Gini coefficient can have values ranging from 0 which represents perfect equity to 1 which indicates total inequity. The adapted formula for Gini coefficient calculation is in Eq.(4).

$$G = 1 - \sum_{i} (y_{n+1} + y_n)\,(x_{n+1} + x_n) \tag{4}$$

Where G is the Gini coefficient; x_n is the number of resource users in population group i/total population; y_n is the total energy used by population group i/total energy use. One of the intentions of this paper is to investigate the energy distribution and the carbon emissions within Luzon across different income clusters using Gini coefficients and Lorenz curves. The study adapts the income clusters defined by Albert et al. (2018).

4. Result discussion

The authors mainly classified household energy sources into two: (1) electricity and (2) non-electricity fuels. FIES includes household expenses for energy sources tagged as ‘other fuels’; however, the study did not include this in the calculations as historical data needed for assessment are currently not available. The methodology presented in this paper can be utilized once information becomes available in the future.

Table 1: Regional energy consumption and emission levels in Luzon

Region	Electricity		Non-Electricity				
	Consumption, GWh	Emissions, Mt CO_{2e}	Consumption, GWh				Emissions, Mt CO_{2e}
			LPG	Kerosene	Fuelwood	Charcoal	
1	1,032.93	0.65	462.57	14.87	29,836.01	615.71	13.06
2	477.56	0.30	355.05	12.82	68,969.10	254.89	29.54
3	3,136.96	1.99	1,563.4	35.81	24,396.31	1,260.39	11.28
4a	4,063.91	2.57	1,973.0	69.02	26,027.86	3,154.39	12.87
4b	374.50	0.24	123.5	37.91	6,254.86	1,325.35	3.26
5	431.70	0.27	163.2	37.76	10,318.04	951.41	4.84
CAR	265.48	0.17	265.3	6.19	7,486.77	44.56	3.27
NCR	5,895.84	3.73	2,721.8	136.55	985.50	1,056.41	1.52
Luzon	15,678.88	9.93	7,627.85	350.95	174,274.45	8,663.12	79.64

The Gini coefficients show greater inequity in electricity distribution based on income, with a value of 0.40 for emissions, while non-electrical combined emissions are distributed more evenly with a coefficient of 0.20, as seen in Figure 2b. Overall emissions exhibit improved distribution with a Gini coefficient of 0.15. While emissions can be combined and added together to calculate the overall Gini coefficient, the same should not be done with energy consumption per fuel source since energy efficiencies in utilizing each fuel source differ.

In NCR, electricity is still the preferred energy source, having the highest consumption for electricity versus other sources, as seen in Table 1. One possible factor is the relatively cheaper electricity cost in NCR in other regions. While the government is implementing a lifeline discount to lower the cost of electricity for poor households, this is based on consumption level rather than income (EPIRA, 2001). The coefficient can give an insight if the discount approved by the government is effective or not if its value is closer to a value of 0 or not. As the Gini coefficient and Lorenz curve only reflect the distribution of a certain resource within a group, careful interpretation should be made in relation to other parameters so as to give proper context to the prevailing inequality. In order to further see the relationship between income and emissions, the CO_{2e} emission per capita from electricity and non-electricity sources is calculated. As seen in Figure 2a, the per capita emissions for electricity increase as per capita income increases. Interestingly, per capita income and per capita emissions for non-electricity exhibit inverse relationship. In relation to the consumption calculations, it can be seen that regional and overall emissions are greater from non-electricity sources except in highly urbanised NCR where higher electricity consumption produces higher emissions. Among all the regions, Region 2 has the highest non-electricity emissions, followed by Regions 1 and 4A. Coincidentally, these regions also have the highest forest areas in the Luzon area where fuelwood can be sourced (DENR, 2017)

Emission factor is a significant variable in calculating the emissions of households. It should be emphasized that the factors used in the calculations are based on existing literature. The emission factor calculated for electricity is higher at 0.63 kg CO_{2e} per kWh. While emission factors for non-electricity fuels are lower based on the document from IPCC. However, it should be noted that this study does not include the technologies used for combustion of non-electricity fuels. According to a study by Skreiberg and Seljeskog (2018), emission factors for new and old combustion devices may greatly vary. As such, this limitation can be addressed in future studies by determining the different types of combustion devices used by households from different income clusters.

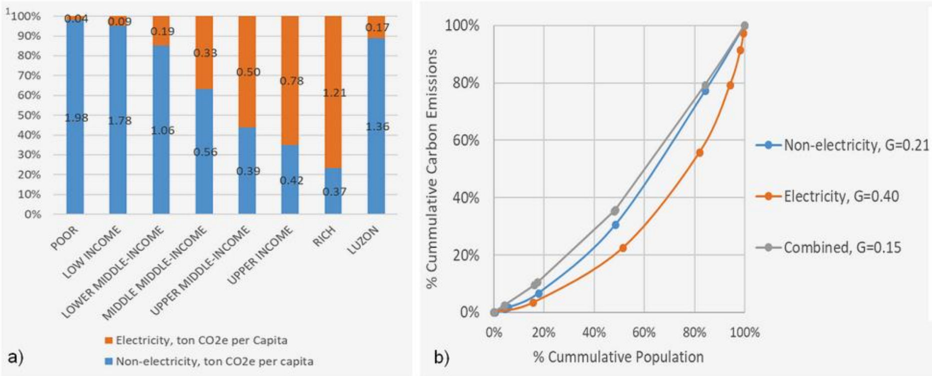

Figure 2: Luzon carbon emissions: (a) per capita emissions, (b) Emissions Lorenz curves and Gini coefficients

5. Conclusion

The Gini coefficient is an important parameter to assess the severity of resource inequity in a group; however, one should be careful to also include other parameters, such as per capita emissions for each income level, to paint a clearer picture of the situation. While the Gini coefficient of 0.20 for non-electricity emissions may seem better than the 0.40 coefficient for that of electricity, looking at their calculated emissions should also be given importance. Actual emissions are much higher for non-electricity energy resources per capita than the emissions per capita for electricity. It can be seen that non-electricity emissions mainly come from poor and low-income houses, both per capita and in total. Total emissions from electricity use mainly come from middle-income households, but per capita use indicates that the great contribution comes from upper-income and rich households. Calculating the Gini coefficient. Therefore, this is only an initial step in determining whether a certain problem exists regardless of income or whether it or any factor plays a role in the existing inequity.

The primary concern highlighted by this paper arises from the observation that there is a tendency for low-income households to rely on non-electrical energy forms to provide for their daily needs, propagating energy inefficiency significantly. Considering that poor families require very little energy, their per capita emissions can outdo higher-income households, which consume more energy because of the poor quality of energy given access to them. Access to cleaner, more efficient energy must be addressed for low-income households.

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