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Essays on energy poverty in Brazilian households

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Doctor Scientiae

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Thesis submitted to the Applied Economics Graduate Program of the Universidade Federal de Viçosa in partial fulfillment of the requirements for the degree of *Doctor Scientiae*.

Adviser: Marcelo Jose Braga

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Dedico este trabalho a Deus, aos meus pais (Sônia Maria Neves da Silva e Fernando César da Silva), e a todos os colegas e professores que me apoiaram ao longo dessa desafiadora jornada, em especial ao Prof. Marcelo José Braga, à Prof. Cristiana Tristão Rodrigues e à Paula Borges da Silveira Bezerra, cujos ensinamentos e apoio foram fundamentais.

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ABSTRACT

SILVA, Lucas Adriano, D.Sc., Universidade Federal de Viçosa, December, 2024. **Essays on energy poverty in Brazilian households.** Adviser: Marcelo Jose Braga. Co-adviser: Cristiana Tristao Rodrigues.

Energy is essential in people's lives, necessary for daily activities such as cooking, watching television, and lighting environments. Therefore, the lack of access to clean, safe, and reliable energy constitutes a concerning issue known as energy poverty. Despite advances in recent decades in access to electricity and cooking gas, many Brazilian households still face energy vulnerability, a situation that can exacerbate food insecurity. This study measured energy poverty in Brazil, considering its multidimensional aspect, different localities, and the most vulnerable family arrangements. The research used the Multidimensional Energy Poverty Index (MEPI) to assess energy poverty, considering dimensions such as fuel use for cooking, final energy use, energy quality, and the ability to pay for electricity. To analyze the impact of the high share of electricity costs on food insecurity, binary and ordinal logistic models were used, along with the instrumental variables method to address potential endogeneity in the model. The results indicated that about 11.7% of Brazilian households are in a situation of energy poverty, with this figure rising to 30.7% in rural areas. Families with children and female headed single parent families are the most vulnerable in terms of the incidence and severity of energy poverty. The analysis showed a significant positive causal relationship between energy poverty and food insecurity. Households facing energy vulnerability are 43.1% more likely to transition from food security to mild, moderate, or serious food insecurity and 43.9% more likely to progress to moderate or serious food insecurity. Even after testing different strategies, the effect of energy vulnerability on food insecurity remained positive and significant. These findings provide a better understanding of energy vulnerability in Brazil, both in terms of its distribution and its impact on families.

Keywords: energy poverty ; vulnerability ; electricity ; food insecurity ; Brazil

RESUMO

SILVA, Lucas Adriano, D.Sc., Universidade Federal de Viçosa, dezembro de 2024. **Ensaio sobre pobreza energética nos domicílios brasileiros.** Orientador: Marcelo Jose Braga. Coorientadora: Cristiana Tristao Rodrigues.

A energia é essencial na vida das pessoas, necessária para atividades diárias como cozinhar, assistir televisão e iluminar ambientes. A falta de acesso a energia limpa, segura e confiável constitui um problema preocupante conhecido como pobreza energética. Apesar dos avanços recentes no acesso à eletricidade e ao gás de cozinha, muitos domicílios brasileiros ainda enfrentam vulnerabilidade energética, situação que pode exacerbar a insegurança alimentar. Este estudo mediu a pobreza energética no Brasil, considerando o seu aspecto multidimensional, diferentes localidades e os arranjos familiares mais vulneráveis. A pesquisa utilizou o Índice Multidimensional de Pobreza Energética (MEPI) para avaliar a pobreza energética, considerando dimensões como uso de combustível para cozinhar, uso final de energia, qualidade da energia e capacidade de pagar por eletricidade. Para analisar o impacto da alta proporção dos custos da eletricidade sobre a insegurança alimentar, foram utilizados modelos logísticos binário e ordinal, juntamente com o método das variáveis instrumentais para abordar a possível endogeneidade no modelo. Os resultados indicaram que cerca de 11,7% dos domicílios brasileiros estão em situação de pobreza energética, com esse índice subindo para 30,7% nas áreas rurais. Famílias com crianças e famílias monoparentais chefiadas por mulheres são as mais vulneráveis em termos de incidência e gravidade da pobreza energética. A análise mostrou uma relação causal positiva significativa entre pobreza energética e insegurança alimentar. As famílias que enfrentam vulnerabilidade energética têm 43,1% mais probabilidade de passar da segurança alimentar para a insegurança alimentar leve, moderada ou grave e 43,9% mais probabilidade de progredir para a insegurança alimentar moderada ou grave. Mesmo após testar diferentes estratégias, o efeito da vulnerabilidade energética na insegurança alimentar permaneceu positivo e significativo. Esses achados fornecem uma melhor compreensão da vulnerabilidade energética no Brasil, tanto em termos de sua distribuição quanto de seu impacto sobre as famílias.

Palavras-chave: pobreza energética ; vulnerabilidade ; eletricidade ; insegurança; alimentar ; Brasil

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1. Introduction

The use of energy is one of the cornerstones of contemporary society, playing a fundamental role in the daily lives of families and in the economic development of nations. The lack of access to energy, more specifically energy services, constitutes a serious social issue. This situation represents a form of vulnerability that can be defined as energy poverty.

Energy poverty transcends geographical boundaries and is a heterogeneous phenomenon observed in diverse countries. Individuals in both developed and developing nations can experience energy poverty or vulnerability. In developed countries with colder climates, the primary concern is the ability of families to afford home heating during winter. The concept of energy poverty originated from this issue, notably influenced by the work of Boardman (1991), who examined the vulnerability of low-income families in the United Kingdom to maintaining warmth in their homes. Over time, the concept has expanded. Nussbaumer, Bazilian, and Modi (2012) highlight that energy poverty refers to a combination of deprivations that exceed a predefined threshold and also affects populations in developing countries, such as Brazil.

Energy deprivation refers not only to the absence of energy or fuel but also to the lack of reliable and safe access to essential daily services (DUBOIS, 2007). In situations of service deprivation, families become increasingly vulnerable to health issues (CHURCHILL; SMITH, 2021), social disadvantages (HERNANDEZ, 2016), and food insecurity (FRY; FARRELL; TEMPLE, 2023). A family may experience the consequences of energy poverty without being formally classified as energy poor; they may simply be in a state of energy vulnerability. Energy vulnerability is understood as a collection of factors or conditions that contribute to energy poverty (BOUZAROVSKI, 2018). Rather than merely describing a current state, vulnerability encompasses the causes or conditions that may lead to poverty.

The research problem emerges from the following question: How does energy poverty affect families in Brazil? The general objective of the thesis is to analyze the susceptibility of energy poverty in vulnerable family arrangements and to assess the impact of energy vulnerability on food insecurity.

This thesis comprises two essays that examine various aspects of energy poverty.

The first essay evaluates energy poverty in Brazil during two distinct periods (2008-09 and 2017-18). Recognizing the phenomenon of heterogeneity and its adaptation to the Brazilian context, a multidimensional approach is employed through the application of the Multidimensional Energy Poverty Index (MEPI) and relevant indicators that have been underutilized in the literature. The analysis focuses on family structures that are typically more vulnerable, including families with children, single-parent households led by women, and families with an obese member.

The second essay assesses the impact of energy vulnerability on household food insecurity. This analysis categorizes food insecurity into three levels: mild, moderate, and serious. To maintain access to electricity, vulnerable households may reduce expenditures deemed non-essential, which can include cutting back on food spending. Both binary and ordinary least squares models are estimated, and an instrumental variables approach is employed to account for potential endogeneity between the variables.

These essays aim to deepen our understanding of significant issues related to energy poverty. Collectively, they strive to enhance our capacity to devise future measures by exploring the most effective ways to measure energy poverty and by developing a comprehensive understanding of its effects. Each essay could be regarded as a contribution to the existing literature. The first essay examines energy poverty in Brazil, with a particular focus on more vulnerable family structures. It employs dimensions identified as especially relevant to the Brazilian context, which have rarely been explored in prior studies. The second essay investigates the impact of energy vulnerability on food insecurity, focusing on a developing country during a period characterized by rising food insecurity and escalating residential electricity costs.

The remainder of this thesis dedicates one chapter to each essay, presented in the order outlined above. A concluding chapter offers general remarks on the findings.

2. Analysing the susceptibility of vulnerable family arrangements to energy poverty in Brazil

Abstract

The study aims to assess the extent of families' exposure to energy poverty, focusing on the Brazilian context. Employing a multidimensional approach, the analysis examines the Multidimensional Energy Poverty Index (MEPI) for two distinct periods (2008-09 and 2017-18), using indicators adapted for developing countries. The results reveal that 11.7% of Brazilian households suffer from energy poverty, with child-bearing families and female single-parent families being particularly vulnerable to energy poverty. Surprisingly, the same vulnerability is not found in families with obesity. These insights are intended to shed light on the differential impacts of energy poverty on different family arrangements, contributing to a better understanding of the issue and informing policy interventions.

Keywords: energy poverty; family arrangements; vulnerable.

2.1. Introduction

The literature describes energy poverty as an interaction of factors, such as high prices of electricity and modern fuels, energy inefficient households, absence of appliances and electronics, low family income and specific energy needs for families (HEALY; CLINCH, 2002; PACHAURI et al., 2004; DUBOIS, 2007; HERNÁNDEZ, 2016; ABBAS et al., 2020; OLIVERAS et al., 2021; PRAKASH; MUNYANYI, 2021). These factors are closely connected to the crucial role of energy in achieving sustainable development, as emphasized by the Sustainable Development Goals (SDGs) (ODS, 2021).

Initially focused on Northern Hemisphere countries due to the challenge of maintaining acceptable indoor temperatures during winter (BOARDMAN, 1991), the analysis of energy poverty has since evolved. It now includes countries with diverse profiles, such as developing nations in the Southern Hemisphere. This broader analysis incorporates variables related to accessibility, perceptions of energy service quality (PACHAURI et al., 2004; VILLALOBOS; CHÁVEZ; URIBE, 2021), and the

concept of capabilities (SEN, 2000). It has been observed that vulnerability to energy poverty is higher among certain family arrangements. Families with children or individuals with chronic illnesses are particularly vulnerable due to spending more time at home (BOUZAROVSKI, 2014; O'SULLIVAN et al., 2016; OLIVERAS et al., 2021).

Boardman (1991), considered the seminal paper on the subject, evaluates the vulnerability of poor families in the UK in order to keep their homes warm, establishing expenditure of more than 10% of family income as an energy poverty line. In the literature, after the work of Boardman (1991) and other works that analyze the situation of developed countries, what is noticed is the adoption of a multidimensional perspective for developing countries and the Southern Hemisphere through multidimensional indicators (DAY; WALKER; SIMCOCK, 2016). Nussbaumer, Bazilian and Modi (2012), in an analysis for 28 countries of the African continent, built up the Multidimensional Energy Poverty Index (MEPI) based on the theory of capabilities. In analysis for South Asia, Abbas et al. (2020) use compound indexes to measure the multidimensionality of energy poverty in the region. In Chile, Villalobos, Chávez and Uribe (2021) use different poverty rates, comparing energy expenditures that exceed 10% of the budget with the proposed Perception-based Multidimensional Energy Poverty Index (PMEPI). In the case of Brazil, there is scarce literature on the subject and the trend of the multidimensional approach is also observed in the works of Poveda, Losekann and Silva (2021) and Bezerra et al. (2022).

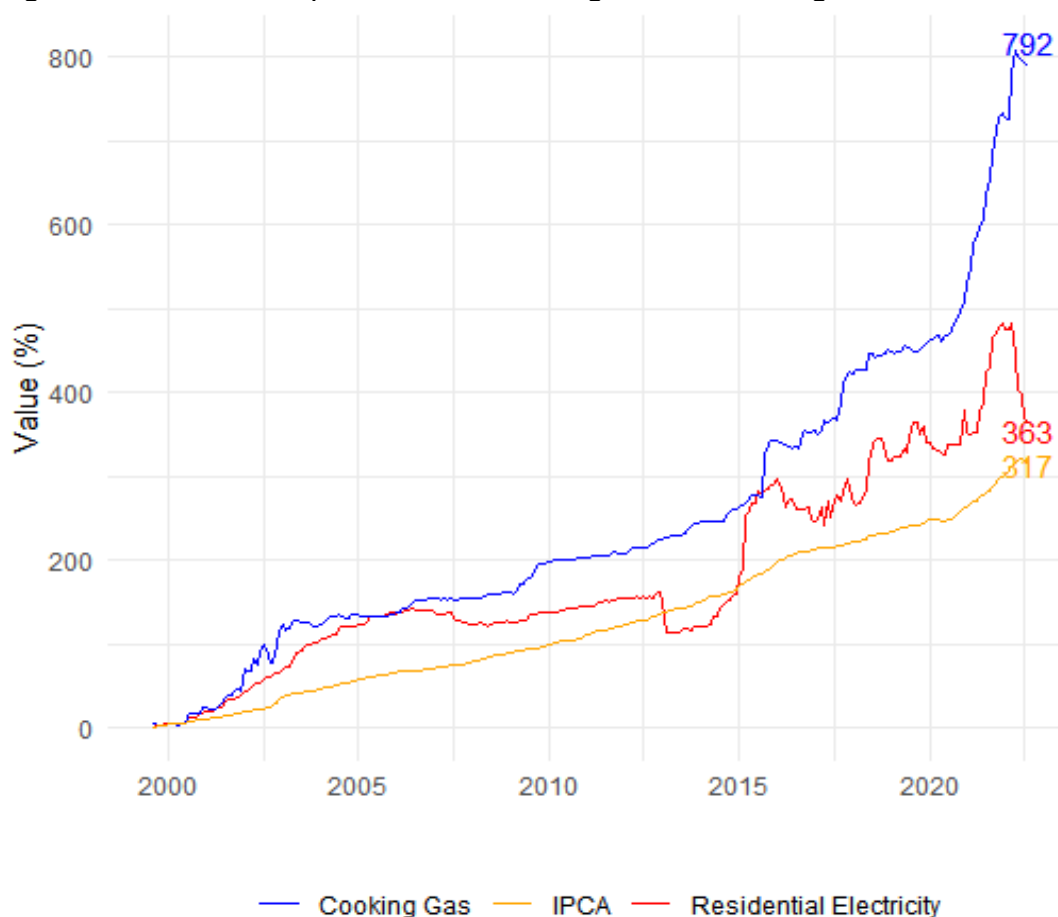
Despite significant advances in recent decades through social programs aimed at universalizing access to energy and modern fuels¹, energy poverty affects around 11% of Brazilian households (BEZERRA et al., 2022). This situation is associated with economic recession, periods of rising electricity charges and rising prices of cooking gas, which has more impact on the population of poor countries². In this context, more vulnerability can be attributed to the markers of social disadvantage, such as certain family arrangements (families with children, single parents, with chronic patients), which tend to suffer more intensely the effects of energy poverty (HERNÁNDEZ, 2016).

¹ Summary of the most important Federal Government social programs in recente decades (BEZERRA et al., 2022): Tarifa Social de Energia Elétrica (2010 - ongoing), Auxílio Gás (2002 - 2003 and 2021 - ongoing), Luz para Todos (2003 - ongoing), Bolsa Família (2003 - 2021), Auxílio Brasil (2021 - ongoing).

² This is due to the fact that poor countries are more structurally vulnerable to energy poverty, because they provide a lower degree of protection to their population in the event of internal and/ or external changes that can lead families to the condition of lack of energy (OLIVERAS et al., 2021).

In the figure below it is possible to observe the Extended National Consumer Price Index (IPCA) and the disaggregation of the values of residential electricity and cooking gas between 1999 and 2022. The accumulated value of electricity reached the value of approximately 363% at the end of the period, with a significant increase in 2015. The exception of a small period in 2013 and 2014, the value of residential electricity remained higher than the general IPCA index during the entire period considered. As for the cooking gas, the accumulated value reaches about 792%, presenting higher values than the IPCA and increasing in almost the entire period.

Figure 1 - Cumulative price index from August 1999 to August 2022



Source: Own elaboration based on IBGE - Extended National Consumer Price Index.

During this period, the increase in cooking gas prices can be attributed to both rising demand and a growing reliance on external sources, particularly from the USA (GONÇALVES, 2020). Electricity prices began to rise after 2014, following a structural shift in 2012 triggered by the federal government's imposition of a price freeze under

Provisional Measure No. 579. This measure led to increased regulatory activities by Aneel and introduced instability into the sector, resulting in several negative consequences that contributed to successive price hikes starting in 2014 (FIORAVANTE, 2022).

Considering the above, the context of vulnerability of families and rising energy prices, this study aims to understand energy poverty in Brazil, and thus obtain a better understanding of this phenomenon, responsible for negative effects on health and well-being of people, linked with different areas of study. For this, this work focuses on observing the rates of energy poverty in certain vulnerable groups, understanding the exposure of these groups to the phenomenon of energy poverty.

The essay presents the determination of a Multidimensional Energy Poverty Index (MEPI) applied in two different periods based on the Consumer Expenditure Survey (POF) from 2008-09 and 2017-18. Vulnerable groups are not yet considered in the literature for developing countries, such as families that have children, especially female single-parent families³ and obese people.

The main objective is to analyze the exposure of families to energy poverty, taking into account two distinct periods, 2008-09 and 2017-18. This study aims to contribute to the literature by measuring energy poverty in Brazil among more vulnerable family arrangements. Additionally, it uses dimensions identified as relevant to the country and seldom addressed in the literature, including perceptions of electricity and household quality.

In addition to this introduction, the essay has five more sections. Section 2.2 explains the theoretical model of multidimensional energy poverty. Section 2.3 presents the research methodology, describing the MEPI methodology, the dimensions and the database used. Section 2.4 provides the results for the energy poverty index. The discussion that follows in Section 2.5 analyzes energy poverty in recent years, considering the exposure of different family arrangements. The conclusion highlights the main conclusions of this study and the possible recommendations for policy development.

³ Family formed only by a person responsible for the female domestic unit with at least one child or stepson (IBGE, 2010a).

2.2. Theoretical reference

To formally explain the multidimensional energy poverty model, it is first necessary to present the conceptual structure, consisting of the theory of Amartya Sen's capabilities and the subsequent adaptation of this theory in the context of energy vulnerability.

2.2.1. The Theory of Sen's Capabilities

The general concept of poverty and development has undergone a process of historical evolution (SEN, 2000) through the formulation of various theories over time. Each new theory, a greater number of elements are incorporated, in order to broaden the focus on reality.

Utilitarianism, created by Bentham (1789), is a consequentialist theory, whose basis is in the judgment of actions based on the results generated (SEN, 1983), in the utility obtained with actions. Rawls' theory of social choice (1971) expands in relation to utility satisfaction, considering an aggregate index composed of social primary goods (basic goods). In the capacity approach developed by Sen (1974, 1979, 1983, 2000), a step is taken forward in the concept of poverty, by incorporating the notion of functionings and capabilities, keeping the focus on the expansion of freedoms. Instead of addressing only material wealth, from variables such as family income and aggregate GDP, in Sen (1974, 1979, 1983, 2000) it develops a theory of multidimensional aspect, centered on improving the lives of individuals and strengthening their freedoms. It is not that income becomes irrelevant, but it is treated only as an important tool for the development of functionings and capabilities (RODRIGUES, 2014).

The functionings are defined as "being" and "doing", in the case of the realization of capacities, which may include states, such as being healthy, and activities, such as carrying out paid work (DAY; WALKER; SIMCOCK, 2016). While, the capabilities are substantive freedoms in the choice of life that has reason to value (SEN, 2000), constituting real opportunities for the execution of operations (DAY; WALKER; SIMCOCK, 2016). The functionings performed constitute what a person

actually does, and the capabilities represent the freedom to perform alternative combinations of functionings among which there is the possibility of choice, that is, real opportunities (RODRIGUES, 2014).

In the theory of capabilities, it is possible to observe a great concern with freedom of choice. The capabilities become the great object of concern, not the functionings, because focusing on the functionings would impose a particular way of life (SEN, 2000; DAY; WALKER; SIMCOCK, 2016). Accordingly, by obtaining capabilities, there is the maximization of real opportunities while the individual still remains free to choose the type of life that has more reason to value (DAY; WALKER; SIMCOCK, 2016).

Poverty can be defined as a deprivation of capacities (SEN, 2000), referring to the impossibility, in the absence of ability to achieve valued functionings such as having good health (DAY; WALKER; SIMCOCK, 2016). Despite highlighting the importance of the free choice of a life that values itself, Sen (2000) presents different examples of valued capabilities, such as good access to health care and education. Therefore, a number of capabilities are recognized, making the capability approach a multidimensional approach to poverty (RODRIGUES, 2014; DAY; WALKER; SIMCOCK, 2016).

2.2.2. The Theory of Capacities applied in energy services

Energy itself is not a necessity, but through the use of energy many basic services are obtained, such as heating, cooling, lighting, cooking and cleaning. The consumption of this type of service is linked to the search for certain capabilities (SEN, 2000; SOVACOOOL, 2011; RODRIGUES, 2014; DAY; WALKER; SIMCOCK, 2016).

In Sen (2000), through different examples, it becomes possible to observe the variety of existing capacities, which makes capacity a multilevel concept (SMITH; SEWARD, 2009). There are more generic capabilities, there are more specific and concrete ones (DAY; WALKER; SIMCOCK, 2016). Based on this difference, capacities can be classified into basic and secondary (SMITH; SEWARD, 2009).

Basic skills are defined as broad and generic forms, understood as the most fundamental (SEN, 2000), such as body and mental health. As for the secondary capacities, these are more concrete and specific (SMITH; SEWARD, 2009), consisting of components of materialization of basic capacities.

Education can be considered a fundamental capacity that encompasses various other capabilities, which may be viewed as secondary due to their specific characteristics, such as access to schools and educational opportunities. Another ability that can be considered as basic is social respect, which results in the ability to wash yourself and your clothes, demanding hot water service that requires energy for the operation of the shower and/ or washing machine (DAY; WALKER; SIMCOCK, 2016).

The ultimate concern of an individual or family is the basic capabilities (or functionings at the time the capabilities are being realized) that requires certain secondary capabilities (SMITH; SEWARD, 2009). In turn, secondary capacities may require energy services that require energy such as electricity and/or fuel (DUBOIS, 2007; SOVACOOOL, 2011; DAY; WALKER; SIMCOCK, 2016; VILLALOBOS; CHÁVEZ; URIBE, 2021). This makes energy not an end in itself, but acts as an important instrument for obtaining a lot of capacities.

The instrumental relationship between energy and capacities is contingent and conditional, and can be variable between families. The amount of energy services required for an individual or family to ensure a good level of secondary capabilities depends on different factors, such as the family arrangement factor (DAY; WALKER; SIMCOCK, 2016; HERNÁNDEZ, 2016), if they have children, people with some chronic disease, among others. Families with children or chronic patients tend to stay longer at home (BOUZAROVSKI, 2014; O'SULLIVAN et al., 2016; OLIVERAS et al., 2021), which makes them demand a higher number of energy services compared to other family arrangements to achieve the same capabilities.

Energy poverty can be defined as an inability to achieve essential capabilities, thus being a direct or indirect consequence of insufficient access to safe, reliable and accessible energy services, taking into account alternative means available, as the possibility for the realization of these capabilities (DAY; WALKER; SIMCOCK, 2016). This makes energy a component associated with multiple dimensions, indispensable for the realization of a range of capacities (DUBOIS, 2007; SMITH; SEWARD, 2009; SOVACOOOL, 2011), such as health and well-being (DAY; WALKER; SIMCOCK, 2016; OLIVERAS et al., 2021).

The multidimensionality of this concept is in line with the situation in Brazil, which in recent years has shown advances in access to electricity and modern fuels, but due to crises and climate issues it still has considerable problems involving the

issue of accessibility to energy and resilience of the use of traditional fuels (COELHO et al., 2018; BEZERRA et al., 2022).

2.2.3. Vulnerable family arrangements

Through the capability approach, it becomes evident that not all individuals are equally positioned to confront energy poverty, and as a result, they face varying levels of risk (DUBOIS, 2007). This framework underscores the significance of individual freedoms, access to resources, and social contexts, elucidating why certain groups are disproportionately affected by energy poverty, while others are better equipped to mitigate its effects.

The evidence highlights vulnerable family arrangements with children and individuals with chronic illnesses, primarily due to their specific energy needs and the extended time they spend at home. These households depend on a stable domestic environment to ensure thermal comfort and adequate health conditions (BOUZAROVSKI, 2014; O'SULLIVAN et al., 2016). In the case of children, the need for a safe space to study, play, and develop often leads to higher energy consumption. Similarly, for individuals with chronic illnesses, inadequate heating or cooling can exacerbate health conditions, increasing the demand for medical care and, consequently, household expenses (OLIVERAS et al., 2021).

Single-parent families, particularly those headed by women, face additional challenges that render them more susceptible to energy poverty. These households often experience lower incomes and greater difficulty in covering basic expenses, including energy costs (HERNÁNDEZ, 2016). Moreover, single mothers frequently bear a disproportionate burden of domestic and caregiving responsibilities, which limits their ability to generate additional income. The combination of these factors leaves such families with fewer resources to invest in energy efficiency measures or to manage high energy tariffs, especially in homes with poor thermal insulation (OLIVERAS et al., 2021).

2.3. Methodology

2.3.1. Energy poverty index

The energy poverty index is developed from Alkire and Foster's dual-cut off method (2011). Based on a traditional poverty measurement index, Foster-Greer-Thorbecke index (FGT), the dual cut-off method consists of first identifying the dimensions that present deprivation. This index has already been utilized in studies on energy poverty, such as those conducted by Bezerra et al. (2022).

After identifying the types of possible deprivation, it is considered a minimum value necessary to characterize a condition of poverty, that is, a condition of deprivation. Being a matrix of deprivations $g_0 = [g_{ij}^0]$, of proportions $n \times d$, with "n" representing the quantity of the sample ($i = 1, 2, 3, \dots, n$) and "d" consisting of the quantity of dimensions ($j = 1, 2, 3, \dots, d$), each representative of the sample (y_{ij}) is related to a vector (z_i). This vector represents the poverty line, from which it is possible to verify if a given household i is suffering from deprivation in some dimension j . There will be deprivation of a certain dimension when it is below its established poverty line ($y_{ij} < z_j$) (ALKIRE; FOSTER, 2011).

$$g_{ij}^0 = w_j \quad \text{if } (y_{ij} < z_j) \quad (1)$$

$$g_{ij}^0 = 0 \quad \text{if } (y_{ij} \geq z_j) \quad (2)$$

After identifying the dimensions in which there is deprivation, being below the corresponding poverty line, the count occurs to identify the total amount of these dimensions. The number of dimensions with deprivation is counted in the column vector c_i (ALKIRE; FOSTER, 2011).

$$c_i = \sum_{j=1}^d g_{ij}^0 \quad (3)$$

The number of dimensions with deprivation has a certain value k as a parameter for poverty. The chosen k can assume the extreme methods of union and intersection, in which deprivation in a single individual dimension or in all existing dimensions, respectively, reflects a situation of poverty (ALKIRE; FOSTER, 2011). In the case of energy poverty, the value adopted for k is usually intermediate, with a certain number of deprivations in modern energy services among the extreme values (NUSSBAUMER; BAZILIAN; MODI, 2012; POVEDA; LOSEKANN; SILVA, 2021). This value can be very sensitive, and the higher the k value, the lower the MEPI, since a larger number of dimensions in which the household suffers deprivation would be necessary to be considered as multidimensionally poor (ALKIRE; FOSTER, 2011).

The Oxford Poverty and Human Development Initiative (2018) sets the value of $1/3$ for cutting global multidimensional poverty. Consequently, a household with a deprivation score equal to or higher than $1/3$ (or 0.33333) is considered multidimensionally poor, identifying simultaneous deprivations in at least two of the total dimensions (OPHI, 2018). This cutoff point aims to balance the identification of poverty by reflecting both the extent and intensity of deprivation. Furthermore, the $1/3$ cutoff serves as a flexible threshold that can be adjusted for different applications. In order to show different intensities of deprivation, different poverty limits are defined (ALKIRE; FOSTER, 2011; NUSSBAUMER; BAZILIAN; MODI, 2012). While households with a c_i score between $1/5$ and $1/3$ are identified as vulnerable, c_i between $1/3$ and $1/2$ are identified as acute, and c_i from $1/2$ identifies an extreme situation (OPHI, 2018). Abbas et al. (2020) and Poveda, Losekann and Silva (2021) use acute poverty cutting ($1/3$) to identify households that are multidimensionally poor in energy.

The notation used to identify poverty is the symbol ρ_k . For the case where an element of the sample is identified as poor, $\rho_k(y_i, z) = 1$. Otherwise, identified as not poor, $\rho_k(y_i, z) = 0$. The total value of poverty can be found by the dual cut-off method of Alkire and Foster (2011) and, from this value, the percentage of poverty is measured through a headcount index (H). This index consists of the result of the number of identified as poor (q), $q = \sum n\rho_k(y_i, z)$ divided by the total number of individuals of the sample (n).

$$H = q/n \quad (4)$$

The dimensions in which there is restriction are summed. With $c(k) = 4$ dimensions in which there is deprivation, there is the average number of deprivations of those characterized as poor, called the adjusted headcount index (A) (ALKIRE; FOSTER, 2011).

$$A = c_i(k)/qd \quad (5)$$

Once multidimensional energy-poor households are identified, MEPI can be calculated as the product of the incidence rate and intensity of multidimensional poverty (ALKIRE; FOSTER, 2011; NUSSBAUMER; BAZILIAN; MODI, 2012; OPHI, 2018).

$$MEPI = H \times A \quad (6)$$

This indicator has a property called dimensional monotonicity. When a family already has enough deprivations to be considered as poor energy, deprivation in an additional dimension reflects the added value of the indicator (NUSSBAUMER; BAZILIAN; MODI, 2012). Other advantages are to observe the individual contribution of each dimension on the poverty index applied and the possibility of poverty decomposition in different subareas (ALKIRE; FOSTER, 2011).

2.3.2. Dimensions, indicators and weights

The type of fuel used for cooking, the end uses of electricity, the quality of electricity services and the quality of housing, and the capacity to pay are the dimensions selected for the energy poverty index.

Most of the work on energy poverty, especially for developing countries, the use of fuel for cooking is used as a dimension. Generally, the indicators that make up this dimension are based on a combination, between families that use traditional fuels for cooking (firewood, coal) and that have low income (POVEDA; LOSEKANN; SILVA, 2021). This combination is carried out in order to really identify families in situations of energy poverty, differentiating these from others that use traditional fuels for cultural reasons (COELHO et al., 2018). Despite the justification for their use, traditional fuels pose serious risks to both health and the environment (GIODA; TOINETTO; LEON, 2017) and are inconsistent with the objectives of the Sustainable Development Goals (SDGs) (ODS, 2021).

Uses of electricity is a dimension formed by durable goods (household appliances and electronics), responsible for access to important energy services (BEZERRA et al., 2022). Refrigerator, computer, washing machine and fan/air-conditioning are goods related to obtaining secondary capabilities such as food refrigeration, information, cleaning and space cooling; resulting in obtaining basic capabilities, such as comfort and well-being (SOVACOOOL, 2011).

The quality of access to electricity and the quality of housing is an important dimension related to the reliability and security of energy services. Formed by the indicator of perception regarding electricity supply, its use is associated with the measurement of access to reliable and safe energy services in a household (VILLALOBOS; CHÁVEZ; URIBE, 2021). As for the housing quality, this is an indicator that seeks to reflect the quality of the residence in which the family is, along with their living condition and surroundings (CRUZ, 2021) consisting of the junction of four binary variables that classify the condition of residence as "high quality" or "low quality".

In the case of payment capacity, formed by the indicator late payment of household bills (water, electricity or gas) and the percentage of energy expenditure (electricity and cooking gas) that surpasses the average percentage of household income expenditure of families earning less than two minimum wages⁴, this is a dimension that represents the main problem associated with energy poverty in developed countries today (BOUZAROVSKI, 2014). Its use is also recommended in Brazil due to the increase in the price of electricity and cooking gas observed in recent years (Figure 1), responsible for hindering the accessibility of households to energy services. Regarding the limit value adopted for energy expenditure, the approximate value of 8.75% was obtained for the biennium 2008-09, and about 9.34% in 2017-18. Values close to the agreed limit of 10% (HEALY; CLINCH, 2002), adopted in different studies. Below, Table 1 seeks to detail the dimensions adopted along with their respective indicators of deprivation and weights.

⁴ Minimum wage of R\$ 465.00 in 2009 and R\$ 954.00 in 2018.

Table 1 - Dimensions, indicators and weights

Dimension	Indicator of deprivation	Weight
Use of fuel for cooking	Combination of two conditions: Use of traditional cooking fuels; and Perception of difficulty of the family in dealing with life until the end of the month with their monthly income.	0.30
End uses of electricity	No refrigerator.	0.05
	No computer.	0.05
	No washing machines.	0.05
	No fan or air conditioning.	0.05
Quality of access to electricity and quality of housing	Poor perception of electricity supply or no access to electricity service.	0.10
	Housing quality level (Household index), combination of the condition of the external walls, roof condition, lighting from public network and piped water.	0.10
Capacity to pay	Declared delay in payment of water, electricity or gas, and percentage of energy expenditure (electricity and kitchen gas) exceeds the average percentage of household spent by households earning less than two wages.	0.30

Source: Own elaboration.

Weights can be categorized into statistical or normative approaches. Statistical approaches are highly contingent upon the specific dataset utilized, which complicates comparisons across different locations. In contrast, normative approaches involve assigning weights based on value judgments that require justification (SANTOS, 2019). Consequently, the majority of literature employs normative weights in the construction of MEPI (ABBAS et al., 2020; POVEDA; LOSEKANN; SILVA, 2021). Moreover, much of the literature assigns varying weights to different dimensions (NUSSBAUMER; BAZILIAN; MODI, 2012; VILLALOBOS; CHÁVEZ; URIBE, 2021).

Dimensions related to fuel use for cooking and the capacity to pay are typically assigned greater weight. This emphasis is based on the critical role these dimensions play in achieving essential outcomes such as health and education (DAY; WALKER; SIMCOCK, 2016). Furthermore, this prioritization is reflected in the literature, which

generally assigns higher weight to the type of fuel and the proportion of energy costs, while attributing lesser weight to the ownership of household appliances and energy quality (ABBAS et al., 2020; NUSSBAUMER; BAZILIAN; MODI, 2012; POVEDA; LOSEKANN; SILVA, 2021).

Cooking is a basic necessity in which energy is required for the supply of heat. According to evidence, significant time is spent, especially in the case of women and children, in collecting traditional fuels (firewood, coal, manure, etc.) for cooking, consisting of an important opportunity cost when compared to more modern fuels (NUSSBAUMER; BAZILIAN; MODI, 2012). Another problem associated with the use of traditional fuels is the internal pollution of households, constituting a significant risk factor for morbidity and mortality (CRUZ, 2021; BEZERRA et al., 2022).

Regarding the capacity to pay, its importance is to examine the financial difficulties that families face in paying electricity and kitchen gas bills, resulting in delays in payments and the commitment of a significant portion of the budget (VILLALOBOS; CHÁVEZ; URIBE, 2021; BEZERRA et al., 2022). This commitment is associated with accessibility, consisting in the inability to maintain access to basic energy services, such as information, food conservation, cleaning and cooling the environment (HEALY; CLINCH, 2002; HERNÁNDEZ, 2016).

In the other dimensions, final uses of electricity and quality of access to electricity and quality of housing, a lower weighting is adopted compared to the other dimensions. It is not about reducing the importance of such dimensions, but only considering that energy poverty covers even more essential issues (NUSSBAUMER; BAZILIAN; MODI, 2012), especially when considering developing countries (ABBAS et al., 2020). Even so, in the case of the quality dimension of access to electricity and housing, it is a relevant dimension, mainly as a way of analyzing the result of public policies for the universalization of electricity and modern fuels (CRUZ, 2021) little used, especially for different periods in time, in works for developing countries.

To be considered as low in energy, the sum of deprivations (c_i) of dimensions must be equal to or higher than the cut-off value (k) defined. It is choose $k = 0.34$, following the poverty criterion of the Oxford Poverty and Human Development Initiative (2018), used in works such as Abbas et al. (2020) to identify acute energy poverty. Different combinations of deprivations can cause a family to be classified as poor energy, requiring some deprivation in at least two different dimensions.

2.3.3. The distribution of energy poverty

Energy poverty is not equally distributed socially and geographically. Areas and regions of the same country may reveal different situations (PACHAURI et al., 2004). In Brazil, the North region and rural areas stand out, places with a high incidence of energy poverty in Brazil (BEZERRA et al., 2022).

But trying to go beyond the issue linked to the distribution of this phenomenon, it is noted that some groups of individuals are more vulnerable with certain family arrangements finding themselves in a situation of more exposure to the effects of energy poverty (HERNÁNDEZ, 2016; OLIVERAS et al., 2021). This is the case of families composed of children and people with chronic diseases who tend to suffer more the consequences of energy poverty, for spending more time inside the house (BOUZAROVSKI, 2014; O'SULLIVAN et al., 2016; OLIVERAS et al., 2021). In the case of families with children, the situation tends to be more serious towards female single-parent families (HERNÁNDEZ, 2016).

For this reason, MEPI is applied to different family backgrounds in order to verify the situation of the most vulnerable groups, with the possibility that these groups most exposed to the effects of energy poverty are also the most affected by this phenomenon in terms of incidence. Thus, there is the situation of families with children (under twelve years of age) and families with obese people⁵ (chronic disease characterized by overweight).

In the case of families with children, the situation of female single-parent families is also taken into account. Regarding the choice of obese people as the only way to represent chronic diseases, this is due to the limitation of the database used, which does not allow the use of different chronic diseases.

⁵ Obesity classified from the value of the Body Mass Index (BMI), $BMI = \text{Weight}/\text{Height}^2$. BMI higher than or equal to 30 indicates obesity (PRAKASH; MUNYANYI, 2021).

2.3.4. Database

The interest in assessing energy poverty, identifying multidimensional energy-poor households in recent years, leads to the use of POF 2008-09 and POF 2017-18, which consists of a complex sample database. It is the only available database that has a large amount of data on household energy spending, in a disaggregated way and at national level.

The POF is a household survey conducted through sampling, aimed primarily at gathering information on budget structures, including expenditures on products and services as well as income, as well as nutritional status and living conditions of Brazilian families. The POF provides insights into the products purchased and services utilized by families over the course of a year, encompassing both urban and rural areas across all federative units of Brazil.

This information gathered from the POF is instrumental in studying changes in family consumption patterns and updating weighting structures essential for the calculation of Consumer Price Indexes. Additionally, the survey's results facilitate a wide range of studies and planning activities related to family expenditures by income level, demographic and socioeconomic factors, anthropometric measurements, quantity of food purchased for home consumption, income distribution, concentration, and inequality, as well as families' perceptions of their living conditions and personal food consumption.

In the sample, the households with zero family income and also energy expenses are removed, as well as missing values in income and expenses. In this way, the sample is restricted to 50,754 and 54,410 observations, in samples from 2008-09 and 2017-18, weighted by expansion factors representing 53,481,884 and 65,712,126 households, respectively.

2.4. Results

2.4.1. Descriptive analysis

The indicators of deprivation form the different dimensions, contributing to the incidence of energy poverty and, consequently, in the calculated value of MEPI. Table 2 below shows the percentage of indicators of deprivation, relative to families in Brazil and considered for the different bienniums (2008-09 and 2017-18).

Table 2 - Indicators of energy poverty in households (%)

Indicator	2008-09	2017-18
Traditional fuels for cooking and income makes it difficult to live a life until the end of the month	7.81	7.55
No refrigerator	5.73	1.31
No computer	70.66	56.94
No washing machines	53.63	34.55
No fan/air conditioning	37.23	19.80
Poor perception of electricity supply or no access to electricity	9.33	5.65
Poor quality level of housing (Household index)	17.45	15.34
Delay in payment of water, electricity or gas and percentage of energy expenditure exceeds the expenditure of households earning up to two minimum wages	6.28	6.16

Source: Own preparation based on POF 2008-09 and POF 2017-18.

Observing the two periods, an overall improvement can be observed in the 2017-18 biennium in relation to the 2008-09 biennium, a result associated with public policies of universalization of access to energy (COELHO et al., 2018), with more prevalence of household appliances in Brazilian homes (BEZERRA et al., 2022).

Although, regarding the indicators of use of traditional fuels/income, it is difficult to live a life until the end of the month and the delay in paying household bills/percentage of energy expenditure, there is a very diluted decrease, little expressive in relation to the other indicators. This may be due to the increase in the price index of cooking gas and electricity in recent years, especially from the year 2015 (as observed in Figure 1). Disaggregating the indicators of deprivation to verify their evolution.

Table 3 - Disaggregated indicators (%)

Indicator		2008-09	2017-18
Traditional fuels for cooking and income makes it difficult to live a life until the end of the month	Traditional fuels for cooking	14.75	19.54
	Income makes it difficult to live a life until the end of the month	60.48	33.34
Poor perception of electricity supply or no access to electricity service	Poor perception of electricity supply	8.79	5.30
	No access to electricity service	0.54	0.37
Poor housing quality level (Household index)	External walls (Taipa, wood used, other unsuitable material)	2.04	0.76
	Roof (wood used, straw, other unsuitable material)	0.87	0.51
	Lighting not from public sector	0.46	0.29
	Water supply not from the general distribution network	15.87	14.51
Delay in payment of water, electricity or gas and percentage of energy expenditure exceeds the expenditure of households earning up to two minimum wages	Delay in payment of water, electricity or gas	37.26	33.41
	Percentage of energy expenditure exceeds the expenditure of households earning up to two minimum wages	12.13	11.85

Source: Own preparation based on POF 2008-09 and POF 2017-18.

In a disaggregated way, it becomes possible to note that the improvement observed in the dimension of quality of access to electricity and quality of housing has more connection with the reduction of the number of households in which there is a poor perception of the electricity supply, a decrease of approximately 3.49 percentage points in 2017-18. Since the percentage of families without access to the electricity service, as well as the percentage of families living in homes with inadequate materials on the external walls and roof and with lighting not coming from the public network, it presents as less relevant, even before the observed periods. Despite the best result

regarding the perception of electricity supply, also observed in the water supply from the general distribution network, there is still room for improvement in these items with the need for better results.

2.4.2. The energy poverty in Brazil

The level of exposure to energy poverty varies based on family location, as certain areas are more prone to energy vulnerability. In Brazil, there are notable differences in energy poverty between rural and urban areas, as well as among different regions.

Table 4 illustrates the varying rates of energy poverty in Brazil, highlighting differences between periods as well as between rural and urban areas.

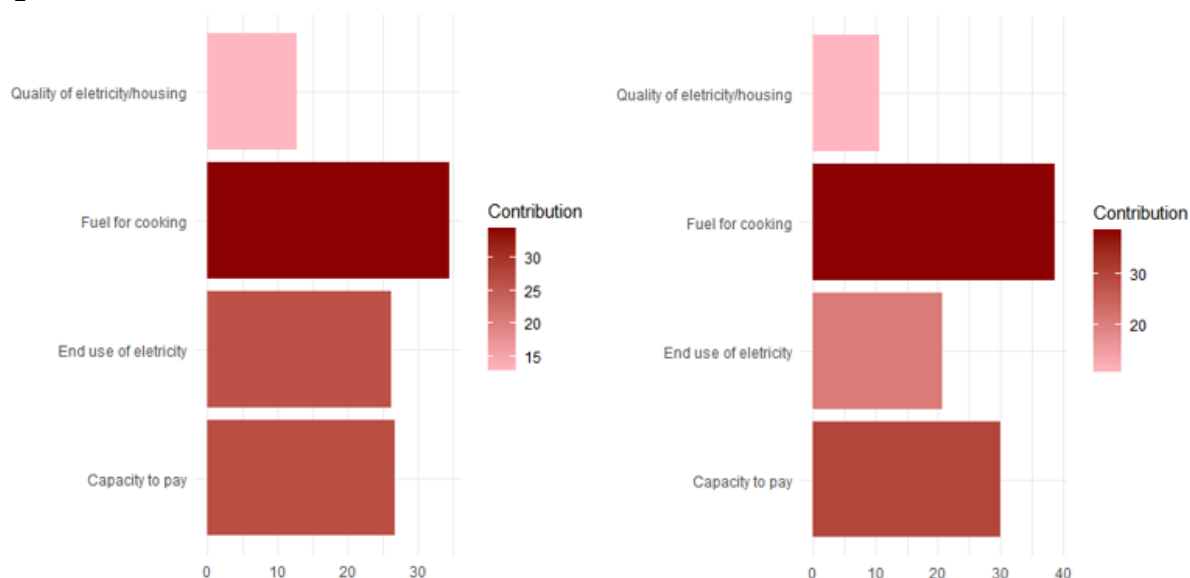
Table 4 - Incidence (H), Intensity (A) and Multidimensional Index of Energy Poverty (MEPI) in Brazil and by areas in 2008-09 and 2017-18

Index 2008-09	Brazil	Rural	Urban
H	0.137	0.379	0.099
A	0.489	0.537	0.465
MEPI	0.067	0.203	0.046
Index 2017-18	Brazil	Rural	Urban
H	0.117	0.307	0.088
A	0.462	0.518	0.432
MEPI	0.054	0.159	0.038

Source: Own preparation based on POF 2008-09 and POF 2017-18.

In 2017-18 there was a general improvement for all indexes, with the reduction of energy poverty, reaching an incidence (H) of 11.7% and a corresponding MEPI of 5.4%, a result that indicates better access to energy services and modern fuels. In the case of the areas, the situation of rural places is significantly worse than in the urban area, for all indexes and periods considered, especially the difference in incidence (H). The results can be better understood through the contribution of the dimensions in the MEPI, observing what contributes most and least to energy poverty in the different periods. This can be accomplished in Figure 2 below.

Figure 2 - Contribution level of the dimensions in MEPI, 2008-09 and 2017-18



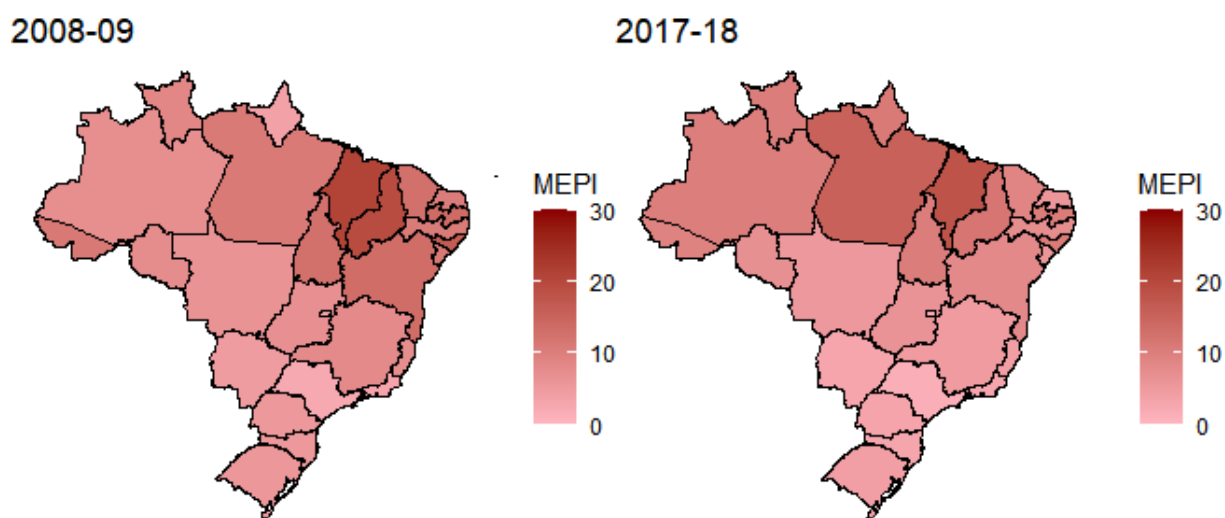
Source: Own preparation based on POF 2008-09 and POF 2017-18.

The dimensions related to the final use of energy and quality of electricity/housing lose importance in 2017-18, while fuel for cooking and payment capacity obtain greater participation in the index. The largest share, for both periods, is relative to the fuel for cooking (the combination of traditional fuel and perception of difficulty of the family in living a life until the end of the month with their monthly income).

Unlike other studies, such as those by Poveda, Losekann, and Silva (2021), which emphasize various dimensions, this study identifies the type of fuel used for cooking as the most critical factor. This difference may arise from a general consideration of traditional fuels for cooking without distinguishing their specific sources. Traditional fuels, regardless of their origin, pose serious risks to both health and the environment (GIODA; TONIETTO; LEON, 2017) and are inconsistent with the objectives of the Sustainable Development Goals (SDGs) (ODS, 2021).

The method adopted, based on Alkire and Foster (2011), makes it possible to observe MEPI calculated for different locations, such as states. This can be seen in Figure 3 below.

Figure 3 - MEPI calculated by state



Source: Own preparation based on POF 2008-09 and POF 2017-18.

Through the maps, it is possible to notice a general improvement in the situation of the states, verified by the reduction of the value of MEPI, with a relatively expressive improvement identified for the states of the Northeast region, such as the states of Maranhão and Piauí that had the highest MEPI values in 2008-09. The exception of this result are the states of the North region, for example Amazon, Pará and Amapá, presenting a worsening situation from one period to the other. The worst result in these states is associated with the situation of lack of energy services, verified mainly in isolated rural areas of the region, remaining until the current moment (BEZERRA et al., 2022).

2.4.3. Energy poverty in vulnerable groups

The Table 5 shows the rates of energy poverty based on family education to identify the situation of more vulnerable family arrangements. From this, families with and without children are considered.

Table 5 - Incidence (H), Intensity (A) and Multidimensional Energy Poverty Index (MEPI) by family formation

Index	2008-09		2017-18	
	With child	Without child	With child	Without child
H	0.183	0.107	0.151	0.100
A	0.492	0.485	0.477	0.460
MEPI	0.090	0.052	0.072	0.046

Source: Own preparation based on POF 2008-09 and POF 2017-18.

The results reveal that families with children are actually more vulnerable to energy poverty, are the most affected and those who suffer more intense effect of this phenomenon. This difference is significant and is present in 2008-09 and 2017-18. Result that is in accordance with the literature (BOUZAROVSKI, 2014; O'SULLIVAN et al., 2016; OLIVERAS et al., 2021).

Because it is associated with a situation of higher economic and social vulnerability, constituting a marker of social disadvantage (HERNÁNDEZ, 2016), the situation of female single-parent families is treated in a particular way, and can be observed in Table 6 below.

Table 6 - MEPI calculated for female single parent families

Family arrangement	MEPI	
	2008-09	2017-18
Single-parent women	0.113	0.087
Non-single-parent women	0.065	0.053

Source: Own preparation based on POF 2008-09 and POF 2017-18.

Energy poverty for female single parent families is more severe than that of other family arrangements, with a considerable difference between the MEPI calculated for these families and the others, revealing a situation of higher vulnerability in the two time periods considered. These results confirm Hernandez (2016), which

states that the phenomenon of energy insecurity is based on specific markers of social disadvantage. There is varying vulnerability to energy poverty depending on family composition.

Another arrangement considered is that of families that have obese people. Table 7 shows the different indexes for this type of social group.

Table 7 - Incidence (H), Intensity (A) and Multidimensional Energy Poverty Index (MEPI) by family formation

Index	2008-09		2017-18	
	With obese	Without obese	With obese	Without obese
H	0.149	0.130	0.119	0.121
A	0.489	0.485	0.454	0.471
MEPI	0.073	0.063	0.054	0.057

Source: Own preparation based on POF 2008-09 and POF 2017-18.

Unlike families with children, especially female single parents, the results involving obese people are not as expressive and/or discrepant. The results of families that have and do not have obese people are relatively close, and families with obese people have a small and apparent improvement in the rates for the period 2017-18.

2.5. Discussion

The results show a reduction of energy poverty in Brazil in recent years. Even with this reduction, it is clear that energy poverty still affects a considerable number of families, especially in the rural area and in the North of the country, a region that has a lower level of progress in access to energy services compared to other regions of Brazil. The estimated energy poverty affects 11.7% of Brazilian households, which corresponds to almost 8 million households and about 24 million people.

Despite the progress observed, there seems to be some resistance to energy poverty in Brazil, which should have shown a bigger drop than observed, considering the history of public policies aimed at universalization of access to electricity and cooking gas (COELHO et al., 2018). A possible explanation can be found in the pre-Covid economic turmoil (BEZERRA et al., 2022), together with the significant increase observed in the price of residential electricity and the price of cooking gas over the past few years. Consequently, even having access to energy services and modern fuels, a

significant part of families has difficulty maintaining continuous access to these services, which is a problem of accessibility.

This trend can be observed through the dimensions that most influence the calculated MEPI. Comparing the MEPI for the periods 2008-09 and 2017-18, while keeping the distribution of weights constant, shows an increase in the contribution of dimensions related to the use of traditional fuels and the ability to pay for energy. Both dimensions pertain to accessibility: the use of traditional fuels is linked to the inability to afford modern fuels, while the ability to pay refers to the proportion of energy expenditure relative to the family budget. This finding aligns with the literature, which identifies difficulties in covering energy costs as a primary factor contributing to energy poverty (COELHO et al., 2018; BEZERRA et al., 2022).

Comparing the MEPI for the periods 2008-09 and 2017-18, while keeping the distribution of weights constant, also shows a decrease in the contribution of dimensions related to the end uses of electricity, quality of access to electricity, and quality of housing. This result is linked to the universalization of modern energy services, reflected in significant improvements in physical access to electricity and ownership of primary household appliances (BEZERRA et al., 2022).

Regarding the distribution of energy poverty, the results show how certain family arrangements can be more or less vulnerable, as they constitute a marker of social disadvantage (HERNÁNDEZ, 2016). This is the case of families with children, more exposed to the intensity of the effect of energy poverty by staying longer at home (BOUZAROVSKI, 2014; O'SULLIVAN et al., 2016; OLIVERAS et al., 2021), demanding more energy services. In addition, according to the results obtained, these families are more likely to be affected, in terms of incidence, by this phenomenon. Consequently, the exposure of families with children to energy poverty is greater, confirming the discussion of different articles in the literature, which indicate the greatest difficulties of these families, especially in relation to the participation of energy spending on the budget (HERNÁNDEZ, 2016; OLIVERAS et al., 2021), associated with accessibility to energy services.

In the specific case of female single-parent families, energy poverty is even higher and more discrepant. Result linked to greater socioeconomic vulnerability of this type of family arrangement, which tends to suffer more with the increase of the residential electricity bill and the price of cooking gas, having great difficulty in maintaining access to safe and reliable energy services (HERNÁNDEZ, 2016). Female

single-parent families are also relatively more vulnerable to times of turbulence and economic crisis, further raising the condition of vulnerability to energy poverty (OLIVERAS et al., 2021).

Families with obese people also tend to suffer more energy poverty, because they spend more time at home (BOUZAROVSKI, 2014; O'SULLIVAN et al., 2016; OLIVERAS et al., 2021), having the need for more energy services. In addition to being related to energy poverty, as the literature points out, obesity is a chronic disease associated with several limitations on a daily basis (PRAKASH; MUNYANYI, 2021). Despite this, the results found do not show great discrepancy between families with or without obese people. This result suggests that obesity is not a significant factor contributing to energy poverty in Brazil.

2.6. Conclusion

The main results show that energy poverty has decreased in recent years, except for some states in the North. In the calculated MEPI, there is an increase in the share of the size corresponding to the use of traditional fuels and the size related to the energy payment capacity, the participation of poor perception about electricity and the household.

When considering the differences arising from the type of family arrangement, the unequal distribution of energy poverty is noticeable, with families that have children, especially female single parents, being the most energetically vulnerable. The same result is not observed in families that have obese people, with little difference in the result of families with and without obese people. A limitation of the study is the lack of comprehensive data on physical limitations, comorbidities, and chronic diseases. Additionally, there is insufficient information on the efficiency of electronic equipment and lighting in homes.

The results of this work may generate subsidies for future analysis on effective ways to eradicate energy poverty in Brazil, especially for more vulnerable groups. Among the possible measures that can be taken in this sense, one can highlight the focus of public policies for groups in situations of higher vulnerability, such as families with children and single parent families. It is necessary to focus on accessibility, on measures that allow families to use modern fuels for cooking without the need to use traditional fuels as a complement, and are able to access reliable and safe energy.

Furthermore, more effective management of energy policy in the country is essential to prevent substantial price increases and sectoral crises.

For future research, it is crucial to use updated data. Furthermore, it is important that new dimensions and indicators can be incorporated in the index, especially regarding the perception of energy quality. Another suggestion is to analyze the situation of other types of family arrangements which are also more vulnerable to energy poverty.

3. Electricity expenses and the food insecurity in Brazilian households: a causal relationship

Abstract

A significant number of Brazilian households encounter difficulties in accessing basic energy services, which is linked to a higher proportion of this type of expense in their budgets. The cost of residential electricity in Brazil has been steadily increasing since 2014, attributed to a combination of crises, and the characteristics of the Brazilian electricity sector. Based on this context, the study endeavors to comprehend the extent to which individuals experiencing constraints in accessing electricity also grapple with inadequate access to food. This evaluation is conducted using probability models that incorporate both binary and multinomial categorical variables, in conjunction with the instrumental variables (IV) method. The results reveal that a causal relationship, wherein energy poverty emerges as a significant factor contributing to the likelihood of families experiencing food insecurity. These insights are intended to shed light on the differential impacts of energy poverty, contributing to a better understanding of the issue and informing interventions.

Keywords: electricity expenses; food insecurity; family income; Brazil.

3.1. Introduction

Energy access is essential for the provision of basic services such as lighting, heating, cooling, cooking, and washing. The lack of this access can characterize energy poverty and vulnerability (BOUZAROVSKI, 2018), precipitating a cascade of adverse consequences. These repercussions encompass diminished levels of subjective well-being, suboptimal self-rated health, afflictions such as circulatory and respiratory diseases, compromised mental well-being, attenuated work capacity, heightened mortality rates, and the onset of sleep disorders (WHO, 2018; LLORCA et al., 2020; NIE; LI; SOUSA-POZA, 2021).

Food insecurity is one of the significant issues associated with restricted access to energy. It is an intricate phenomenon involving various factors that result in

limited or uncertain access to nutritious food (HOFFMANN, 2013; MATTOS; BIANCHI; TOIGO, 2020). Notably, households grappling with energy vulnerability have heightened susceptibility to conditions of food and nutritional insecurity. This vulnerability stems from the household financial constraints that leads to the inherent trade-off between food and energy (NORD; KANTOR, 2006; BASOLE; BASU, 2015; HERNÁNDEZ, 2016; SOLA et al., 2016; SAMBODO; NOVANDRA, 2019; FRY; FARRELL; TEMPLE, 2023).

Nord and Kantor (2006) examination of diverse U.S. states reveals the prevalent phenomena of "heat or eat" and "cool or eat," elucidating the adverse impact of seasonally elevated heating and cooling costs on food consumption. Delving into the circumstances of low-income families in the United Kingdom, Anderson, White, and Finney (2012) scrutinise various strategies adopted to manage energy expenditures, often at the expense of curtailing other indispensable outlays, such as those related to nutrition. In the Indian context, Basole and Basu (2015) establish a causal relationship between increased fuel expenses for cooking and a decline in calorie intake, evidenced by the decrease in average calorie intake despite an increase in actual monthly expenses. Fry, Farrell, and Temple (2023), in a study for Australia, assess the relationship between energy prices and food security, concluding that the rise in electricity prices increases susceptibility to a trade-off between energy and food.

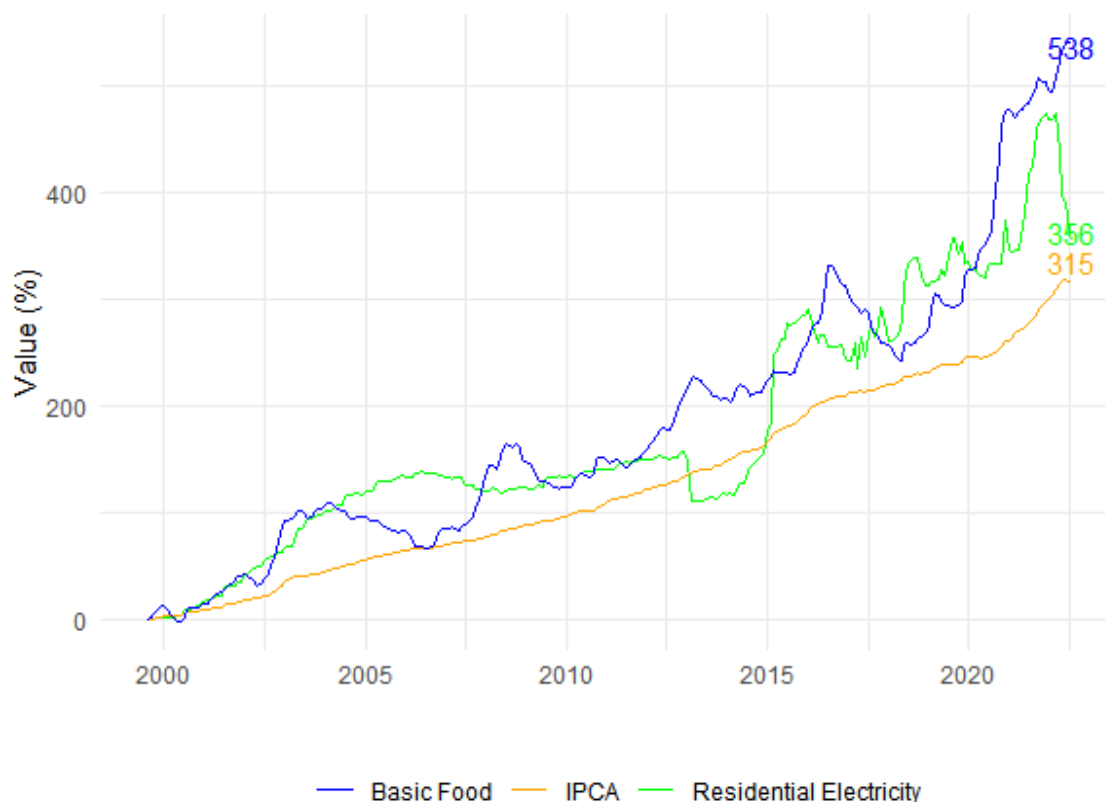
Despite making progress in access to modern energy sources through the implementation of public electrification policies, Brazil still faces challenges (BEZERRA et al., 2022; COELHO et al., 2018). A significant number of households have difficulty managing energy-related expenditures, a predicament associated with elevated costs in this domain. Families ensnared in this scenario find arduous to uphold access to essential energy services, rendering them to be more susceptible to the "cool or eat" phenomenon (NORD; KANTOR, 2006; HERNÁNDEZ, 2016). This dilemma is can be exacerbated by the escalated energy expenses, leading to a reduction in calorie intake (BASOLE; BASU, 2015; FRY; FARRELL; TEMPLE, 2023).

In Brazil, there were an increase in food insecurity observed when juxtaposed the 2017-2018 Households Expenditure Survey (POF) with data from antecedent surveys. Since 2014 Brazil has witnessed consecutive escalations in the cost of residential electricity, positioning the country among those with the highest residential

electricity expenses worldwide⁶. This circumstance can be ascribed to a confluence of crises in the electrical sector (GUTIERREZ, 2022). Electricity prices rose following the federal government's imposition of a price freeze under Provisional Measure No. 579. This measure led to increased regulatory activities by Aneel and introduced instability into the sector, resulting in several negative consequences that contributed to successive price hikes starting in 2014 (FIORAVANTE, 2022).

The growth of residential electricity costs surpassed the IPCA value throughout almost the entire observed period, having exceeded the value of basic food items at various points, particularly between 2014 and 2020 (Figure 4).

Figure 4 - Cumulative price index from August 1999 to December 2023

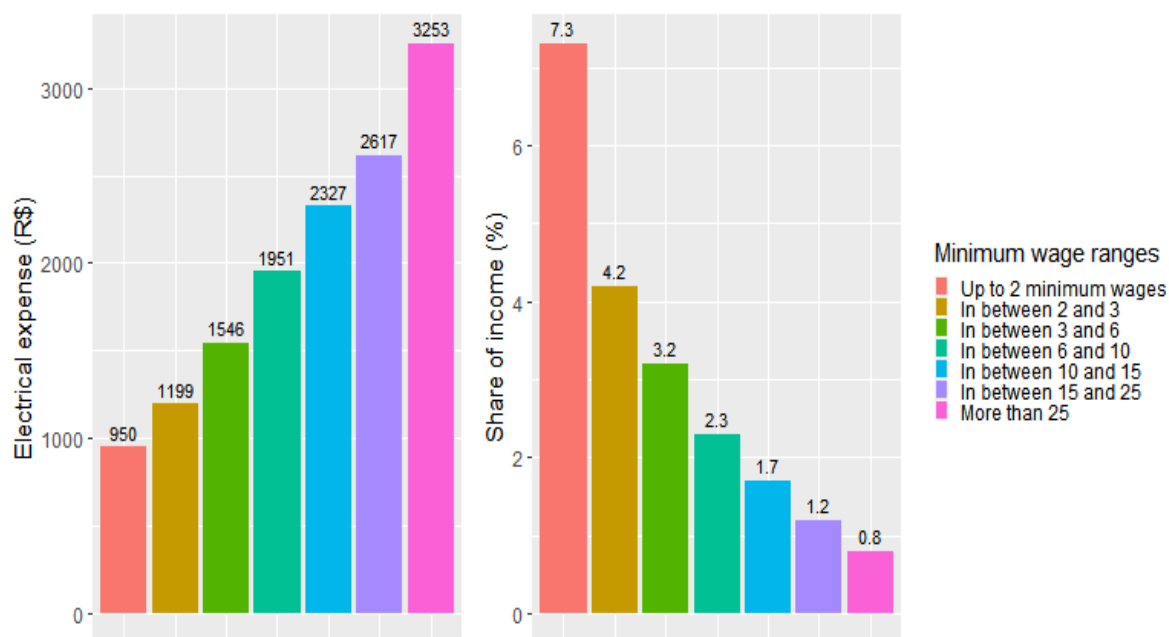


Source: Own elaboration based on IBGE - Extended National Consumer Price Index.

⁶ In assessing the Energy Cost/Per Capita Income indicator, the analysis incorporates residential tariff data for Brazil from Aneel, residential tariffs for OECD countries from the IEA, and GDP per capita data from the IMF.

The rise in residential electricity expenses disproportionately impacts lower-income families who allocate a larger portion of their budget to these costs. Despite consuming less electricity compared to higher-income households. This trend is illustrated in Figure 5 below.

Figure 5 - Average annual expense and electricity's share of income in Brazilian households



Source: Own preparation with data from POF 2017-18.

In light of the aforementioned context, this study endeavors to comprehend the extent to which individuals experiencing constraints in accessing electricity also grapple with inadequate access to food. The central aim of this essay is to evaluate the impact of energy vulnerability on food insecurity. By scrutinizing a developing country like Brazil, during a period marked by growing food insecurity and escalating residential electricity costs, this study aims to contribute substantially to the existing literature on the subject. Furthermore, special attention will be devoted to examining different levels of food insecurity.

The remainder of the paper is organized as follows. Section 3.2 contains a brief review of related work in the literature. Section 3.3 describes theoretical framework used in this study. Section 3.4 presents degree of food security and insecurity. Section 3.5 presents the research methods and data source for the case study. Section 3.6 provides the results of the analysis. The discussion of results follows in Section 3.7. The conclusion highlights the main findings of this study and offers possible recommendations.

3.2. Literature review

The initial emphasis on analyzing the relationship between energy and food security was directed towards Africa, particularly in the sub-Saharan region (FAO, 2015; FLEURET, 1990). Adams et al. (1980) seek to clarify the relationship between fuel availability and nutritional status. This inquiry is prompted by the nutritional challenges observed in sub-Saharan African countries due to impediments in accessing firewood. Fleuret (1990) presents several hypotheses on how this shortage could potentially reshape behavior concerning food, encompassing the stages of production, distribution, and consumption.

The established relationship between energy security and food security is also evident in developed countries. In the context of European nations, the approach to vulnerability in energy access is associated with the tradeoff between heating in households during winter and food. Boardman (1991) is considered to be the seminal article on the topic, setting spending surpassing 10% of UK family income as the energy poverty line. In this scenario, Morgan et al. (1996) observe that the demand for fuel to heat homes in winter may lead to a reduction in food expenditures. Anderson, White, and Finney (2012) found that poor British families often sacrificed food costs to maintain access to energy during the winter months. As the cost of fuel rises, families encounter heightened challenges in adequately heating their homes, potentially resulting in cutbacks in other expenditure categories. These issues are not confined to cold climates but are also evident in regions with moderate (OLIVERAS et al., 2021) and even high temperatures (CHURCHILL; SMITH, 2021).

Bhattacharya et al. (2003) scrutinise the decisions made by many low-income Americans families during winter, where the added cost of heating can only be offset by reductions in the food budget, resulting in a decline in caloric intake. Nord and

Kantor (2006) pinpoint that substantial expenses on both heating and cooling household temperatures impact the food security of families through a trade-off. This phenomenon is commonly known as "heat or eat" or "cool or eat," where increased energy expenditures lead to a reduction in food expenses.

The escalated spending on energy extends beyond concerns related solely to the seasonality of low or high temperatures, as evidenced in countries such as India (BASOLE; BASU, 2015), Australia (FRY; FARRELL; TEMPLE, 2023), China (NIE; LI; SOUSA-POZA, 2021), Indonesia (SAMBODO; NOVANDRA, 2019), and Brazil (BEZERRA et al., 2022).

In India, the rise in expenditures on cooking fuel contributes to an increase in real monthly spending, concomitant with a reduction in average calorie intake (BASOLE; BASU, 2015). Basole and Basu (2015) delve into this household spending pattern, identifying a causal link between the upswing in cooking fuel expenditures and a downturn in calorie intake. This relationship is explained by the constriction of the food budget for Indian families as consequence of the rapid surge in fuel expenses. Australia has witnessed a sustained rise in electricity expenses, particularly following the global financial crisis, and Fry, Farrell, and Temple (2023) empirically establish a correlation between escalating energy prices and reduced food intake. The phenomenon of energy poverty is identified as the primary factor leading to a curtailment in food expenditure. Given the greater ease of short-term control over food expenses, individuals tend to prioritise energy costs, often resulting in budgetary adjustments where food spending is sacrificed to meet energy bills.

The financial commitment to energy expenses, intricately linked to tariff increases stemming from crises in the electricity sector or climate-related effects, not only poses challenges to access energy but also compels these families to navigate intricate trade-offs between energy and other foundational needs, such as food. This substantial allocation of the household budget to energy expenditure diminishes the ability to procure food, impacting both its quantity and quality (BASOLE; BASU, 2015; HERNÁNDEZ, 2016; SOLA et al., 2016; SAMBODO; NOVANDRA, 2019; FRY; FARRELL; TEMPLE, 2023).

In the context of Brazil, despite significant strides in improving the population's access to modern energy sources, there has been a noticeable surge in the cost of electricity in recent years (FIORAVANTE, 2022). Additionally, findings from the 2017-18 Family Budgets Survey (POF) reveal a regression in recent years increase in food

security, with 36.7% of Brazilian households (equivalent to 25.3 million out of 68.9 million households) experiencing some degree of food insecurity (IBGE, 2020).

The literature on the situation in Brazil has predominantly addressed the interplay between energy and food production at a macro level. Mercure et al. (2019) analyse the tradeoff between biofuel production and food production, given the global demand for liquid raw materials for first-generation biofuels. Their analysis highlights the conflicts and compromises that arise when prioritising biofuel crops over food crops, emphasising the broader implications for food security.

3.3. Theoretical framework

3.3.1. The effect of price changes on demand

The demand for a good depends directly or indirectly on its price, the relative prices of other goods, income and consumer preferences (VARIAN, 1978). This dependence creates differences in the quantity demanded. The variation, or sensitivity, of the quantity demanded related to changes in prices is a measure of elasticity. The degree of elasticity of a good varies according to the relative needs for it. The demand for a good can be more or less elastic in relation to its price, with the difference in the degree of elasticity consisting of the amplitude of demand variation in relation to price variation (VARIAN, 1978). The greater the impact of a given price on demand for a given product, the greater the elasticity.

The variation in the quantity demanded of a product in relation to its own price, commonly called price elasticity of demand, depends on different factors such as availability of substitute products, the specific need for the product, time and relevance in the budget, etc. The smaller the number of substitute goods and the greater the need for a given good, the lower its elasticity, that is, the smaller the variation in demand for that good in relation to the variation in its price (SÁ JÚNIOR, 1994).

The increase in the price of a good is responsible for the substitution effect and the income effect. The substitution effect leads to the replacement of the relatively more expensive goods by relatively cheaper goods when there is increasing prices. Meanwhile, the income effect arises from the decrease in the consumer's real income when the price of a good increases, creating a condition of reduced purchasing power,

thus resulting in the purchase of lesser quantities of the good and of various products (SÁ JÚNIOR, 1994).

3.3.2. 'Juggling' between the main domestic costs

Energy and food are part of different markets, with their own characteristics and particularities. In general, while part of the electrical energy production chain consists of a natural monopoly (transmission and distribution), with high entry barriers and very controlled (FIORAVANTE, 2022; GUTIERREZ, 2022), the food market is free entry (MATTOS; BIANCHI; TOIGO, 2020).

The energy market is widely considered to be opaque, being quite inflexible, given the few possibilities of finding substitutes or other equivalent options. In particular, the opacity of the energy market arises from its complex and multifaceted nature. Energy production, distribution, and pricing mechanisms involve intricate systems and instruments that can be challenging for consumers to fully understand (GUTIERREZ, 2022).

Moreover, the energy market's inflexibility stems from its reliance on a largely centralised and capital-intensive infrastructure. These investments often have long payback periods and are difficult to adjust quickly in response to changing demand or market conditions. The lack of readily available substitutes or equivalent options further restricts the flexibility of the energy market. Unlike many consumer goods where consumers can easily switch between brands or products, energy services are standardised and homogeneous, with limited alternatives (ANDERSON; BRANCA; FINNEY, 2012).

Regulatory frameworks and market structures can also contribute to the perceived inflexibility of the energy market. Regulatory barriers, such as licensing requirements and permitting processes, can impede the entry of new market players and inhibit competition (FIORAVANTE, 2022). Long-term contracts and obligations are common in energy procurement agreements, and limit consumers' ability to adapt to changing market conditions or seek alternative suppliers (GUTIERREZ, 2022). These characteristics contribute to explaining the price elasticity of electricity. Electric energy is an inelastic good in both the short and long term (CASARIN; DELFINO, 2011).

In the case of food, the situation is quite different. Due to the different opportunities found in the market the food market has a relatively high flexibility. For food, there are opportunities to look for bargains and lower prices, even at the cost of lower quality food (ANDERSON; BRANCA; FINNEY, 2012).

One key factor contributing to the flexibility of the food market is its inherent diversity. Food products come in countless varieties, brands, and quality levels, allowing consumers to tailor their purchases to their preferences, needs, and budget constraints. This diversity opens up numerous avenues for consumers to explore alternatives enabling them to find bargains and lower prices, even if it means compromising their food security (IBGE, 2021; MATTOS; BIANCHI; TOIGO, 2020).

Given all stated above and the fact that electricity plays an important role in various daily activities (HERNÁNDEZ, 2016) being an essential commodity with little room for change (ANDERSON; BRANCA; FINNEY, 2012), during periods of limited resources or increasing prices, families develop strategies to manage their use of electricity. These strategies frequently involve cutting back on other expenses, including those related to essential goods such as food (ANDERSON; BRANCA; FINNEY, 2012; GIBBONS; SINGLER, 2008). In order to deal with limited resources in a period of increasing energy expenditure, families adopt 'juggling' with their main household costs to fit the financial resources available for their needs. Confronted with this trade-off, households frequently find themselves needing to reduce spending in various areas, such as social activities, clothing, and groceries (GIBBONS; SINGLER, 2008).

The procedure typically begins with eliminating discretionary spending or "indulgences", such as social outings and vacations, followed by reductions in spending on flexible budget categories like food (GIBBONS; SINGLER, 2008). Given that food expenses are perceived as more adaptable and responsive to daily fluctuations, they are typically reduced during times of increased spending on electricity (ANDERSON; BRANCA; FINNEY, 2012).

But, the reductions on food spending, does not necessarily mean reduce of food consumption. Families begin to reduce the variety and quality of food purchased, looking for lower prices, opting for canned food instead of fresh food and reducing meat consumption (ANDERSON; BRANCA; FINNEY, 2012). With these restrictions for the food spending, there is a tendency to increase the chance of families finding themselves in a situation of food insecurity (MATTOS; BIANCHI; TOIGO, 2020).

3.4. Scales of food security and insecurity

The concept of food security is broad, encompassing a multitude of dimensions and various analytical possibilities. Consequently, a wide range of indicators can be employed to assess it. One commonly utilized method in national surveys involves the use of psychometric scales to measure family access to food, such as the Brazilian Food Insecurity Scale (EBIA) (MATTOS; BIANCHI; TOIGO, 2020).

The advantage of employing psychometric scales is their ability to directly measure the phenomenon based on the experiences of food insecurity perceived by affected individuals (IBGE, 2021). These scales capture not only the challenges in accessing food but also the psychosocial dimensions of food insecurity, with households as the unit of analysis. Measurement scales like EBIA provide valuable information for the management of social policies and programs, enabling the identification and quantification of at-risk social groups, as well as their determinants and consequences (MATTOS; BIANCHI; TOIGO, 2020).

Table 8 - Description of degrees of food security and insecurity

Degree	
Food security (or not food insecurity)	The family/household has regular and permanent access to quality food, in sufficient quantity, without compromising access to other essential needs.
Mild food insecurity	Concern or uncertainty regarding access to food in the future; inadequate food quality resulting from strategies that aim not to compromise the quantity of food.
Moderate food insecurity	Quantitative reduction of food among adults and/or disruption in eating patterns resulting from lack of food among adults.
Serious food insecurity	Quantitative reduction of food also among children, that is, disruption in eating patterns resulting from the lack of food among all residents, including children. In this situation, hunger becomes an experience lived at home.

Source: Adapted from Analysis of food security in Brazil Measuring food and nutritional security (IBGE, 2021).

The idea of the scale of food insecurity is centered on the capacity and limitation of access to food by families. However, to classify the insecurity of a household, there is a score (Table 9).

Table 9 - Household Food Insecurity Score

Score	Household thresholds	
	With children under 18 years old	No children under 18 years old
Food security (or not food insecurity)	0	0
Mild food insecurity	1-5	1-3
Moderates food insecurity	6-9	4-5
Serious food insecurity	10-14	6-8

Source: Adapted from Analysis of food security in Brazil Measuring food and nutritional security (IBGE, 2021).

The EBIA analysis uses a final score, calculated from the sum of affirmative answers to 14 questions. This score is compared to the cut-off points listed in Table 9, which align with the theoretical constructs of food security presented in Table 8. In addition, the sum of these responses generates an overall score that categorizes the household into one of four categories: food security, mild food insecurity, moderate food insecurity, or serious food insecurity. The cutoff points for each category also vary depending on whether there are residents under or over 18 years old (IBGE, 2021).

3.5. Methodology

3.5.1. Identification strategy

The relationship between energy and nutritional status (specifically, electrical energy and food insecurity) can be established through three channels: i) Causality – higher expenditures on electrical energy lead to a reduction in food expenses (ANDERSON; BRANCA; FINNEY, 2012); ii) Reverse causality – households experiencing food insecurity tend to have a lower income level, with the electricity bill accounting for a relatively high portion of their budget (BEZERRA et al., 2022); iii) Lack of causality – the relationship between electrical energy expenses and food insecurity may be attributed to other potential sources affecting both variables (CHURCHILL; SMITH, 2021).

It is necessary to consider the asymmetric effects of explanatory variables concerning different categories of food insecurity (MATTOS; BIANCHI; TOIGO, 2020), based on the findings from the literature and the reference. This characteristic leads to the use of ordered probit as an alternative.

The ideal experiment would be one in which the level of electricity's participation in the family budget is assigned entirely randomly, while maintaining all other characteristics. Thus, it would be possible to observe the effect of higher electricity expenses on the prevalence of food insecurity without the result being subject to selection biases (ANGRIST; PISCHKE, 2009).

However, it is known that such an experiment is unfeasible, as it cannot be assumed with total confidence that the control variables used are not influenced by the dependent variable studied (food insecurity). Nevertheless, international studies have sought plausible alternatives for causal identification, using instrumental variables such as the price of electricity (CHURCHILL; SMITH, 2021).

3.5.2. Logistic models

Probability models with categorical dependent variables can be categorized into three main types: binary, multinomial, and categorical ordinal. The first type is the logistic probability model, widely applied to dependent variables in the (0,1) format. Multinomial models are employed for dependent variables with more than two categories, which, although distinct, lack a hierarchical order. The third type is utilized in situations with more than two different categories, and there is an observable hierarchical order.

To address the aforementioned issue, binary and ordinal model classes are considered. Starting from the general expression of logistic probability models:

$$P(Y_i > j) = g(X\beta_j) = \frac{\exp(\alpha_j + X_i\beta_j)}{1 + \exp(\alpha_j + X_i\beta_j)}, j = 1, 2, \dots, M - 1 \quad (7)$$

where M represents the number of categories of the dependent variable, α and β are the estimated coefficients, and X is the vector of explanatory variables (WILLIAMS, 2006). Based on the above, it can be determined that the probabilities that Y will take on each of the values $1, \dots, M$.

$$P(Y_i = 1) = 1 - g(X_i\beta_j) \quad (8)$$

$$P(Y_i = j) = g(X_i\beta_{j-1}) - g(X_i\beta_j), j = 2, \dots, M - 1 \quad (9)$$

$$P(Y_i = M) = g(X_i\beta_{M-1}) \quad (10)$$

The dependent variable of binary logistic regression combines food security and mild food insecurity into one category, in contrast to moderate and serious food insecurity. In this case, equation (7) represents only two categories ($M = 2$). An ordered logistic model is presented as the second model, with equation (11) undergoing a slight modification.

$$P(Y_i > j) = g(X\beta) = \frac{\exp(\alpha_j + X_i\beta)}{1 + \exp(\alpha_j + X_i\beta)}, j = 1, 2, \dots, M - 1 \quad (11)$$

In this equation, the four categories ($M = 4$) are represented: food security, mild food insecurity, moderate, and serious food insecurity. The β coefficients do not depend on the category of the explained variable Y ; there is only one angular coefficient for each explanatory variable in the estimated equation, and the probabilities for each category vary only depending on the level coefficients (α_j). This implies the need to ensure the hypothesis of parallelism to maintain this equality of coefficients.

The Brant test formulates hypotheses of parallelism (MATTOS; BIANCHI; TOIGO, 2020). This test is commonly employed to evaluate whether the observed

deviations from what the proportional odds model predicts exceed what could be attributed solely to chance (WILLIAMS, 2006).

3.5.3. Instrumental Variable (IV)

By employing various models, the aim is to initiate a discussion on how different methods contribute to the complexity of food insecurity, providing diverse perspectives on the phenomenon. Furthermore, a more comprehensive discussion of the results based on the available literature is sought.

Electrical energy expense variable is likely to be endogenous, meaning it is influenced by factors within the system being studied rather than external factors. One potential source of endogeneity is omitted variable bias, which occurs when relevant variables are left out of the analysis, leading to biased estimates. In the context of energy vulnerability, omitting variables such as housing quality, income variability, or regional differences in energy prices could bias the results. This bias could manifest as either overestimation (upward bias) or underestimation (downward bias) of the coefficient distorting true impact.

The measurement error in estimating energy vulnerability can introduce endogeneity bias. This occurs when households inaccurately report their expenditure on household energy, which is a common issue due to the complexity of energy bills and variations in consumption patterns. Simultaneity bias is another source of endogeneity. This bias arises when the relationship is bidirectional, meaning they mutually influence each other.

If the measure of energy vulnerability is endogenous, the consistency of the estimated coefficients is not guaranteed by the regression of the logistic models. Therefore, a naive estimation of equations (7) and (8) may yield inconsistent coefficients (β 's) due to the possibility of individual and unobservable specific effects. This possibility necessitates the use of the Instrumental Variables (IV) method as a means to address the potential problem of endogeneity.

The IV method is applied in two stages to estimate the relationship between food insecurity⁷ and the share of electricity expenditure on family income. Control

⁷ Binary model, combining food security and mild food insecurity into one category, as opposed to moderate and serious food insecurity, representing two categories ($M = 2$).

function estimators first estimate the model of endogenous regressors as a function of instruments, akin to the 'first stage' of two-stage least squares (2SLS), and subsequently utilize the errors from this model as an additional regressor in the primary model. This methodological approach exhibits a broader scope than maximum likelihood estimation, as the first stage function can encompass semiparametric or nonparametric specifications, and the joint distribution of errors need not be fully parameterized (LEWBEL; DONG; YANG, 2012). Regress the continuous endogenous variable X (share of electricity expenditure on family income) on the instrument Z (price of electricity):

$$Y_i = \alpha + Z_i' \pi + n_i \quad (12)$$

and then use fitted values in a logit second stage to estimate.

$$\Pr(Y_i = 1 | \hat{X}_i) = \Pr(\beta \hat{X}_i + \varepsilon_i > 0) \quad (13)$$

The standard errors may be inaccurate because \hat{X}_i is not a random variable but an estimated quantity. To mitigate this concern, a viable approach involves simultaneously bootstrapping both the first and second stages (LEWBEL; DONG; YANG, 2012).

The instrument utilizes the energy price calculated for each household, which is based on the total amount paid for electricity consumed. This variable have been previously reported in studies investigating the relationship between energy poverty and health or well-being (CHURCHILL; SMYTH; FARRELL, 2020; CHURCHILL; SMITH, 2021). The rationale is that energy prices are highly correlated with a situation of energy vulnerability, given that energy prices determine the level of energy expenditure (AZPITARTE; JOHNSON; SULLIVAN, 2015). Assuming that individuals are primarily concerned about fluctuations in energy prices because it determines their energy expenditure, any changes in energy prices will likely influence food insecurity solely through electrical energy expenditure.

For the Instrumental Variables (IV) method to be appropriately applied, it is essential that the instruments be “good,” meaning they must be both relevant and valid. This means that the instruments must be correlated with the endogenous regressors and uncorrelated with the regression disturbance. To evaluate these conditions, the weak identification test (CRAGG; DONALD, 1993; KLEIBERGEN; PAAP, 2006), and the Stock-Yogo test (STOCK; YOGO, 2005) are utilized.

3.5.4. Variables and database

Consumer Expenditure Surveys (POF) was the selected database to this study. This is the only available database with an extensive data on household expenditures, including energy and food expenses, and other important household and individual characteristics data, as such the food insecurity levels. For this work, households with zero family income and zero energy expenses are excluded. The sample is narrowed down to 48,925 observations, weighted by expansion factors representing 66,790,258 households and approximately 200,370,774 people.

The POF is a household survey conducted through sampling, aimed primarily at gathering information on budget structures, including expenditures on products and services as well as income, as well as nutritional status and living conditions of Brazilian families. The POF provides insights into the products purchased and services utilized by families over the course of a year, encompassing both urban and rural areas across all federative units of Brazil.

This information gathered from the POF is instrumental in studying changes in family consumption patterns and updating weighting structures essential for the calculation of Consumer Price Indexes. Additionally, the survey's results facilitate a wide range of studies and planning activities related to family expenditures by income level, demographic and socioeconomic factors, anthropometric measurements, quantity of food purchased for home consumption, income distribution, concentration, and inequality, as well as families' perceptions of their living conditions and personal food consumption.

Furthermore, in the POF there are different levels of food insecurity organized into categories. Below, the distribution of food insecurity levels for the sample considered (IBGE, 2021).

Table 10 - Distribution of household food insecurity levels in the sample – considering expansion factors – Brazil, 2017-18

Insecurity levels	Absolute Frequency	%
1 – Security	41,409,959	61.57
2 – Mild insecurity	16,697,564	24.95
3 – Moderate insecurity	6,011,123	8.73
4 – Serious insecurity	3,339,512	4.78
Total	66,790,258	100

Source: Own preparation with data from POF 2017-18.

As compared to previous years there is an increase in food insecurity. In 2013, the distribution of levels of moderate and serious household food insecurity were 2.9 and 4.3 respectively (MATTOS; BIANCHI; TOIGO, 2020). While for 2017-18 these values are respectively 8.73 and 4.78.

The proportion of electricity expenses within the budgets of the most economically disadvantaged families will serve as a benchmark, delineating a state of energy poverty characterized by a substantial allocation of income toward electricity costs. Percentage of energy expenditure electricity exceeds the average percentage of household income spent by households earning up to two minimum wages, corresponding to about 7% (Figure 5).

Energy poverty and energy vulnerability are related concepts. However, while energy poverty refers to inadequate and unreliable access to energy, energy vulnerability pertains more to exposure to risks and the capacity to confront and adapt to those risks (BOUZAROVSKI, 2018). The energy vulnerability encompasses not only the risk of falling into energy poverty but also issues such as susceptibility to fluctuations in energy prices. In developing countries, energy poverty is often defined through a combination of dimensional restrictions (BEZERRA et al., 2022). In contrast, energy vulnerability can often be identified through a single deprivation, given that it is more about susceptibility to energy-related risks and problems (BOUZAROVSKI, 2018).

Other socioeconomic variables contribute to elucidating the situation of families concerning food insecurity. Regarding personal variables, the individual identified as the "reference person" represents the household's classification.

Table 11 - Sociodemographic variables

Variable	Mean	Standard Deviation
Age	50.15	0.162
Number of Rooms	6.07	0.023
Education (%)		
Incomplete Fundamental	38.74	0.005
Incomplete Medium	13.38	0.003
Upper Middle	47.88	0.006
Gender (%)		
Feminine	45.06	0.005
Masculine	54.94	0.005
Race (%)		
Not White	52.93	0.004
White	47.07	0.004
Household Index ⁸ (%)	46.06	0.131
Poor Quality Housing	14.20	0.003
No Poor Quality Housing	85.80	0.003
Sufficient Income ⁹ (%)		
Difficulty	33.03	0.004
Ease	66.97	0.004
Region and Area (%)		
Midwest	7.67	0.002
Southeast	44.86	0.004
South	16.18	0.003
North	6.47	0.001
North East	24.81	0.003
Urban	87.86	0.003
Rural	12.14	0.003
Midwest Urban	7.15	0.002
North Urban	5.37	0.001
North East Urban	18.79	0.002
South Urban	14.14	0.003
Southeast Urban	42.41	0.004
Midwest Rural	0.52	0.000
North Rural	1.11	0.001
North East Rural	6.02	0.002
South Rural	2.05	0.001
Southeast Rural	24.81	0.001

Source: Own preparation with data from POF 2017-18.

⁸ Combination of the condition of the external walls, roof condition, lighting from public network and piped water.

⁹ It assesses the perception of the family's total income, focusing on their ability to manage until the end of the month. The responses range from: 1 – A lot of difficulty, 2 – Difficulty, 3 – Some difficulty, 4 – Some ease, 5 – Ease, to 6 – A lot of ease.

This set of variables is relatively common in the literature on the subject, constituting the explanatory variables of the estimated models. It is observed that the majority of households are headed by male, non-white individuals with at least a high school education. Additionally, the majority of households are located in the Southeast region and urban areas.

3.6. Results

3.6.1. Determinants of food insecurity

The initial estimated model adopts the conventional logit approach, employing robust standard errors and acknowledging the complex nature of the sampling process. It estimates the probability of households experiencing either food security or mild food insecurity, contrasting with those facing moderate or serious food insecurity. The findings of this model are detailed in Table 12.

In column (1), the model exclusively includes the variable representing the significant proportion of electricity expenses within family income, reflective of the expenditure pattern among lower-income families. Column (2) incorporates additional socioeconomic variables into the model, while column (3) supplements these variables with region-specific dummies.

Table 12 - Logit model estimates for food insecurity in Brazilian households

Variable	(1)	(2)	(3)
EV	0.844*** (0.0532)	0.390*** (0.077)	0.389*** (0.078)
Incomp. medium		-0.383*** (0.092)	-0.351*** (0.093)
Upper Middle		-0.537*** (0.075)	-0.531*** (0.077)
Age		-0.008*** (0.002)	-0.007*** (0.002)
Gender		0.354*** (0.059)	0.332*** (0.060)
Race		0.470*** (0.066)	0.249*** (0.069)
Household Index		0.274*** (0.070)	0.128* (0.075)
Number of Rooms		-0.223*** (0.019)	-0.231*** (0.019)
Sufficient Income		1.869*** (0.065)	1.835*** (0.067)
Midwest Urban			-0.219** (0.105)
North Urban			0.119 (0.104)
South Urban			-0.911*** (0.123)
Southeast Urban			-0.606*** (0.084)
Midwest Rural			-0.359** (0.164)
North Rural			0.107 (0.177)
South Rural			-1.270*** (0.182)
Southeast Rural			-0.832*** (0.187)
Prob > F	0.000	0.000	0.000

Source: Own preparation with data from POF 2017-18.

Note: Robust standard errors in parentheses

*** significant at 1%; ** significant at 5%; * significant at 10%.

The overall significance of the model is highly pronounced (Prob > F = 0.000) across all variables (1), (2), and (3). This underscores that the collective influence of the independent variables significantly impacts food insecurity.

The findings consistently demonstrate a positive correlation between energy poverty and food insecurity across all models, even with the inclusion of new variables. This suggests that households facing significant financial strain due to electricity bills tend to experience moderate or serious food insecurity.

Regarding other variables outlined in columns (2) and (3), the results generally align with expectations. A higher educational attainment among household heads correlates with decreased likelihood of experiencing food insecurity. This trend is observable when comparing household heads with incomplete primary education to those with incomplete secondary education, completed secondary education, or completed higher education. Households with non-white and/or female heads are more prone to food insecurity. Additionally, advancing age of the household reference individual correlates with lower probabilities of food insecurity within the household. These results align with the findings of Hoffmann (2013), and Mattos, Bianchi and Toigo (2020).

Incorporating regional dummies in column (3) highlights heightened vulnerability among households in the northeast and north regions of Brazil. Compared to other regions, households in these areas are more predisposed to food insecurity, with the northeast serving as the reference region. Notably, the northern region exhibits a positive effect on food insecurity, contrasting with the negative effects observed in other regions.

The introduction of new categories serves to enhance the comprehension of food insecurity determinants, expanding the framework to encompass four distinct levels: food security, mild, moderate, and serious food insecurity. As a result, the model shifts away from its binary structure, necessitating the adoption of an ordered model.

Employing an ordered model mandates adherence to the parallelism hypothesis. The literature advocates for the utilization of tests such as the Brand test to ensure model validity (WILLIAMS, 2006).

Table 13 - Brant test for parallel regression assumption

Variable	Chi-Square	Prob > Chi-Square	DF
All	185.48	0.000	34
EV	2.15	0.342	2
Incomp. medium	0.96	0.620	2
Upper Middle	0.93	0.629	2
Age	79.08	0.000	2
Gender	0.80	0.670	2
Race	3.21	0.200	2
Household Index	0.38	0.826	2
Number of Rooms	44.35	0.000	2
Sufficient Income	21.96	0.000	2
Midwest Urban	10.45	0.005	2
North Urban	3.71	0.157	2
South Urban	12.65	0.002	2
Southeast Urban	2.44	0.295	2
Midwest Rural	3.09	0.214	2
North Rural	2.07	0.356	2
South Rural	1.98	0.372	2
Southeast Rural	0.72	0.699	2

Source: Own preparation with data from POF 2017-18.

The Chi-square statistic of 185.48 indicates evidence that the parallel regression assumption has been violated, with a very low p-value of 0.000. This suggests asymmetric effects among different variables concerning food insecurity categories. Consequently due to this, there is a potential for distortion in the interpretation of coefficients within the ordered logistic regression model, leading to estimates that may not accurately reflect the true relationship between independent variables and food insecurity.

Given the violation of the proportional probabilities assumption, it becomes imperative to explore alternative models, such as the generalized ordered logistic regression model (GOLM). Unlike traditional models, GOLM offers flexibility in accommodating deviations from the assumption of proportional probabilities, thereby providing a more nuanced understanding of the relationships between variables and food insecurity categories.

Table 14 - Generalized Ordered Logistic Regression Model (GOLM) estimates for food insecurity in Brazilian households

Variables	Mild insecurity		Moderate insecurity		Serious insecurity	
	Coef.	Odds ratio	Coef.	Odds ratio	Coef.	Odds ratio
EV	0.359*** (0.064)	1.431*** (0.092)	0.364*** (0.078)	1.439*** (0.112)	0.392*** (0.120)	1.479*** (0.178)
Incomp. Medium	-0.237*** (0.067)	0.789*** (0.053)	-0.347*** (0.093)	0.707*** (0.066)	-0.398*** (0.133)	0.672*** (0.089)
Upper Middle	-0.553*** (0.053)	0.575*** 0.030	-0.558*** (0.075)	0.572*** (0.043)	-0.559*** (0.106)	0.572*** (0.060)
Age	-0.021*** (0.001)	0.979*** (0.000)	-0.007*** (0.002)	0.993*** (0.002)	-0.007*** (0.003)	0.993*** (0.003)
Gender	0.276** (0.044)	1.318*** (0.057)	0.312*** (0.059)	1.367*** (0.080)	0.293*** (0.095)	1.339*** (0.128)
Race	0.324*** (0.049)	1.383*** (0.068)	0.255*** (0.068)	1.290*** (0.088)	0.332*** (0.121)	1.394*** (0.168)
Household Index	0.175*** (0.063)	1.192*** (0.049)	0.116 (0.073)	1.123 (0.082)	0.015 (0.112)	1.015 (0.114)
Number Rooms	-0.149*** (0.013)	0.862*** (0.011)	-0.233*** (0.019)	0.792*** (0.015)	-0.264*** (0.029)	0.768*** (0.023)
Sufficient Income	1.614*** (0.044)	5.025*** (0.223)	1.821*** (0.066)	6.177*** (0.409)	1.974*** (0.106)	7.198*** (0.761)
Midwest Urban	-0.319*** (0.082)	0.727*** (0.059)	-0.243*** (0.101)	0.784*** (0.079)	-0.016 (0.133)	0.984 (0.131)
North Urban	0.253*** (0.084)	1.288*** (0.108)	0.135 (0.100)	1.144 (0.115)	0.244 (0.149)	1.276 (0.189)
South Urban	-0.945*** (0.078)	0.389*** (0.030)	-0.926*** (0.121)	0.396*** (0.048)	-0.517*** (0.188)	0.597*** (0.112)
Southeast Urban	-0.483*** (0.063)	0.617*** (0.039)	-0.602*** (0.084)	0.548** (0.046)	-0.498** (0.142)	0.608*** (0.086)
Midwest Rural	-0.557*** (0.141)	0.573*** (0.081)	-0.334** (0.164)	0.716** (0.117)	-0.289 (0.276)	0.749 (0.207)
North Rural	0.244* (0.133)	1.277* (0.169)	0.067 (0.161)	1.069 (0.172)	0.343 (0.242)	1.409 (0.341)
South Rural	-1.221*** (0.119)	0.295*** (0.035)	-1.309*** (0.182)	0.269*** (0.049)	-0.957*** (0.280)	0.384*** (0.108)
Southeast Rural	-0.706*** (0.129)	0.494*** (0.063)	-0.831*** (0.189)	0.436*** (0.083)	-0.580** (0.301)	0.559** (0.168)

Source: Own preparation with data from POF 2017-18.

Note: Robust standard errors in parentheses

*** significant at 1%, ** significant at 5%, * significant at 10%.

Energy-vulnerable households face a heightened risk of food insecurity at all levels. These households are 43.1% more likely to transition from food insecurity to mild, moderate, or serious food insecurity compared to their non-vulnerable counterparts. Additionally, they have a 43.9% increased likelihood of progressing to moderate or serious food insecurity, and a 47.9% chance of reaching serious food insecurity.

Elevating educational attainment emerges as a pivotal factor in mitigating the incidence of food insecurity. Households led by individuals with such educational backgrounds experience a reduction of approximately 40% in the likelihood of transitioning from food security to serious food insecurity, compared to those headed by individuals with incomplete elementary school education.

In terms of gender and race dynamics, households headed by women and/or non-white individuals exhibit a heightened likelihood of transitioning from food security to more severe levels of food insecurity. Conversely, the impact of age on reducing the likelihood of transitioning from food security to any level of food insecurity is comparatively modest.

In relation to having enough income to get through the month, families that experience some level of difficulty have a greater chance of transitioning to some level of food insecurity. Moreover, there is a negative relationship between the number of rooms in the home and the likelihood of food insecurity.

Households residing in the North and Northeast regions manifest a greater propensity for food insecurity. Particularly dire is the situation in the North region, which surpasses other regions in its likelihood of transitioning from food security to any level of food insecurity, notably serious food insecurity.

3.6.2. Establishing causality between energy vulnerability and food insecurity

The analysis of determinants indicates a positive and significant impact of energy vulnerability on household food insecurity. However, the current findings do not consider potential endogeneity between the variables, as there is a lack of exogenous variation in energy vulnerability. To overcome this limitation, the instrumental variables method is employed to mitigate endogeneity bias, thereby enabling a more accurate estimation of the true causal effect.

As outlined in the methodology section, the price of electricity is the chosen instrument, and the model estimates both the first and second stages. In the first stage, the dependent variable is the proportion of the energy bill in the family budget, while in the second stage, the focus shifts to food insecurity as the dependent variable. This is presented in the Table 15 below.

Table 15 - Instrumental Variable model estimates

Variable	Share of energy bill in income	Food insecurity
	First stage	Second stage
Electricity price	178.566*** (17.497)	-
Electricity price estimated	-	8.464*** (1.318)
Incomp. Medium	0.002* (0.001)	-0.345*** (0.093)
Upper Middle	-0.005*** (0.001)	-0.449*** (0.080)
Age	0.001*** (0.000)	-0.005** (0.002)
Gender	0.003*** (0.001)	0.298*** (0.061)
Race	-0.004** (0.001)	0.227*** (0.070)
Household Index	-0.002 (0.001)	0.109 (0.077)
Number of Rooms	-0.001*** (0.000)	-0.216*** (0.019)
Sufficient Income	0.007*** (0.001)	1.780*** (0.067)
Midwest Urban	0.009*** (0.001)	-0.207** (0.104)
North Urban	0.029*** (0.002)	0.003 (0.108)
South Urban	0.011*** (0.002)	-0.932*** (0.126)
Southeast Urban	0.011*** (0.001)	0.604*** (0.084)
Midwest Rural	0.009*** (0.002)	-0.357** (0.166)
North Rural	-0.004 (0.003)	0.123 (0.176)
South Rural	0.008*** (0.002)	-1.227** (0.183)
Southeast Rural	0.013*** (0.002)	-0.837** (0.187)

Weak identification test (Cragg–Donald Wald F statistic)	961.609
Stock–Yogo weak ID test critical values (10% max IV size)	52.77
Adjusted Wald test	41.25
Prob > F	0.000

Source: Own preparation with data from POF 2017-18.

Note: Robust standard errors in parentheses

*** significant at 1%; ** significant at 5%, * significant at 10%.

The weak identification test (Cragg-Donald Wald F statistic), and adjusted Wald test statistic providing robust evidence that the instrument significantly influences the predicted energy price for food insecurity. The F-statistic is much higher than the Stock-Yogo critical value of 52.77, indicating the instrument is not weak. In column 2, the estimated electricity prices of 8.464 show a positive and significant relationship, suggesting that higher electricity prices are generally associated with increased food insecurity.

There is no alteration to the other variables in the model, which largely maintain their original significance and signs. This remains consistent for families whose reference person is a woman and/or non-white, as they have a greater chance of experiencing food insecurity. Similarly, families in which the reference person has higher education and/or is older maintain a negative relationship with food insecurity.

It is essential to recognize that the instrumented variable represents an estimated variable rather than a random one. To address this issue, bootstrapping is used for correction, as demonstrated in Table 16. Bootstrapping estimates standard errors and confidence intervals for estimates derived from intricate models, thereby ensuring the reliability of the analysis. Through the correction, it becomes possible to interpret the effect of the instrumentalized variable as closer to a true causal relationship.

Table 16 - Bootstrapping model estimates

Variable	Bootstrapping
Electricity price Random	9.131*** (1.155)
Incomplete Medium	-0.252*** (0.062)
Upper Middle	-0.483*** (0.049)
Age	-0.006** (0.002)
Gender	0.317*** (0.041)
Race	-0.223*** (0.042)
Household Index	0.109** (0.048)
Number of Rooms	-0.215*** (0.016)
Sufficient Income	1.695*** (0.051)
Midwest Urban	-0.234*** (0.068)
North Urban	0.041 (0.069)
South Urban	-0.949*** (0.103)
Southeast Urban	-0.589*** (0.060)
Midwest Rural	-0.398*** (0.147)
North Rural	-0.035 (0.104)
South Rural	-1.178*** (0.177)
Southeast Rural	-0.798*** (0.134)

Source: Own preparation with data from POF 2017-18.

Note: Robust standard errors in parentheses

*** significant at 1%, ** significant at 5%.

The results too indicate that the price of electricity is responsible for the increase in food insecurity among families. The positive and significant effect of 9.131 demonstrates that as the price rises, the likelihood of a family experiencing moderate or serious food insecurity also increases. This finding supports the theory that certain families may even forgo food to maintain access to electricity. These results align with the findings of Anderson, White, and Finney (2012), and Fry, Farrell and Temple (2023)

which increases in the price of energy generate a reduction in food consumption by low-income families.

3.7. Discussion

The literature suggests that families vulnerable to energy-related challenges face a spectrum of issues, including food insecurity, stemming from the need to make difficult choices to sustain energy access (NORD; KANTOR, 2006; BASOLE; BASU, 2015; HERNÁNDEZ, 2016; FRY; FARRELL; TEMPLE, 2023). The results confirm this trend. A positive relationship between energy vulnerability and moderate to serious food insecurity is observed using the simple logit model. As additional variables were introduced, the relationship remained consistently positive and significant.

As food insecurity can be arranged into four ordinal categories (food security, mild, moderate and serious insecurity), the ordered model was adopted in order to understand the effect of energy vulnerability on the change in the state of food security/insecurity of families. The model was adopted based on the results of the Brant test, which confirmed the existence of asymmetric effects of the explanatory variables in relation to the different categories of food insecurity.

The results of the ordered model suggest that families whose budget is significantly compromised by spending on electricity tend to be more food insecure. These families have around a 43.1% chance of moving from a situation of food security to mild, moderate, or serious food insecurity; a 43.9% chance of moving to moderate or serious food insecurity; and a 47.9% chance of moving to serious food insecurity. The other variables produced the expected results and are consistent with the findings of Hoffmann (2013), and Mattos, Bianchi and Toigo (2020), which suggest that having a male and/or an educated individual as a reference person also enhances the probability of having favorable food conditions, similar to being white.

These findings underscore a direct correlation between energy vulnerability and levels food insecurity. Notably, this association amplifies with the severity of food insecurity levels, indicating that energy vulnerability not only elevates the probability of food insecurity but also intensifies its severity. This is observed when the highest value refers to a shift towards serious food insecurity.

Although the results continue to indicate a positive relationship between energy vulnerability and food insecurity, confirming the findings of Anderson, White, and Finney (2012) and Fry, Farrell, and Temple (2023), addressing potential endogeneity was necessary. Due to this possible problem, the 2SLS-IV method is applied, with energy price calculated for each household as the valid IV (CHURCHILL; SMITH, 2021).

The results of this model indicate a positive and significant effect between the instrumented variable and food insecurity. The estimated energy price has an effect of 8.464 on increasing food insecurity. In the bootstrapping estimates, through which the randomized electricity price was obtained, the effect of the electricity price remains positive and significant, reaching 9.131.

Hence, the results suggest a positive causal relationship between energy vulnerability and food insecurity. This phenomenon can be attributed to families' prioritization of maintaining energy access, even amidst periods of cost escalation, often at the expense of food quality. In contrast to energy costs, which are less negotiable, the food market offers greater flexibility, providing more opportunities for negotiation and bargains.

The greater flexibility does not necessarily result in increased quantity or quality of food and may even have the opposite effect. In situations of energy vulnerability, families might allocate fewer resources to food to maintain energy access (ANDERSON; WHITE; FINNEY, 2012; FRY; FARRELL; TEMPLE, 2023). This shift in food choices can reduce both the quality and quantity of food, leaving families more exposed to high levels of food insecurity.

Brazil's energy vulnerability is predominantly driven by economic factors, particularly evident in the successive rises in residential electricity costs since 2014. These escalations are attributed to a combination of crises within the energy sector and structural barriers that hinder competition and innovation (FIORAVANTE, 2022; GUTIERREZ, 2022). Unlike countries where energy vulnerability may be primarily linked to the seasonal variations in extreme temperatures, Brazil's problem is more structural.

This economic dominance in energy vulnerability stems from various sources. The concentration of power within the energy sector leads to limited competition, reducing incentives for efficiency and affordability (GUTIERREZ, 2022). Economic downturns or crises can directly impact households' ability to afford energy and fuel,

exacerbating their vulnerability. Moreover, structural inequalities within the Brazilian society contribute to disparities in energy access and affordability, further amplifying the economic dimension of vulnerability.

The obtained results indicate that energy vulnerability contributes to the increase in food insecurity among Brazilian families. This effect persists across different estimations, even after considering and controlling for potential endogeneity. The mechanism explaining the positive effect on food insecurity involves making difficult choices and tradeoffs between access to electricity and food (NORD; KANTOR, 2006; HERNÁNDEZ, 2016; FRY; FARRELL; TEMPLE, 2023), coupled with strategies aimed at maintaining energy access (ANDERSON; WHITE; FINNEY, 2012).

3.8. Conclusion

Brazil continues to grapple with a significant number of families vulnerable to energy challenges. Unlike in other countries, energy poverty in Brazil is more closely tied to economic factors and the characteristics of the country's electricity sector rather than seasonal variations in climate.

The results highlight a causal relationship, wherein energy vulnerability emerges as a significant factor contributing to the likelihood of families experiencing food insecurity. Families vulnerable to energy constraints are more likely to face a trade-off between allocating resources to electricity or food, thereby increasing their susceptibility to food insecurity. A limitation of the study is the restricted time frame, which limits the ability to compare the effects of energy vulnerability on food insecurity across different periods.

These findings offer insights for future analyses aimed at addressing energy vulnerability in Brazil effectively. One potential avenue for intervention involves improvements in the electricity sector, such as reducing market concentration and barriers to entry, thereby fostering greater competition.

As a suggestion for future research, an in-depth analysis of potential enhancements to the electricity sector could be undertaken, considering its complexity and unique characteristics. Additionally, given that the impacts of energy vulnerability extend beyond food insecurity, exploring its effects on other aspects such as health status and overall well-being could provide further understanding of the issue.

4. Conclusion

The two essays presented in this thesis investigate critical questions regarding energy poverty in Brazil. Collectively, the essays aim to identify the number and types of household arrangements most exposed to energy poverty and to examine whether energy vulnerability impacts household food insecurity.

The first essay utilizes the Multidimensional Energy Poverty Index (MEPI) to measure energy poverty across various household contexts. The results indicate that approximately 11.7% of Brazilian households are still in this condition, with a notably high incidence of 30.7% in rural areas. Between 2008-09 and 2017-18, a general improvement can be observed across all regions of Brazil, with the exception of the northern region. Additionally, dimensions related to the use of traditional cooking fuels and the share of energy expenditure in household income have increased in the MEPI. Families with children and single-parent households led by women emerge as the most vulnerable groups in terms of both the incidence and intensity of energy poverty.

The second essay further explores how energy vulnerability can affect food security. The research reveals that vulnerable households, prioritizing the payment of their electricity bills, often reduce expenditures in other essential areas, including food. The logistic and instrumental variables models confirm a significant causal relationship between energy vulnerability and food insecurity. Vulnerable households are 43.1% more likely to experience mild, moderate, or serious food insecurity and 47.9% more likely to progress to a more severe level of food insecurity. These findings underscore the interdependence between energy access and food security, highlighting that inadequate access to energy services can compromise households' ability to maintain adequate and healthy nutrition.

From these essays, it is evident that energy poverty still constitutes a significant problem in Brazil, mainly for vulnerable family arrangements. Even in light of recent advances in energy access, the ongoing crisis in the electricity sector and the rising electricity prices since 2014 are notable factors. This situation is exacerbated by the fact that energy-vulnerable households are more susceptible to food insecurity.

With families facing challenges in energy accessibility, maintaining access to energy indicate that other expenditures in the family budget are compromised. The substantial share of energy expenses reduces the amount of income available for other necessary expenses. Results demonstrate that households are compromising food

expenditures to ensure continued access to energy. A limitation of this study is the absence of data on physical limitations and comorbidities, as well as the lack of data for other time periods.

Secure access to basic energy services is essential not only for directly addressing energy poverty but also for mitigating food insecurity. The connection between energy vulnerability and food insecurity suggests that families experiencing energy vulnerability are more likely to encounter mild, moderate, or serious food insecurity. In this context, ensuring stability in the energy market by minimizing sector interference is crucial. Public policies focused on enhancing energy efficiency and reducing tariffs can facilitate access to electricity and modern fuels, particularly during periods of high prices. These measures should target the most vulnerable households and be implemented in a manner that avoids significant market distortions.

Building on these insights, future research is expected to assess energy poverty among other vulnerable groups, employing diverse dimensions and indicators. Additionally, the investigation will explore other potential impacts of energy vulnerability in Brazil.

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Appendix

Table 17 - Ordered logistics model estimates for food insecurity in Brazilian households

Variable	Coef.	Odds ratio
Energy vulnerability	0.363*** (0.059)	1.437*** (0.086)
Incomplete medium	-0.278*** (0.062)	0.757*** (0.047)
Upper Middle	-0.552*** (0.050)	0.576*** (0.029)
Age	-0.018*** (0.001)	0.982*** (0.001)
Gender	0.282*** (0.041)	1.326** (0.055)
Race	-0.315*** (0.048)	1.371*** (0.065)
Household Index	0.145*** (0.057)	1.156*** (0.066)
Number of Rooms	-0.167*** (0.013)	0.846** (0.011)
Sufficient Income	-1.660*** (0.042)	5.262*** (0.219)
Midwest Urban	-0.281*** (0.078)	0.755*** (0.059)
North Urban	0.228*** (0.073)	1.256*** (0.092)
South Urban	-0.938*** (0.079)	0.391*** (0.031)
Southeast Urban	-0.503*** (0.061)	0.604*** (0.037)
Midwest Rural	-0.502*** (0.135)	0.606*** (0.082)
North Rural	0.202 (0.126)	1.224 (0.154)
South Rural	-1.217*** (0.116)	0.296*** (0.034)
Southeast Rural	-0.721*** (0.126)	0.486*** (0.061)
/cut1	-0.848 (0.112)	
/cut2	0.863 (0.113)	
/cut3	2.140 (0.117)	

Source: Own preparation with data from POF 2017-18.

Note: Robust standard errors in parentheses

*** significant at 1%, ** significant at 5%, * significant at 10%.