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Exploring the determinants of energy poverty in Indonesia's households: empirical evidence from the 2015–2019 SUSENAS

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This study explores the determinants of household-level energy poverty in Indonesia by using highly granular, household-level socioeconomic data on Indonesia from the 2015–2019 National Socioeconomic Survey (SUSENAS). This study utilizes two distinct methods to assess energy poverty in Indonesia with regard to accessibility, aiming to gain a more comprehensive understanding of the issue. Using logistic regression with the combination of district-level fixed effects and interactions between regional and yearly terms, this study finds that, in general, the likelihood of a household being under energy poverty is negatively associated with household expenditure, dwelling size, family size, full-time employment status, and the marital status and educational attainment of the household head, while the associations with other determinants, such as the gender of the household head and LPG and electricity prices, are positive. These associations between the incidence of energy poverty and households' socioeconomic and demographic variables, as well as the prices of modern and alternative energy, are in parallel with the findings from other similar studies that have been conducted in other developing countries or regions. Furthermore, this study finds some substantial variations in the estimation results for Java and outside Java.

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Introduction

Energy poverty, which refers to a lack of affordability or access to basic energy services, has been an integral topic within the study of global development. The issue has become significant, as studies have found that solving the energy poverty issue also intertwines with solving socioeconomic issues (Sharma et al., 2019). Escaping from energy poverty, where a certain level of energy access has been attained, has favorable implications for crucial aspects of the economy and human development, including education (Oum, 2019), health (Oum, 2019; Po et al., 2011), productivity (Modi et al., 2006), and other aspects of welfare (Barnes et al., 2011; Sambodo and Novandra, 2019). In a context where capital and labor must be combined to achieve higher production levels, having sufficient and affordable energy can create additional employment opportunities. The reason is that it enhances production capacity, ultimately boosting the demand for labor. Access to reliable and affordable energy services can also improve the quality and availability of education services and increase students' likelihood of attending and completing school (IEA, 2010; UNDP, 2005). With adequate access to energy, students can study more effectively, and schools can offer education services more efficiently. Empirical studies show that with the addition of 1 household with good and affordable electricity access, the number of people with malnutrition will decrease by 7 (Sambodo and Novandra, 2019). Furthermore, there is a strong association between access to electricity and community welfare, as measured by income and education quality. Having access to electricity can increase income by 21%, along with a 1.5% reduction in the yearly poverty rate (Khandker et al., 2012).

The benefit of alleviating energy poverty for socioeconomic issues makes energy poverty part of the broader discussion on global poverty alleviation (Sharma et al., 2019). While poverty represents the challenge of attaining a basic standard of living, energy poverty signifies the struggle to reach a specific level of energy access necessary to sustain a livable life. In the context of the Sustainable Development Goals (SDGs), alleviating energy poverty is central to achieving not only SDG 7 (ensuring access to affordable, reliable, and sustainable energy) but also to SDG 1 (ending poverty in all its form everywhere) and SDG 3 (ensuring healthy lives and promoting well-being for all at all ages).

Nevertheless, energy poverty is still a significant problem faced by many countries globally (Sambodo and Novandra, 2019), especially developing countries. Approximately 3 billion people did not have access to clean cooking technology in 2018. A report by the International Energy Agency (2017) also showed that there are 1.3 billion people who still have no access to electricity and 2.7 billion people who have no access to clean cooking facilities. Most of them reside across sub-Saharan Africa and Asia, including Indonesia. Indonesia's total per capita energy use is still far below the global average and the average in the upper-middle-income country group (see Fig. 1). Indonesia's consumption of fossil fuels in 2022 was only 760.9 kgoe per capita, which is less than half of the average energy consumption of upper-middle-income countries. Additionally, Indonesia's per capita oil consumption in 2022 was 265.7 kgoe, and the per capita electricity consumption was 1173 kWh. Comparatively, the average electricity consumption in the Association of Southeast Asian Nation itself was 3672 kWh per capita in the same year. According to 2019 SUSENAS data, approximately 11% of Indonesia's households fall into the energy-poor household category using the minimum energy consumption threshold approach (MECTA), which implies that they still have a burdening energy expenditure share. Hence, it is clear that energy poverty poses a significant threat to Indonesia's well-being.

Several policies and interventions to improve the use of clean energy have been implemented by the government in many developing countries. These interventions generally involve the substitution of traditional cooking fuel for clean energy such as LPG, infrastructure development for electricity, and energy subsidies (Crentsil et al., 2019). In the case of Indonesia, a kerosene-to-LPG conversion program through subsidized LPG was legalized in 2006 to improve the accessibility of clean energy for cooking fuel. A mega project of power plant development and electricity subsidies for low-income households have also been implemented by the Indonesian government (Hartono et al., 2020). Nevertheless, there exist several important factors that may hinder clean energy consumption in addition to price, such as cultural and socioeconomic factors (Ashagidigbi et al., 2020; Ozughalu and Ogwumike, 2019). Investigating that factors affecting energy poverty is useful for the government to evaluate and design an appropriate policy to achieve universal access to clean energy.

Studies exploring the factors contributing to energy poverty have been carried out in numerous countries, with a particular focus on developing nations and regions such as Ethiopia (Alem and Demeke, 2020), India (Sharma et al., 2019), and Africa (Ismail and Khembo, 2015). Several points are usually discussed first before estimating the determinants of energy poverty. One of the main discussions concerns the measurement of energy poverty itself. Previous studies have used different approaches to measure the extent and magnitude of energy poverty. In developed countries, achieving affordable energy for all is the main focus of many energy studies (Crentsil et al., 2019). Meanwhile, in developing countries, the primary emphasis is often on ensuring access to clean energy. This focus encompasses not only affordability but also adequate access to modern energy sources (González-Eguino, 2015).

We also found different thresholds for classifying energy-poor and energy-sufficient households, usually based on different quantities consumed or different types of energy (Modi et al., 2006; Pangaribowo and Iskandar, 2022; Sambodo and Novandra, 2019). Several famous indicators are the 10% indicator (Boardman, 1991), 2 M indicators (Schuessler, 2014), low-income-high-cost (Hills, 2011), the after fuel cost poverty indicator (Moore, 2012), and the minimum consumption of modern energy/MECTA (Modi et al., 2006; Sambodo and Novandra, 2019). This variation is not entirely surprising, considering the inexistence of a single standard to measure energy poverty (Ulucak et al., 2021).

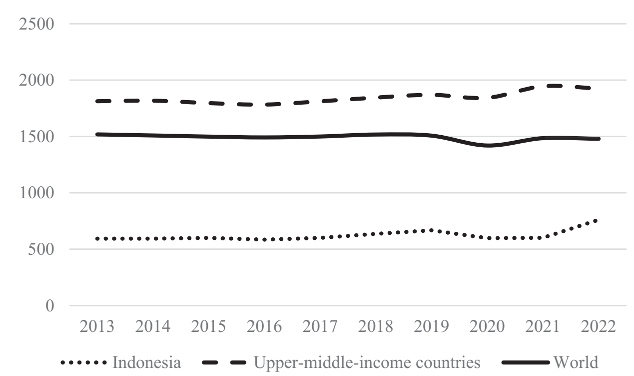

Fig. 1 Fossil fuel consumption. This figure shows fossil fuel consumption in Indonesia, upper-middle-income countries, and all countries (world) in kg of oil equivalent per capita between 2013–2022. Source: Energy Institute, 2023.

Another aspect to discuss is the set of determinants that these studies examined. For example, the latest study by Qurat-ul-Ann and Mirza (2021) investigated the determinants of multidimensional energy poverty in Pakistan using the multidimensional energy poverty index (MEPI). However, the study did not consider energy price factors. Ideally, the analysis of energy poverty determinants should consider all relevant factors, such as energy prices and household socioeconomic status (Alem and Demeke, 2020; Ismail and Khembo, 2015; Modi et al., 2006; Sharma et al., 2019).

In general, studies of energy poverty determinants argue that energy prices, household economic conditions, and household demographic status are closely related to the household energy poverty status. However, the result should be taken locally, as every region has a different culture and socioeconomic structure. Even in the same country, studies also report differences in the factors affecting energy poverty in rural/urban areas or low/high-income households (Crentsil et al., 2019). Although numerous studies on energy poverty have been conducted in various countries, limited studies have investigated the determinants of energy poverty within the Indonesian context.

This study aims to identify and describe the determinants of energy poverty in Indonesia, aiming to bridge the existing gap in knowledge on this matter. To the best of our knowledge, only the study by Pangaribowo and Iskandar (2022) enriches the literature on the determinants of household energy choices for cooking. However, they limit their study to Eastern Indonesian households and focus on energy for cooking. The present study will extend the coverage of the study by Pangaribowo and Iskandar (2022) to cover household samples throughout Indonesia as well as energy poverty through the perspective of electricity usage. In addition, this study uses multiple approaches and thresholds to show and compare the incidence of energy poverty. This step is important for understanding the incidence of energy poverty in Indonesia from an accessibility perspective. Second, this study discusses a range of determinants of energy poverty, which consist of modern and alternative energy prices, socioeconomic factors, and demographic factors, using logistic regression. The method is commonly used and well suited for modeling binary dependent variables. It is also considered highly efficient, particularly for a large number of observations. Third, this study contributes by recommending policy implications relevant to the findings and discussion in this study.

To better understand how the variation in regional context enables differences in the incidence of energy poverty and how determinants correlate with energy poverty, this study also discusses the incidence of energy poverty and a range of determinants of energy poverty in two regions, Java and outside Java. This comparison is important given that these two regions have some stark differences across multiple perspectives. As of 2016, Java was a populous urban area in which 56.69% of Indonesia's population lived, even though it accounted for only 6.75% of Indonesia's total landmass. On the other hand, the regions outside of Java are more sparsely populated. Furthermore, a more densely populated Java region was home to 66.34% of Indonesia's total urban population in 2019. The stark differences in population concentration and the urbanization rate correlate with how economic activity is so concentrated in the Java area, where 56.65% of Indonesia's real gross domestic product was generated within the Java region. These stark differences motivate this study to further investigate the variation that may appear across Java and outside the Java region.

Energy poverty and its underlying determinants

Energy poverty can be defined as a lack of access to adequate, reliable, and modern energy services (Lin and Okyere, 2020). In broad terms, energy poverty has been recognized and defined historically since the late 1970s (Isherwood and Hancock, 1979). Formally defined in terms of energy income and expenditure, energy poverty occurs when households are unable to meet their energy needs with 10% or less of their income (Boardman, 1991). Since that time, numerous academic studies on energy poverty have continued to be conducted, exploring both relative and multidimensional aspects (Grevisse and Brynart, 2011; Li, 2014; Thomson and Snell, 2013). Nevertheless, the scope of this field can be categorized into two specific areas: one centered on energy poverty, highlighting access and fundamental requirements primarily in low-income developing regions, and the other centered on fuel poverty, emphasizing affordability primarily in European and other developed nations. However, to date, there has been no consensus on the conceptual issues and methods used for measuring energy poverty (Barnes et al., 2011). This condition has led to various studies using different definitions of energy poverty.

There are several popular methods that are used to measure and define energy poverty. The famous methods are the 10% indicator where a household is considered to be in energy poverty if it spends 10% or more of its income on meeting its energy needs (Boardman, 1991). However, the Indonesian government utilizes an indicator based on the minimum consumption of modern energy, often referred to as MECTA (Modi et al., 2006; Sambodo and Novandra, 2019). The MECTA framework specifically defines energy poverty as the lack of accessibility to modern energy to meet basic energy needs. MECTA defines energy poverty as the level at which a household is unable to cook with modern cooking fuels and faces difficulties in providing lighting for reading or other productive activities after sunset. According to this definition, energy poverty is indicated by an annual consumption of at least 50 kilograms of oil equivalent (kgoe) for commercial electricity and LPG consumption per capita. This approach is well suited for countries where a significant portion of the population still relies on conventional energy sources to meet its basic needs. The MECTA approach has been implemented in Indonesia based on the decision of the Ministry of Energy and Mineral Resources (Sambodo and Novandra, 2019).

In addition to the growth measurement of energy poverty, many researchers discuss how to solve the lack of knowledge regarding the drivers of energy poverty. Exploring the determinants of energy poverty is essential for conceptualizing effective policies to reduce household energy poverty. Several studies have shown that energy poverty can be affected by income and wealth poverty, as income poverty occurs along with social underdevelopment (Sadath and Acharya, 2017). This finding is supported by previous studies that showed that low-income household groups in India experienced an increase in energy poverty rates (Sharma et al., 2019). Analysis using panel data from several South Asian countries also showed that household wealth considerably affected energy poverty (Abbas et al., 2020). Therefore, previous studies have incorporated households' socioeconomic features into the UK's energy demand model using the conditional demand approach (Baker et al., 1989). As household income increases, individuals' purchasing power indirectly increases the household's ability to obtain better energy options. Subsequently, individuals are more likely to increase their energy consumption and switch to cleaner and better energy options (Khandker et al., 2012; Rahut et al., 2014). Therefore, higher income and total consumption will increase the probability of energy consumption moving away from the energy poverty threshold.

Household energy consumption decisions are also influenced by energy prices (Renner et al., 2019; Xia and Hu, 2012). The higher the energy price is, the lower the purchasing power of people, which indirectly affects households' energy poverty status (Ziramba, 2008). Additionally, the prices of energy, which comes in various types, can influence each other, as different types of energy can substitute for one another. For instance, households have tools for both lighting and cooking that replace one another; thus, they can use more than one type of energy fuel (Dubin and McFadden, 1984). Therefore, to maximize utility in energy use, households consider one type of energy and another energy as an alternative based on each energy's availability and affordability (Alem and Demeke, 2020).

Energy poverty could also be built by several other determinants related to household demographics (Alem and Demeke, 2020). Studies have shown that households with a better understanding of the significance of energy tend to consume higher amounts of it. The understanding of energy, as indicated and represented by educational levels, can impact household energy usage in two distinct ways. First, education can increase income, thereby improving access to higher levels of energy consumption. Second, knowledge can influence consumer preferences, leading to more efficient household energy consumption patterns (Narasimha and Reddy, 2007). Other studies have indicated that households with more educated heads tend to shift toward cleaner energy sources, as they have a better understanding of the positive impact of cleaner energy on health (Heltberg, 2005; Pachauri and Jiang, 2008). In addition, household heads who have a higher educational level tend to use modern energy because it is more time efficient in practice (Reddy and Srinivas, 2009). The preference for energy use also varies between men and women. Women tend to have a high priority for current energy sources in the household and can be categorized as the primary energy users (Scholz, 2012). The roles of female household members vary from collecting fuel in low-income households to making decisions about more environmentally friendly fuel options in high-income households (Reddy and Srinivas, 2009). For example, one study found that in Indonesia, women in Javanese households have a stronger preference for clean energy sources, given their higher involvement in cooking activities (Israel, 2002). Furthermore, household heads with a partner will tend to find more energy-efficient measures than those with no partner (Poortinga et al., 2003). They will consume more energy but at the same time become more efficient.

Another possible determinant is family size, which decisively influences household decisions regarding the type and amount of energy to consume. The higher the number of members in a household is, the more energy is needed; hence, energy demand will also increase (Arntzen and Kgathi, 1984; Pachauri and Jiang, 2008). The energy consumption pattern in a household also depends on the type of work of its members. Household members with part-time jobs and retirees are more likely to spend more time at home than at work, leading to an increased use of housing facilities and higher household energy consumption. Similar to household members, larger dwellings tend to have variations in electricity use because they require more lighting facilities and other energy facilities, consequently increasing energy demand (Bedir et al., 2013).

The age of the household head is also one of the determining factors of energy consumption in the household. Investment in better, more efficient energy types is less prevalent among older household members since they believe that better, more efficient energy will not bring any benefits for them in the short term (Sardianou, 2008). Meanwhile, younger household members tend to prefer the latest technology, which is more efficient most of the time. In other words, households with younger heads are more likely to adopt energy-saving measures (Carlsson-Kanyama and Lindén, 2007). Therefore, assuming an equal level of resources, older household heads tend to choose less efficient and more traditional energy devices compared to younger household heads.

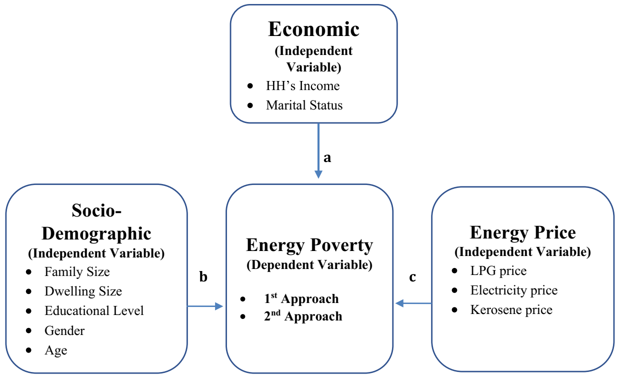

Fig. 2 Research model. This figure shows the research model explaining the impact of socioeconomic, demographic, and energy price variables on energy poverty.

Another finding shows that household location and access to electricity are essential factors in explaining energy poverty in South African households (Ismail and Khembo, 2015). In the Indonesian regional context, households living outside Java tend to experience energy poverty compared to households living in Java (Barnes et al., 2011). These findings show that household sociodemographics are good determinants of a household's energy-poor status and condition (Fuerst et al., 2020).

Based on previous empirical evidence and data availability, this study aims to examine the extent to which nine determinants, categorized into three sets of indicators, can explain the probability of households in Indonesia falling into an energy-poor status. The determinants to be tested are related to energy prices, household sociodemographic status, and household economic conditions (see Fig. 2). Specifically, the study focuses on the cost of two types of modern energy, i.e., the electricity price and LPG price, as well as the price of their alternative, kerosene. In general, better economic conditions (e.g., higher income) and sociodemographic characteristics that signal higher income (e.g., larger dwelling size, a higher educational level, older age) are associated with a lower probability of a household falling into energy poverty. Assuming all else remains constant, higher energy prices will reduce a household's capacity to allocate resources for energy-related expenditures, thereby increasing the probability of falling into energy poverty.

Empirical strategy and data

Measurement of energy poverty. Following the Indonesia Ministry of Energy and Mineral Resources, this study applies the MECTA framework to measure energy poverty. This approach utilizes an accessibility perspective to capture not only the affordability aspect but also adequacy. This perspective is commonly used as the main focus of energy poverty alleviation in developing countries (González-Eguino, 2015).

Based on the MECTA framework, this study uses two approaches: the measurements of energy consumption used by Modi et al. (2005) and Sambodo and Novandra (2019). The energy poverty measurement method used by both utilized the minimum amount of energy consumption needed by a household to meet general basic needs as the energy poverty line. However, Modi et al. (2005) aggregated the consumption of LPG and electricity (approach 1). Meanwhile, Sambodo and Novandra (2019) concentrated solely on electricity consumption, aligning with the size criteria outlined by the UNDP (approach 2).

Modi et al. (2005) categorized households as energy-poor households if the amount of energy consumption is less than the reasonable threshold for energy consumption, which is 50 kgoe per year. This estimation is based on energy consumption of approximately 40 kgoe per capita for cooking and 10 kgoe used as electricity fuel. This standard is derived from the analysis of other countries, such as India, where the annual per capita commercial energy consumption can range from 400 to 500 kgoe, while many impoverished individuals cannot afford or even access 50 kgoe. Consequently, setting the 50 kgoe benchmark as the minimum threshold for essential household energy needs appears reasonable. In addition, upon reviewing the energy usage patterns in Indonesia examined by Hartono et al. (2020), the findings confirm that the measurement and threshold used by Modi et al. (2005) may still be applied in Indonesia's setting of energy poverty. Therefore, based on the approach used by Modi et al. (2005), this study classifies a household as an energy-poor household if it consumes less than 50 kgoe of modern energy consisting of LPG and electricity per year. Throughout this study, *Approach 1* refers to this definition of an energy-poor household.

The energy poverty measurement method used by Sambodo and Novandra (2019) was derived from the threshold of electricity consumption. This threshold is set based on Indonesia's Presidential Regulation of Republic Indonesia No. 47 in 2017, regulating solar panel lighting for households without electricity access. Households are categorized as energy-poor households if they receive one set of 20 W solar panels and four light-emitting diodes, which is equivalent to 32.4 kWh of electricity per month per household. This set of standards is used as the reference for Sambodo and Novandra (2019) to determine that if households consume less than 32.4 kWh of electricity per month, they have an energy-poor status. Therefore, based on this approach, the present study classifies a household as an energy-poor household if it consumes less than 32.4 kWh of electricity per month. This study refers to this approach as *Approach 2*.

Using these approaches, one of the critical issues that needs to be addressed is how the variation in household size might affect energy consumption, which will ultimately affect the energy poverty status. Figure 3 shows that household size across different provinces correlates with modern energy consumption. It shows that there is no dramatic variation in household size between provinces. In addition, the correlation between household size and energy consumption between 2015 and 2019 is small; the correlation between modern energy consumed in terms of kgoe per year and household size is 0.09, and that between electricity consumption in kWh and household size is 0.06. Thus, as the objective of this study is to produce comparable outputs between Modi et al. (2005) and Sambodo and Novandra (2019), similar correlations between different types of modern energy and household size show that the utilization of both of these approaches is still reasonable.

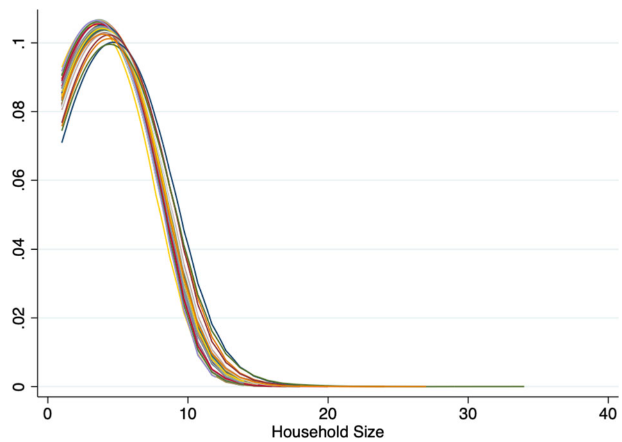

Fig. 3 Household size and energy consumption. This figure shows the correlation between household size (x-axis) and energy consumption (y-axis) across Provinces in 2019. Source: SUSENAS, 2019.

Empirical strategy. This study divides households in the dataset into two different groups: energy-poor households and non-energy-poor households. As mentioned earlier, this study has different measurements of energy poverty. The energy poverty measure for this approach can be written as follows:

$$EPM = \frac{1}{N}\sum_{n=1}^{N} I\left(y_n < k\right) \tag{1}$$

where EPM denotes the energy poverty measure, N denotes the size of a population, y_n denotes the attainment (here, energy consumption) of individual n, and k is the poverty cutoff. Following the approaches of Modi et al. (2005) and Sambodo and Novandra (2019), the energy poverty cutoff used in this study is 50 kgoe of LPG and electricity for Approach 1 and 32.4 kWh of electricity for Approach 2. $I()$ is an indicator function equal to 1 if the expression in parentheses is true and 0 otherwise.

This study employs logistic regression to identify how each determinant in the model is associated with different energy poverty measurements (Alem and Demeke, 2020; Ismail and Khembo, 2015). The method is commonly used and well-suited for modeling binary dependent variables. This study focuses on each variable's average marginal effect in logistic regression. The following mathematical equation, referring to the model employed by Ismail and Khembo (2015), shows the logistic regression model that is used to test the determinants:

$$\begin{aligned} Pr(EP|ikrt = 1 \vee x) = {} & \alpha_0 + \alpha_1 * ln(NEE)_{ikrt} \\ & + \alpha_2 * DWELL_{ikrt} + \alpha_3 * ikrt \\ & + \alpha_4 * MARRIED_{ikrt} + \alpha_5 * EDUC_{ikrt} \\ & + \alpha_6 * GENDER_{ikrt} + \alpha_7 * EMPLOY_{ikrt} \\ & + \alpha_8 * AGE_{ikrt} + \alpha_9 * ln(PRICELPG)_{ikrt} \\ & + \alpha_{10} * ln(PRICEELEC)_{ikrt} \\ & + \alpha_{11} * ln(PRICEKERO)_{ikrt} \\ & + K_k + R_k * T_t + \mu_i \end{aligned} \tag{2}$$

where EP or energy poverty status is a binary variable, in which the value is one if the household falls into the energy-poor category and 0 otherwise. K represents district-level fixed effects. Throughout the analysis, district-level fixed effects are included to control for any district-level variation across different districts, such as a variation in energy policy (Alkon et al., 2016). This study also adds R (island) and T (year) to the equation to control the variables across different combinations of year and island. The subscripts e, i, k, and r represent the approach used to measure energy poverty, i.e., the household unit, the district, the island, and the year, respectively. Meanwhile, all the definitions of other explanatory variables can be found in Table 1.

Fixed effects are used to control for the diversity of Indonesia's energy sector across regions, which exists because of several factors functioning simultaneously among different regions and influencing energy prices in Indonesia. Transportation costs and the availability of varying energy generators and transmission systems are the key factors causing energy prices to vary between islands in Indonesia. Energy poverty can be characterized by the function of supply-side conditions and geographic constraints, which concurrently affect the cost of distribution (Hasibuan and Nasrudin, 2022). For instance, regions with large forest areas or mountainous terrains, which are less accessible and have lower

Table 1 List of determinants.

Indicator	Variable	Definition	Symbol
Socioeconomic	Nonenergy expenditure	Total expenditure without energy expenditure per month in rupiah	NEE
	Dwelling size	Size of the dwelling in square meters	DWELL
	Education	Dummy, = 1 if the household head's highest educational attainment is senior high school or higher	EDUC
	Occupational status	Dummy, = 1 if the household head works in the formal sector	EMPLOY
Demographic	Family size	Number of household members	SIZE
	Marital status	Dummy, = 1 if the household head is married	MARRIED
	Gender	Dummy, = 1 if the household head is male	GENDER
	Age	Household head's age	AGE
Energy Price	The unit price of LPG	Price of LPG per kg	PRICELPG
	The unit price of electricity	Price of electricity per kWh	PRICEELEC
	The unit price of kerosene	Price of kerosene per liter	PRICEKERO

population concentrations, tend to have a higher incidence of energy poverty.

For Approach 2, this study takes PRICELPG out of Eq. (2) because in that approach, fuel/LPG is not considered in the energy poverty measurement. Thus, Approach 2 tests the determinants using Eq. (3).

$$\begin{aligned} Pr(EP|ikrt = 1 \vee x) = \beta_0 &+ \beta_1 * ln(NEE)_{ikrt} \\ &+ \beta_2 * DWELL_{ikrt} + \beta_3 * ikrt \\ &+ \beta_4 * MARRIED_{ikrt} + \beta_5 * EDUC_{ikrt} \\ &+ \beta_6 * GENDER_{ikrt} + \beta_7 * EMPLOY_{ikrt} \\ &+ \beta_8 * AGE_{ikrt} + \beta_9 * ln(PRICEELEC)_{ikrt} \\ &+ \beta_{10} * ln(PRICEKERO)_{ikrt} \\ &+ K_k + R_k * T_t + \varepsilon_i \end{aligned} \tag{3}$$

Furthermore, to understand the variation in association across regions, this study analyzes the association in Java and outside Java, in addition to the aggregated level (national-level analysis).

Determinant variables. In general, the determinants in this study follow the independent variables used by Alem and Demeke (2020), Sharma et al. (2019), and Hartono et al. (2020). However, some variables are added and modified considering the local situation and data availability. In general, the independent variables are related to energy prices, household socioeconomic characteristics, and household demographic profiles from 2015 to 2019. We use household socioeconomic characteristics and household demographics to capture how social, economic, and demographic variations at the household level might explain the variations in the incidence of energy poverty. We also consider energy prices, which tend to vary across regions in Indonesia due to the country's challenging geographical and archipelagic nature, to understand how they might explain the variations in the incidence of energy poverty.

In terms of calculating the household socioeconomic indicator, previous studies used income as one of the main proxies (Alem and Demeke, 2020; Sharma et al., 2019). However, due to the unavailability of household income data in the SUSENAS data, this study proxies the household's income using another measurement. In this circumstance, total expenditure is not a valid proxy for household income because energy expenditure, which is the main element that determines energy poverty in a household, is the total expenditure function. Hence, it is almost tautological that total expenditure and energy expenditure are positively correlated in nature (Alkon et al., 2016). This study follows the approach used by Alkon et al., (2016) by employing nonenergy expenditure as the proxy for income. The construction of nonenergy costs in this study is straightforward; it takes energy expenditure out of total spending to obtain the value of nonenergy costs. Aside from energy expenditure, we use dwelling size (in meters squared), educational attainment, and occupational status as proxies for the other socioeconomic indicators. This study uses the educational attainment and the occupational status of the household head for measuring educational attainment and occupational status, respectively.

For the household demographic profile, the set of determinants used in this study refers to previous empirical research (Alem and Demeke, 2020; Hartono et al., 2020). The determinants, which are available in previous studies, are also used in this study. They are the number of household members, the marital status of the head of household, the gender of the head of household, and the age of the head of household. Since this study focuses on modern energy, this study's most crucial energy prices are modern energy for cooking (LPG) and modern energy for domestic operation (electricity). In addition to these types of modern energy, given the strong substitutive relationship between current and alternative energy (Alem and Demeke, 2020), this study includes the price of kerosene as a proxy for the cost of alternative energy. The following details the determinants used in this study (see Table 1).

Data. To measure energy poverty status and analyze the association between household socioeconomic characteristics and demographic information and energy poverty, this study uses data from Indonesia's National Socioeconomic Survey (SUSENAS) covering five different years, from 2015 to 2019, to form a repeated cross-section of data. To measure energy poverty, the dataset provides energy consumption data by source, particularly LPG and electricity, at the household level. We also use household-level data from the dataset to measure the sociodemographic and economic indicators. Meanwhile, the average energy prices per unit faced by households are measured at the district-level to identify the level of energy prices. The district is the second-level local government in a decentralized Indonesia, right below the central government and provincial government. As of 2020, there were 514 district or district-equivalent regions in Indonesia.

Results and discussions

The incidence of energy poverty. Overall, this study finds a notable variation across different measurements of energy poverty. Approaches 1 and 2 show that the incidence of energy poverty at the household level has been declining since 2015. Figure 4 shows the share of energy-poor households in Indonesia based on various measurements used in this study from 2015 to 2019.

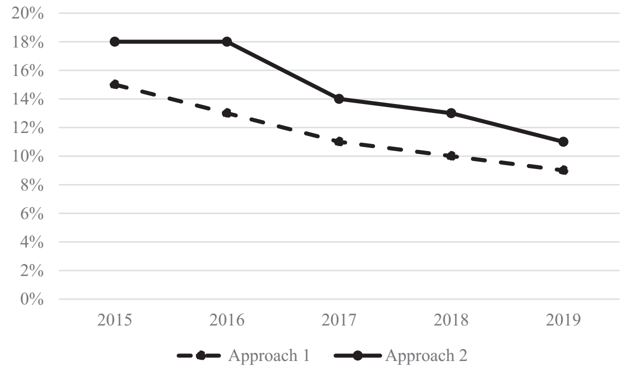

Fig. 4 Share of energy-poor households. This figure shows share of energy poor-household with approach 1 (based on LPG and electricity consumption) and approach 2 (based on solely electricity consumption) between 2015–2019. Source: SUSENAS, 2015–2019.

Figure 4 presents the incidence of energy poverty through the years analyzed using the two measures. A total of 1,485,425 households are observed. Measured using both approaches, Fig. 4 shows that the incidence of energy poverty declined from the base year, i.e., 2015, to 2019. The baseline for the share of energy-poor households dropped from approximately 15% in 2015 to less than 10% in 2019, as shown in Approach 1 (combination of LPG and electricity). The same pattern emerges when this study employs Approach 2 (only electricity); the share of energy-poor households declined from approximately 18% in 2015 to less than 12% in 2019.

By integrating the fact that households' volume of energy consumption in Indonesia increased by 38.6% and the share of households with access to modern energy (electricity and LPG) rose (by 1.4 and 15.04%, respectively), while the use of kerosene declined by 34.40% in the 2015–2019 period, it is clear that households in Indonesia are having increasingly better access to modern energy. Therefore, the ability to pass a certain threshold level to be defined as a non-energy-poor household has increased. This condition ultimately leads to a lower share of households with energy poverty status from the perspective of the volume of energy consumption, as measured by Approaches 1 and 2.

The trends that emerge in Java and outside Java areas are similar to what appears at the national level. In 2015 and 2019, the share of energy-poor households in Java and outside Java steadily decreased. Even though they share similar trends, the intensity of energy poverty varies between Java and outside Java. The share of households with energy poverty status based on the measurement used in Approaches 1 and 2 was more prevalent outside Java than in Java between 2015 and 2019.

Figures 5 and 6 show that the gap between Java and outside Java persisted between 2015 and 2019. The incidences of energy poverty status outside Java, in both Approaches 1 and 2, dropped from more than 20% in 2015 to below 15% in 2019. However, the progress that was made outside Java was not enough to catch up with Java. Between 2015 and 2019, the incidence of energy poverty in Java declined to below 10% in both approaches in 2019. From Fig. 6, we also see that there was a slight bump in the progress of energy poverty reduction in Java based on Approach 2. In 2016, the major provinces in Java, the three provinces with the highest populations, experienced a decrease in electricity consumption. However, this study does not see that those substantial transitory decreases disrupted the overall trend, which shows that the number of households living under energy poverty was decreasing over time.

The determinants of energy poverty. Before the estimation results, this study presents descriptive statistics, as shown in

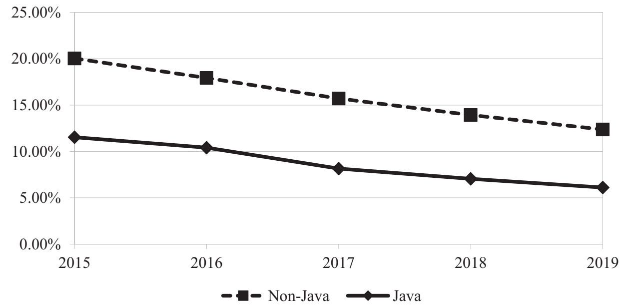

Fig. 5 Share of energy-poor households: approach 1. This figure shows share of energy poor-household based on LPG and electricity consumption (approach 1) in Java and Non-Java Island between 2015–2019. Source: SUSENAS, 2015–2019.

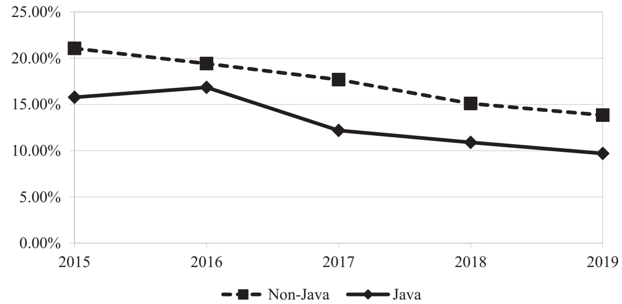

Fig. 6 Share of energy-poor households: approach 2. This figure shows share of energy poor-household based on solely electricity consumption (approach 2) in Java and Non-Java Island between 2015–2019. Source: SUSENAS, 2015–2019.

Table 2. Tables 3, 4, and 5 present the average marginal effects based on Eq. (2)'s logistic regression model. Referring to the regression results, socioeconomic and demographic determinant variables and energy prices are considerably correlated with the energy poverty status of households in Indonesia using both real consumption approaches. Using 1.49 million households in five different years (2015–2019), this study shows that Approaches 1 and 2 produce similar directions of association between energy poverty and its determinants. When discussing the determinants of energy poverty, this study compares the results with other comparable studies, mostly in developing countries, that extensively discuss the determinants.

Based on the estimation results, we find that household expenditure has a negative association with the probability of households enduring an energy poverty status in all approaches. The negative association also consistently appears in Java and outside Java. An increase in household expenditure reduces the probability of households having an energy-poor status by −0.09 to −0.14, with the highest association coming from the region outside Java. This finding supports previous research, suggesting that higher household income correlates with higher energy consumption and a lower probability of being an energy-poor household (Sharma et al., 2019). The lower probability of households enduring an energy poverty status is the outcome of having a more robust economic capacity (Khandker et al., 2012; Narasimha and Reddy, 2007; Rahut et al., 2014). This means that a higher income or expenditure indicates that a household has a higher purchasing power to increase its energy consumption, moving toward more modern energy types. This study also suggests that the marginal effects of nonenergy expenditure in both approaches are higher outside Java than in Java. This finding indicates that the leverage of higher purchasing power on modern

Table 2 Descriptive statistics.

Variable	Number of observations	Mean	Standard deviation	Minimum value	Maximum value
NEE	1,485,425	3737060.0	3840401.0	110245.2	474000000.0
DWELL	1,485,425	76.7	57.5	3.0	997.0
SIZE	1,485,425	3.8	1.6	1.0	34.0
MARRIED	1,485,425	0.8	0.4	0	1
EDUC	1,485,425	0.3	0.5	0	1
GENDER	1,485,425	0.8	0.4	0	1
AGE	1,485,425	47.9	13.9	10.0	97.0
EMPLOY	1,485,425	0.7	0.5	0	1
PRICEELEC	1,485,425	909.7	681.2	65.1	50201.3
PRICELPG	1,485,425	7995.6	4403.7	3191.7	233000.0
PRICEKERO	1,485,425	11013.1	3714.4	2441.4	65902.3

Table 3 The determinant of energy poverty—national level (2015–2019).

	Approach 1	Approach 2
ln(NEE)	−0.0912*** (0.00003)	−0.1008*** (0.00003)
DWELL	−0.0009*** (0.00000)	−0.0008*** (0.00000)
SIZE	−0.006*** (0.00001)	−0.0071*** (0.00001)
MARRIED	−0.0613*** (0.00006)	−0.0411*** (0.00006)
EDUC	−0.0282*** (0.00003)	−0.0422*** (0.00004)
GENDER	0.0354*** (0.00004)	0.0245*** (0.00005)
AGE	−0.0001*** (0.00000)	−0.0008*** (0.00000)
EMPLOY	−0.0109*** (0.00003)	−0.0072*** (0.00003)
ln(PRICEELEC)	0.0694*** (0.00007)	0.1545*** (0.00008)
ln(PRICELPG)	0.0127*** (0.00013)	
ln(PRICEKERO)	−0.0034*** (0.00008)	−0.0011*** (0.00009)
Observations	1,485,425	1,485,425
R-squared	0.470	0.157
District Fixed Effects	Yes	Yes
Island-Year Fixed Effects	Yes	Yes
Sensitivity (%)	34.7	24.8
Specificity (%)	98.2	97.9
Correctly classified (%)	90.8	87.1

The coefficient in the table above shows the value of the average marginal effect of the logistic regression. Robust standard errors are in parentheses.
***$p < 0.01$.

Table 4 The determinants of energy poverty—java (2015–2019).

	Approach 1	Approach 2
ln(NEE)	−0.0729*** (0.00003)	−0.0892*** (0,00004)
DWELL	−0.0007*** (0.00000)	−0.0006*** (0.00000)
SIZE	−0.0148*** (0.00001)	−0.0136*** (0.00002)
MARRIED	−0.0512*** (0.00007)	−0.0379*** (0.00008)
EDUC	−0.0172*** (0.00004)	−0.0391*** (0.00005)
GENDER	0.0313*** (0.00005)	0.0212*** (0.00007)
AGE	−0.0001*** (0.00000)	−0.0007*** (0.00000)
EMPLOY	−0.0109*** (0.00004)	−0.006*** (0.00005)
ln(PRICEELEC)	0.0681*** (0.0001)	0.1711*** (0.00011)
ln(PRICELPG)	−0.005*** (0.00027)	
ln(PRICEKERO)	−0.0027*** (0.00008)	−0.0027*** (0.0001)
Observations	477,631	477,631
R-squared	0.345	0.140
District Fixed Effects	Yes	Yes
Island-Year Fixed Effects	Yes	Yes
Sensitivity (%)	15.4	11.3
Specificity (%)	99.4	99.3
Correctly classified (%)	95.0	91.9

The coefficient in the table above shows the value of the average marginal effect of the logistic regression. Robust standard errors are in parentheses.
***$p < 0.01$.

Table 5 The determinants of energy poverty—outside java (2015–2019).

	Approach 1	Approach 2
ln(NEE)	−0.1124*** (0.00005)	−0.1152*** (0.00006)
DWELL	−0.0011*** (0.00000)	−0.0011*** (0.00000)
SIZE	0.0009*** (0.00001)	−0.0006*** (0.00001)
MARRIED	−0.0641*** (0.0001)	−0.0418*** (0.00012)
EDUC	−0.041*** (0.00005)	−0.0451*** (0.00006)
GENDER	0.0397*** (0.00009)	0.0294*** (0.00009)
AGE	0.0001*** (0.00000)	−0.0008*** (0.00000)
EMPLOY	0.0098*** (0.00005)	−0.0082*** (0.00006)
ln(PRICEELEC)	0.0744*** (0.00011)	0.1338*** (0.00014)
ln(PRICELPG)	0.0418*** (0.00017)	
ln(PRICEKERO)	−0.0088*** (0.00023)	0.0048*** (0.00025)
Observations	1,007,794	1,007,794
R-squared	0.524	0.191
District Fixed Effects	Yes	Yes
Island-Year Fixed Effects	Yes	Yes
Sensitivity (%)	43.5	32.5
Specificity (%)	96.4	95.9
Correctly classified (%)	86.5	81.9

The coefficient in the table above shows the value of the average marginal effect of the logistic regression. Robust standard errors are in parentheses.
***$p < 0.01$.

energy consumption is more substantial outside Java. As modern energy is more established and developed in Java, the effect of income is lower in Java Island.

Using Approaches 1 and 2, this study finds that the association between dwelling size and the likelihood of being an energy-poor household is negative, but the coefficient is very small. The finding in this study is similar to that in the previous study by Bedir et al. (2013), showing that a larger dwelling size tends to have higher and more varied demands for electricity. Hartono et al. (2020) also reached a similar conclusion for a more comprehensive set of energy used by households in Indonesia. A larger dwelling size tends to require a higher supply of energy and vice versa. Hence, on the one hand, the need for a higher reserve for energy drives energy consumption to increase for households with large dwelling sizes. This study also finds that the size of the effect of dwelling size on energy poverty status is larger outside Java than in Java. One of the most plausible explanations for this result is that the use of modern energy outside Java is less common in Java. Hence, the effect of an increase in dwelling size, which reflects an increase in welfare and economic status, is more apparent outside Java than in Java, where the use of modern energy is already prevalent.

In general, the results of the association between family size and the probability of households enduring an energy-poor status are negative. In addition to the reasoning similar to that for the dwelling size result, many family members tend to consume energy at a more efficient level (Chen and Pitt, 2017). A larger family size increases energy consumption, and therefore, it direct the household to move away from the energy-poor status. However, when comparing Java and outside Java, while Approach 2 shows similar results, the association for Approach 1 in outside Java is positive, but the coefficient is very small. It seems that increasing or starting the consumption of both LPG and electricity may not be the priority or be necessary for households outside Java as their family size grows.

The full-time employment status of the household head is negatively associated with the probability of being an energy-poor household across all types of approaches. The same pattern also appears in the estimation in Java. Nationwide and in Java, the full-time employment status of the household head provides a higher income and sense of security regarding the economic condition (Fuerst et al., 2020). Thus, households can consume modern energy beyond the reasonable limit of energy consumption. The result is similar to the that in the previous study by Erol and Yu (1987), who argued that there is a negligible correlation between types of employment and household energy consumption in both the short term and the long term. However, outside Java, the association is positive in Approach 1. Furthermore, even though statistically significant, the effect size is smaller than the national and Java estimates. This finding suggests that having employment does not necessarily increase the consumption of modern energy, particularly for LPG, outside Java.

Overall, this study finds that a married household head tends to decrease a household's probability of being energy-poor. The coefficient ranges from −0.04 to −0.06. Interestingly, the association is quite strong compared to other determinants. The presence of a partnership in the form of marriage increases energy needs and, therefore, lifts the household's energy consumption (Abdul-Wakeel and Dasmani, 2019). In general, this study finds that the coefficient or effect size for Java is larger than that for outside Java. In Java, both men and women in one marital unit are more likely to work and therefore have a better ability to form a larger income pool, making them have a higher level of purchasing power for energy compared to men and women in one marital unit outside Java.

In terms of education, this study shows that if a household head has a senior high school diploma or higher, then the probability of the household becoming an energy-poor household decreases. Similar to marital status, the effect size of education is quite strong compared to other determinants, ranging from −0.02 to −0.05. A similar direction emerges at the national-, Java-, and outside Java-level estimations. With a better-educated head, a household will be more aware of the possible dangers from the use of nonmodern fuels, and it will be more open to switching to more modern fuels. Additionally, a more educated head may have a better occupation and therefore be able to obtain more modern fuels to serve his or her household's needs. This finding follows the conclusion of previous studies (Alem and Demeke, 2020; Sharma et al., 2019), explaining that compared to household heads who do not have formal education, household heads with primary, secondary, or high education at formal educational institutions will have a lower probability of being the head of an energy-poor household. Furthermore, this study finds that the impact of higher education on energy poverty status is more significant outside Java than in Java. One of the most plausible explanations is that the use of modern energy outside Java is less common. Hence, the effect of an increase in education is more apparent outside Java.

This study finds that if a household has a male head, the household tends to have a higher probability of falling into energy poverty based on both approaches. The same pattern with a similar effect size emerges across estimations at the national, Java, and outside Java levels. This pattern supports the argument that, in general, women have a stronger preference for using modern energy than men (Scholz, 2012). According to Alem and Demeke (2020), Hartono et al. (2020), and Sharma et al. (2019), this preference, paired with a woman's higher authority as the head of household, leads to the outcome where a household led by a woman tends to have a higher level of current energy consumption compared to a household led by a man, especially to meet the household's cooking needs. Households led by a male are more likely to fall into energy poverty based on the definition that relies on some minimum energy consumption to be considered a non-energy-poor household, such as in Approaches 1 and 2.

In assessing the association between energy prices and the incidence of energy poverty, this study considers the price of modern energy, consisting of LPG and electricity, and the cost of kerosene, a more traditional energy source. In this context, kerosene might be used to substitute for LPG and electricity for cooking and lighting purposes, respectively. Overall, this study supports the argument that higher LPG and electricity prices correlate with a higher probability of households falling into an energy-poor status. Price plays a pivotal role in determining a household's energy consumption; as the energy price increases, the household's purchasing power for energy and energy consumption will be lower (Xia and Hu, 2012). Ultimately, lower energy consumption leads to an energy poverty status at the household level (Ziramba, 2008). Despite the overall similarity in the general findings, this study finds a minor divergence in the regional-level estimation. In Java, the price of LPG has a negative correlation with energy poverty status. Since the enactment of the LPG program by the government of Indonesia in the late 2000s, LPG has become a primary need in various regions in Indonesia, especially in urban areas within Java Island. Given the strong existing demand for LPG, a lower price of LPG might indicate a decrease in the quantity of LPG demand in Java. Ultimately, this decrease in quantity demand contributes to lower energy consumption, and therefore, it increases the probability of falling into energy poverty.

In addition to LPG and electricity, this study examines the price of kerosene, which constitutes an alternative energy source. To the best of our knowledge, this study is the first study in Indonesia to explore the dynamics of kerosene prices as an alternative source of energy and energy poverty. In general, this study finds that the association between kerosene prices and the probability of being an energy-poor household is negative. Increasing kerosene prices will incentivize households to switch to cleaner energy choices, such as LPG and electricity, and ultimately increase their current energy consumption. Higher clean energy consumption will lower households' probability of falling into energy poverty based on Approaches 1 and 2. Despite the overall similarity in the general findings, this study finds a minor divergence in the regional-level estimation. Outside Java, Approach 2 shows that the price of kerosene has a positive correlation with energy poverty status. Outside Java, this correlation might occur because the increase in the price of kerosene indicates a higher demand for kerosene from people who cannot afford LPG and/or electricity. As they switch back to kerosene and subsequently increase the demand for and price of kerosene, their LPG and/or electricity consumption decreases, and their probability of falling into energy poverty increases.

Conclusion

The general worsening rate of energy poverty is, to some extent, caused by households' lack of access to modern energy. The focus of this study was to determine the factors affecting households' energy poverty status, namely, the use of modern energy for cooking (LPG) and electricity in Indonesia. Based on National Socioeconomics Survey (SUSENAS) repeated cross-sectional data from 2015 to 2019 and using two types of approaches to measure household energy poverty, this study proved that the proportion of energy-poor households in Indonesia decreased steadily from 2015 to 2019.

The higher the total household energy consumption is, the further away from the energy poverty line under Approaches 1 and 2. This increased energy consumption also causes an increase in household energy expenditure, which is not proportional to the rise in household income, causing an increasing trend of energy poverty under the approaches. This study found that the determinant variables of energy poverty in Indonesia are household socioeconomic variables, such as household income, dwelling size, and employment status; household demographic variables, such as family size, marital status, and the educational level, age, and gender of the household head; and the variables of modern energy prices, electricity, and LPG, as well as the price of an alternative energy source, kerosene.

All the determinants tested are considerably correlated, with the correlations between the approaches to measuring energy poverty showing a similar direction. The same results between measurements were obtained in the socioeconomic analysis. The same effect was also found for the variable of the employment status of the household head. The likelihood of Java households experiencing energy poverty decreases when household heads in Java have a permanent job. However, this result is different from the energy-poor status of households outside Java, which is not correlated with employment status and shows zero correlation with employment status. Dwelling size is also a determining factor in which the more extensive the dwelling size is, the lower the probability of a household being categorized as energy insufficient. Demographic variables have different impacts on measures of energy poverty. Family size explains the negative correlation with energy poverty status. The marital status of household heads also considerably correlates with the energy-poor status, decreasing the likelihood of being an energy-poor household. The level of education is also a strong determinant of energy poverty. Among household heads, a higher educational level can reduce the probability of being an energy-poor household. The gender of the household head has a strong effect on the household's energy poverty status. Male household heads increase the chance of a household experiencing energy poverty. The age of household heads is the only determinant that has a very small correlation coefficient.

The findings of this study suggest several important policy decisions. First, many households in Indonesia are still energy-poor. Outside Java, a more common occurrence is that households do not have adequate access to and consume a reasonable amount of modern energy. From the supply side, this condition implies that policy-makers need to increase the current energy distribution, such as LPG and formal electricity, to remote areas in Indonesia. From the demand side, more aggressive price support is also worth considering, such as subsidies, so that households, especially those outside Java, have better purchasing power to cover their energy expenses. Furthermore, since this study found that household nonenergy expenditure has a strong link in helping households move out of energy-poor status, it is essential to develop households' purchasing power to further reduce Indonesia's energy poverty. Energy prices are also an important determinant of energy poverty. In 2014, the Indonesia National Energy Council (*Dewan Energi Nasional*) reported that energy subsidies are already underway in Indonesia to the extent that these subsidies will help households achieve purchasing power and target disadvantaged groups in society to help shape equitable energy consumption. Education also plays an essential role in alleviating energy poverty in Indonesia. The government needs to continue to strive to increase the net enrollment rate in Indonesia, especially the enrollment rate for senior secondary schools or higher. This effort is expected to improve households' literacy regarding why they should adopt modern energy. The study also observes that households headed by women tend to have a lower likelihood of falling into energy-poor status. This result implies the need for women to be more involved in determining household energy choices and consumption.

Despite the findings above, this study has potential limitations because it focuses only on explaining the determinants of energy poverty, which is inadequate for establishing causal inferences. Consequently, the application of causality explanations in this study may result in biased estimations. Furthermore, the use of the latest available data from 2019 is due to the constraints of limited data sources.

Data availability

The datasets generated during and/or analyzed during this study are available from the corresponding author upon reasonable request.

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Author contributions
NKS and DH designed the research and wrote the paper. Data collection and analyzed the data prepared by LDS and NKS. NKS, LDS, and DH refined and corrected the statistical analysis. NKS and LDS revised and polished the paper. All authors discussed the results and contributed to the final manuscript. DH and NKS further improved the draft, preparing it for publication. All authors contributed to the article and approved the submitted version.

Competing interests
The authors declare no competing interests.

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This article does not contain any studies with human participants performed by any of the authors.

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