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The relationship between income inequality and energy poverty in the context of sustainable development goals: A micro-instrumental variables estimation in Türkiye

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HIGHLIGHTS

- Energy poverty is negatively related to personal income inequality in Türkiye.
- The relationship differs across income groups.
- The poor suffer the most from the adverse consequences of energy poverty.
- Micro policies should target the most vulnerable first.

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ABSTRACT

Energy poverty has adverse consequences on individuals' lives. It endangers their health, interrupts their education, and may even undermine equality both within and between them. Since income inequality remains a significant problem on the path to achieving sustainable development in Türkiye, identifying its determinants on a micro scale is of great importance. In this regard, this study analysed the relationship of energy poverty to personal income inequality in Türkiye, utilising the TurkStat 2017-2020 income and living conditions survey micro-panel dataset. Instrumental variables estimation was used, and robustness checks were applied to achieve this aim. According to this, energy poverty is negatively related to personal income inequality. To check for heterogeneity, this relationship was re-examined within three income groups. The findings suggested that while energy poverty is positively related to personal income inequality at the bottom of the income distribution, it is negatively related to personal income inequality at the top of the income distribution. This study mainly contributes to the literature by providing the first micro-level evidence on the relationship between income inequality and energy poverty. A combination of targeted social and energy policies is required to tackle both energy poverty and income inequality on the micro scale in Türkiye.

1. Introduction

Income inequality has been a persistent issue for Türkiye, especially since the 1980s (Örnek and Elveren, 2010). According to the most recent data, income inequality in the country was measured at .410 in 2025 (TurkStat Press Release, 2025a). Sachs et al. (2025) also found that the Sustainable Development Goal (SDG) 10 score for Türkiye has stagnated. Tahsin (2024) argues that while absolute poverty is no longer a problem in the country, further improvement is needed to alleviate the issues of income inequality as well as material deprivation and multidimensional poverty, as these issues are strongly related to the other SDGs. The author also discusses that health, education, and employment policies are the keys to achieving (energy) poverty and income inequality reduction goals and realizing sustainable development in

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Türkiye.

At this point, it is noteworthy to mention that energy poverty is a form of both material deprivation and multidimensional poverty. It manifests itself in several ways in Türkiye, namely heating inadequacy, substandard dwelling conditions, and unaffordable electricity, gas, and water bills (Eurostat, 2025a; TurkStat Press Release, 2025b). Sachs et al. (2025) pointed out that the SDG 7 score for the country is unsatisfactory in achieving the goal. In 2025, 27.9% of the population could not heat their dwellings due to inadequate insulation in Türkiye, while 19.6% faced the same problem due to economic constraints (TurkStat Press Release, 2025b; TurkStat Press Release, 2025c). These numbers are relatively high, especially compared to the EUaverage (Eurostat, 2025b), and they show the urgency of tackling these issues properly to improve the individual standard of living and achieve economic and sustainable development in the country.

Türkiye is classified among upper-middle-income countries and, like other countries in this category, is characterised by rapid industrialisation and urbanisation (Göçoğlu and Göksu, 2024). Given the relatively high inflation rates and the economic strain that housing expenses place on individuals/households in the country (Azman et al., 2026), studying Türkiye as a case study shifts the focus from the energy accessibility problem to the issue of energy affordability. This makes the individuals' vulnerable nature to energy poverty in terms of affordable and efficient heating issues more visible, especially considering their limited access to credits and insurance in Türkiye (Orhangazi and Yeldan, 2025).

To date, no study has specifically examined the relationship between income inequality and energy poverty in the domestic literature. On the contrary, a couple of studies examined the relationship of income inequality to energy consumption and poverty on a macro level (Arı, 2022; Barış and Demir, 2023; Nar, 2021). Budak (2025) is the only exception that discusses the relationship of energy poverty to income inequality. It is argued in the study that energy poverty deepens inequalities and vulnerabilities in a society. Adopting a macroeconomic perspective, the author theoretically justifies the necessity of doing research on the relationship between income inequality and energy poverty by using energy taxes and subsidies in the article. According to this, low-income individuals suffer from these taxes the most because the energy burden on their budgets deepens.

Having said that, a few studies focused on the microeconomic determinants of income inequality in Türkiye (Aydın, 2012; İpek and Sekmen, 2016; Limanlı, 2017). These studies commonly emphasized that individual (household) factors such as age (of the household's reference person), education, poverty, occupation and unemployment, and poor health come into prominence as the microeconomic determinants of income inequality.

Scarcity of studies that particularly focus on determinants of income inequality on a personal level as well as those that analyse the relationship of energy poverty to personal income inequality implies that there exists a research gap that should be addressed both in the domestic and international literature. Therefore, this study examines the relationship between personal income inequalityand fuel poverty in Türkiye to understand whether individual heating inadequacy changes the probability of individuals living in a relatively high-inequality state.

Economic relationships are mostly interrelated. This means they can influence each other. In addition, some individual characteristics that are constant over time cannot be explicitly measured in econometric models. Therefore, to reduce the risk of endogeneity, instrumental variables regression was chosen as the main method, and several robustness checks were conducted in the context of pooled and panel data. As far as it is known, this is the first micro-level evidence on the nature of the relationship of fuel poverty to personal income inequality in Türkiye by using both instrumental-variables regression and a relatively novel income inequality measurement method, which will be explained in detail in section 3.1.1. The main motivation for this research is to reveal the relationship between income inequality and fuel poverty within and among individuals to manifest their living standards in Türkiye.

The main contribution of the article to the domestic and international literature is to measure income inequality on a micro scale, highlighting that macro-level empirical studies in the international literature, which use aggregate inequality measures, alone are insufficient to capture the probability of individuals living in a relatively high-inequality state and fight against this problem. While aggregate income inequality measurement methods such as the Gini coefficient give researchers an idea about the extent of income inequality in a country, they mostly overlook individuals' relative position in an income distribution -in other words, individuals' relative exposure to income inequality. When viewed from this perspective, income inequality ceases to be merely an abstract ratio and instead emerges as an issue that individuals will experience differently depending on their relative position in the income distribution. Another noteworthy contribution of the article to the domestic and international literature is to check for the heterogeneous relationship between income inequality and fuel poverty across income groups on a micro scale. The final contribution of the article to the domestic and international literature is to suggest micro-level instrument variables for fuel poverty for the first time, which is quite noteworthy to grasp the true nature of the relationship between personal income inequality and fuel poverty. It is expected that this research will pave the way for a more comprehensive examination of this issue, especially in countries that share similar characteristics with Türkiye through micro and macroeconomic indicators.

In the remainder of this study, the theoretical framework, material and methods, results, discussion, and conclusion sections will be addressed, respectively. These sections will cover theory on the relationship between income inequality and energy poverty, data and methodology used, main findings, implications, advantages, and limitations of the study.

2. Theoretical framework

2.1. The relationship between income inequality and energy poverty

Macro-empirical studies on this relationship have emerged in recent years. The first part of this section focuses on these studies since they provide important foundational information on the core of the topic. The literature both focused on the relationship of energy poverty to income inequality (Acheampong et al., 2021; Adom et al., 2021; Opoku et al., 2024; Song et al., 2023) and simultaneity between these concepts (Nguyen and Nasir, 2021). According to this, while improved electricity access is negatively related to global income inequality, improved modern, clean, and renewable energy access is positively related to it (Acheampong et al., 2021; Song et al., 2023; Opoku et al., 2024). First, it implies that the poor people and those who live in the rural areas may especially benefit from increased electricity access because energy provides them with the opportunity to work under suitable conditions, thereby enabling them to increase their income. Second, it implies that the use of clean energy may not be prevalent in most of the regions in the world because of its high cost (Acheampong et al., 2021). This finding also emphasises the importance of improved access to affordable energy in reducing income inequality. It is also attributed to different development levels of countries in a country-level study, which implies a heterogeneous relationship between the variables (Song et al., 2023). On the other hand, there is also some research on the direct positive relationship between income inequality and energy poverty (Adom et al., 2021; Nguyen and Nasir, 2021). Finally, an increase in energy consumption is found to reduce the income gap in some of the Central and Eastern European countries. This finding shows the positive contribution of consuming more energy in reducing income inequality and explains this relationship through the importance of increased capabilities, energy access and affordability, energy-powered economic prosperity that result in increased employment and higher income, and energy benefits and tax reliefs for energy transition (Donath et al.,

2025).

These studies based their examination of this relationship on both capability approach (Sen, 1979) and the direct impact of energy poverty, especially on education, employment, and health. Energy is an integral part of individuals' lives because it facilitates individual functioning and capability. On the other hand, it has a direct relationship with increased education, employment, and health opportunities, which indirectly affects its relationship to income inequality (Acheampong et al., 2021; Nguyen and Nasir, 2021). The remainder of this section focuses on these potential mechanisms linking fuel poverty to personal income inequality at both micro and macro levels.

Energy poverty, with its objective and subjective indicators, is negatively related to individual health status in Türkiye in a micro-panel data context (İpek and İpek, 2024). This finding still applies when mental health is taken into consideration at both micro and macro levels (Sen et al., 2024). In addition to health, it is also known that energy poverty has a detrimental impact on learning activities, and this affects the relationship of energy poverty to individual socioeconomic status (Xiao et al., 2021). Furthermore, using country-level data, it is found that increased energy access lessens education gap and enables individuals to study at night without interruption (Sule et al., 2022). Katoch et al. (2024) complement this perspective by arguing that energy poverty deteriorates both individual health and educational status. Fuel poverty is also considered to increase individuals' job search intensification, but this effort does not turn into immediate employment. In this sense, it is observed that fuel poverty leads to a job search of inadequate quality, through attentional and emotional obstacles created by it. These obstacles could be poor health and well-being, and the time required to find ways to cope with energy bills (Welters and Gerards, 2025). On the other hand, it is found that energy access is positively related to economic growth and contributes to economic development in some of the ECO countries, including Türkiye (Akın and Ateş, 2025). Further, energy poverty can be considered a moderator variable while examining the relationship of financial inclusion to economic growth (Rahman, 2024).

The relevant literature is particularly noteworthy in the sense that it shows the nature of the relationship between energy access/consumption and aggregate income inequality, considering the endogeneity issue, and it discusses potential mechanisms of this relationship. They imply that it is noteworthy to look at the relationship of energy poverty to income inequality, and energy poverty could be related to increased income inequality, especially through poor health, misery, being unable to work and learn, and reduced income at both micro and macro levels. This also means that improved energy access, adequate energy consumption with affordable pricing, as well as adequate and affordable heating and high-quality housing are important prerequisites for income equality.

The drawbacks of these studies, however, are that they exclude Türkiye as a case study, adopt a macroeconomic perspective on the nature of the relationship between income inequality and energy poverty, use aggregate energy poverty and income inequality measures, and consequently, they could not specifically capture issues regarding individual quality of life, probably because of the adoption of the traditional inequality measurement methods in the economics discipline. This research, on the other hand, aims to partially solve these problems by examining the relationship between income inequality and fuel poverty from a microeconomic perspective, considering individuals' perceptions of fuel poverty and their relative exposure to income inequality, which have been overlooked in macro-level research. This perspective takes account of individuals' relative living standards, and it is also expected to complement the results obtained from macroeconomic studies.

2.2. The socioeconomic determinants of income inequality

Income inequality is generally measured at the macro scale; however, some studies particularly focus on the microeconomic determinants of it (Akin-Olagunju and Omonona, 2013; Crespo et al., 2012; De Vita and Luo, 2021; Dustmann et al., 2022; Waris et al., 2023). To identify these determinants, one of the methods used in the literature is the regression-based income inequality decomposition technique (Akin-Olagunju and Omonona, 2013). According to this, education is found to contribute to the Gini coefficient in a negative way. On the other hand, household size, marital status, land size, and agricultural credit are found to contribute to the Gini coefficient in a positive way. It is also found that the differences in active age, education, and income sources are positively related to income inequality (Crespo et al., 2012). Similarly, household debt is found to be an income inequality increasing factor (De Vita and Luo, 2021). Furthermore, it is argued that a change in housing costs increases income inequality, and the poorest ones are adversely affected by this situation (Dustmann et al., 2022). Finally, it is also discussed that while an increase in age is positively related to income inequality, an increase in the educational level of and the number of dependent people in households are negatively related to it (Waris et al., 2023).

The relevant literature implies that in addition to macroeconomic factors, microeconomic characteristics are also related to income inequality. This implication is reasonable because individuals as citizens are at the heart of the economy, and thereby, they are the ones who will be directly affected by the economic situation of their countries. For instance, a poor economic condition in a country may lead to these individuals being economically and socially excluded, and this may in turn affect income inequality on a personal level. Therefore, an individual analysis allows for a closer look at individuals' lives by particularly focusing on both their characteristics and economic and housing conditions. This study aims to contribute, albeit in a limited way, to the existing literature on this point, while also considering that the relationship between personal income inequality and its determinants may vary depending on the characteristics of the country and its residents in question.

3. Material & methods

3.1. Material

Since 2006, the "Survey of Income and Living Conditions (SILC)" has been conducted to reveal the distribution of income between individuals and households, as well as to measure living conditions in Türkiye, to ensure alignment with European Union standards. This study utilises the TurkStat 2017-2020 micro-panel dataset (2022) that has a rotational (unbalanced) nature. It has a two-stage stratified cluster sampling. While 75% of the participants permanently stay in the survey over the four years, 25% of them cyclically enter and exit it. Therefore, some individuals were observed for three years or less in the survey over the whole period. Statistical institutes use this method to refresh the data over time and provide cost efficiency (Steel and McLaren, 2008). An unbalanced dataset was used in the analysis without converting it to a balanced one to make use of all the information provided by it. When the data merging and cleaning processes were completed, the dataset consisted of 52.429 individuals.

Table 1 explains the variables used in the econometric analyses.

"Arrears on utility bills" and "leaking roof, damp walls, rot in window frames, etc." were used as instrument variables for fuel poverty. Those who have arrears on utility bills might spend more on housing needs, and therefore, their remaining income might be inadequate to keep their home warm (Polimeni et al., 2022). On the other hand, poor housing quality reflects a lack of insulation (poor energy efficiency) in homes, which is more likely to result in fuel poverty (Alvarez and Tol, 2021; Horta et al., 2019). Berger and Höltl (2019) also argue that proper insulation may reduce energy demand and improve the quality of indoor temperature.

To the best of its knowledge, these variables are suggested as instruments for the first time in a micro-level analysis. First, it is required

Table 1
The nature of the variables used in the study.

Variables	TurkStat Codebook	Original Data Categories	Data Used
Outcome variable: Personal income inequality (piineq)	Not found in the TurkStat Codebook. It was created using equivalised household disposable real income based on the Davies' (2021) Gini-admissible personal income inequality (GAPII) formula.	-	**Modified (binary) variable:** **0** Below-median personal income inequality (Relatively low personal income inequality) **1** Above-median personal income inequality (Relatively high personal income inequality)
Endogenous (explanatory) variable: Fuel poverty (fuelpov)	"Ability to keep home adequately warm"	-	**Binary variable:** **0** Yes (not fuel poor) **1** No (fuel poor)
Control Variables			
Age (65 years of age and above)	"Age" (as of 2019, December)	**Continuous variable:** 15-99	**Modified (binary) variable:** **0** Others **1** Those who are *65 years of age and above*
Poor health	"General health status": Categorical variable	1. Very good 2. Good 3. Fair 4. Bad 5. Very bad	**Modified (binary) variable:** **0** Others **1** Those whose general health status is *bad and very bad*
Married	"Marital status": Categorical variable	1. Married 2. Never married (single) 3. Widowed 4. Divorced 5. Live separately	**Modified (binary) variable:** **0** Others **1** Those who are married
On income	"Self-defined current economic status": Categorical variable	1. Employee (working full-time) 2. Employee (working part-time) 3. Self-employed (working full-time) 4. Self-employed (working part-time) 5. Looking for a job 6. Pupil, student or unpaid work experience 7. In retirement or in early retirement or has given up business 8. Disabled and/or unfit to work 9. Fulfilling domestic tasks and care responsibilities 10. Another inactive person	**Modified (binary) variable:** **0** Others **1** Those who receive income or pension for their (past) work ("full-time and part-time employee", "full-time and part-time self-employed", "in retirement or in early retirement or has given up business")
Higher education	"Highest education level attained": Categorical variable	1. Illiterate 2. Literate but not a graduate 3. Primary school 4. Secondary, vocational secondary or primary education school 5. High school 6. Vocational or technical high school 7. Faculty/ university, college or higher education level	**Modified (binary) variable:** **0** Others **1** Those who "attained faculty/university, college or higher education level"
Homeowner	"Tenure status"**:** Categorical variable	1. Owner 2. Tenant 3. Lodging 4. Other (rent-free accommodation)	**Modified (binary) variable:** **0** Others **1** Those who purchase a home and thereby have an ownership over the home (owner)
Household size	"Household size"	**Continuous variable:** 1-16 persons in a household	-
Arrears on instalments	"Arrears on hire purchase instalments, credit cards or other loan payments in the last 12 months"**:** Categorical variable	1. Yes (once) 2. Yes (twice or more)" 3. No (Individuals have instalments, credit cards, etc. but they have no arrears in the last 12 months.) 4. There is no such kind of payment (They have *no* instalments, credit card debts, or other payments.)	**Modified (binary) variable:** **0** Others **1** Those who "have arrears on instalments" and could not pay them *once or twice or more* in the last 12 months
1st income quintile:	Not found in the TurkStat codebook. It was created using *continuous* equivalised household disposable *real* income (Base year: 2016).	-	**Modified (binary) variable:** **0** Others **1** Those who earn 226 TL - 9838.90 TL
2nd income quintile	Not found in the TurkStat codebook. It was created using *continuous* equivalised household disposable *real* income (Base year: 2016).	-	**Modified (binary) variable:** **0** Others **1** Those who earn 9838.92 TL – 14.450,5 TL
3rd income quintile	Not found in the TurkStat codebook. It was created using *continuous* equivalised household disposable *real* income (Base year: 2016).	-	**Modified (binary) variable:** **0** Others **1** Those who earn 14.453 TL – 19.596,83 TL

(*continued on next page*)

Table 1 (*continued*)

Variables	TurkStat Codebook	Original Data Categories	Data Used
4th income quintile	Not found in the TurkStat codebook. It was created using *continuous* equivalised household disposable *real* income (Base year: 2016).	-	**Modified (binary) variable:** **0** Others **1** Those who earn 19.596,85 TL – 28.635,30 TL
5th income quintile (Reference income category)	Not found in the TurkStat codebook. It was created using *continuous* equivalised household disposable *real* income (Base year: 2016).	-	**Modified (binary) variable** **0** Others **1** Those who earn 28.647,01 TL – 725.593 TL
Internet access	"Internet connection possession of the household": Categorical variable	1. Yes 2. No, cannot afford 3. No, other reason	**Modified (binary) variable** **0** Others **1** Presence of internet connection at home
Instrument variables for fuel poverty (fuelpov)			
Utility bills	"Arrears on utility bills in the last 12 months": Categorical variable	1. Yes (Once) 2. Yes (Twice or more) 3. No (Individuals have utility bills but no arrears.) There is no such kind of payment (Individuals have no utility bills.)	**Modified (binary) variable:** **0** Others **1** Those who have "arrears on utility (electricity, gas and water) bills in the last 12 months" (once or twice or more)
Leaky roof	"Leaking roof, damp walls or rot in window frames problem": Categorical variable	-	**Binary variable:** **0** Those who have no leaky "roof, damp walls, rot in window frames, etc." **1** Those who have "leaking roof, damp walls, rot in window frames in their dwellings"

Source: TurkStat (2022). In the dataset, annual household income refers to the previous year.

to mention that identifying suitable instruments in a micro-level dataset can be challenging due to data restrictions and violations regarding the instrument exogeneity. The main reason for choosing them as instruments, however, is their ability to explain the endogenous variable well, meaning that they are *closely* and *specifically* related to fuel poverty in the relevant literature. This directly meets the relevance rule. The second reason for choosing them as instruments is the findings of the overidentifying restrictions tests. According to this, it was observed that the selected instruments were valid. In addition, the Lewbel estimator was used to identify the model with both generated and external instruments, and it was found that the model identification did not merely depend on the external instruments.

It is worthy of consideration that exclusion restrictions can never be tested directly (Mellon, 2025). However, the following theoretical arguments are still noteworthy to support the selection of the variables in this study and, most importantly, the exogeneity of instruments. First, arrears on utility bills may also restrict individuals' ability to pay instalments, credit card or other loan payments, or reduce income, thereby impacting individuals' relative exposure to inequality. Therefore, it is crucial to include financial strain, proxied by the arrears on instalments, credit cards, or other loan payments indicator, and specific income groups in the models. Second, it is noteworthy to refer to the observed macroeconomic relationship between energy efficiency and income inequality through social productivity in the literature (Dong et al., 2022). Since "leaking roof, damp walls, rot in window frames, etc." could be considered an energy efficiency indicator, it is of significant importance to take the proxies of social productivity into account. In micro-level research, social productivity can be proxied by individuals' educational, self-reported health and employment statuses and household infrastructure such as internet access, etc. (UKHospitality, 2025). A leaky roof, damp walls, or rot in window frames, for instance, may lead to poor physical and mental health conditions (Wimalasena et al., 2021). This may result in an increase in the probability of individuals living in a relatively high-inequality state. In addition, poor housing quality may be associated with individuals being exposed to greater inequality through low socioeconomic status, which can be proxied by income groups and education (Nutakor et al., 2023). . Therefore, the models in this study included educational and self-defined economic and health statuses, and internet access at home, in addition to income categories and financial strain to be able to clear the impact of these channels based on the available data (Jachimowicz et al., 2020). More importantly, the 1st stage F statistic (>10 as a rule of thumb) shows that the instruments do not weaken even after these control variables were included in the models. This is important because it shows that the instruments continued to directly explain fuel poverty even after various control variables were included in the model.

3.1.1. The indicator of personal income inequality

Davies (2021) argues that income inequality can be calculated at the personal level by making use of the formula of the Gini coefficient. It is suggested that the average of the total Gini-admissible personal income inequality value gives the Gini index (G). Clark and D'Ambrosio (2019) performed it by using the initial version of the paper. They highlighted the relative nature of an inequality measurement, and approached GAPII from the perspective of "individual alienation", while decomposing the index. In this study, however, the index form was chosen due to the nature of the research question. It can be expressed as follows:

$G = \frac{1}{n}\sum_{i=1}^{n} G_i$, where G_i represents the GAPII.

The main formula of personal income inequality based on GAPII is as follows:

$$G_i = \frac{1}{2n\bar{y}}\left[n_i^l\left(y_i - \bar{y}_i^{\,l}\right) + n_i^h\left(\bar{y}_i^{\,h} - y_i\right)\right],$$

where n_i^l represents the number of individuals whose incomes are less than or equal to y_i, with individual i excluded, n_i^h represents the number of individuals whose incomes are strictly greater than y_i, $\bar{y}_i^l$ represents the average income among those whose incomes are less than or equal to y_i, with individual i excluded, and finally, $\bar{y}_i^h$ represents the average income among those whose incomes are strictly greater than y_i.

Upon completion of the annual computations, it was found that some of the GAPII numbers exceeded 1. Davies (2021) explains its reason by pointing out the large income gap between the richest individuals and others, as it is quite hard for the poorer ones to catch up with those at the top. However, income inequality traditionally varies between 0 and 1. Therefore, after combining the data to create a panel, the total min-max normalization method was used to normalize the GAPII values, and values ranging between 0 and 1 were obtained for each individual. This method was preferred because it does not change the shape of the original distribution of the data; it only changes the scale of the values (Cabello-Solorzano et al., 2023). It is expected that this may allow for the consistent observation of the overall trend in the relationship between the two variables over the four years. Next, a binary variable,

representing values higher than or less than or equal to the median level, was created for personal income inequality by making use of the normalized continuous GAPII values to better understand whether individuals are relatively exposed to a higher income inequality or not in relation to fuel poverty. This approach can be used when a specific accepted threshold for income inequality is not suggested (Celeste et al., 2009), and since the use of the median threshold is robust to the extreme values in the dataset (Kuş and Aydemir, 2026).

3.2. Methods

Theoretically, endogeneity results in model bias, and it obscures the true nature of the relationship between variables (Budziński and Czajkowski, 2022). In this case, the endogeneity test performed for this analysis revealed that fuel poverty was endogenous. This means that the OLS estimation would be inconsistent. Therefore, this study utilises the two-stage least squares (2SLS), static, linear, two-step GMM, and IV-Probit estimators in the pooled data context, and the fixed effect- (FE), random effect- (RE), Lewbel-2SLS, and control function (CF) estimators in the panel data context.

Angrist and Pischke (2009) advocate the use of the LPM-2SLS estimator even if dependent and endogenous variables are binary. Similarly, Wooldridge (2010) suggested the use of LPM as a "linear projection" of the binary dependent variable on independent variables to obtain average partial effects. He also suggested that the LPM may perform better if binary explanatory variables are included in the model. In addition, binary data enables researchers to interpret the findings in a simpler way. Since the bivariate probit model did not perform well in this study as a robustness check (the presence of missing standard errors, z- and p-values, confidence intervals of income quintiles, and missing constant in the second stage of the model with a cluster-robust option), it is thought that sparsity, together with model and panel data complexity, can be a concern when performing this model. Greenland et al. (2016), Hamra et al. (2013) and Walker and Smith (2019) argue that if maximum likelihood estimators such as logit and probit models are used with sparse data, the problems of estimation bias, perfect prediction, and/or inflated coefficients may occur. In such cases, the LPM may be preferable to these models.

The structural equation of the baseline model is as follows:

$$y_{1i} = y'_{2i}\beta_1 + x'_{1i}\beta_2 + u_i, i = 1, \ldots, N, \tag{1}$$

where y'_{2i} represent the endogenous variables that are correlated with the error term, u_i, and x'_{1i} represent the exogenous variables that are not correlated with the error term, u_i.

CF approach can be applied both to show that the CF estimates are identical to the 2SLS estimates, and to perform a robust Hausman test for proving whether the relevant variable is endogenous or not (Wooldridge, 2015).

A pooled IV-Probit estimator can be used as a robustness check that is thought to be relatively less demanding than the bivariate probit model to take the true nature of the dependent variable into account (Wooldridge, 2010).

Finally, Lewbel's 2SLS approach can be used as a supplementarymethod to increase the efficiency of the standard 2SLS estimator and make use of the additional internal instruments (Baum et al., 2013; Lewbel, 2012).

According to this, the main econometric expression of the models is as follows:

Structural personal income inequality equation performed in panel and pooled cross-sectional data:

$$\begin{aligned} piineq_{it} = {} & \beta_0 + \beta_1 fuelpov_{it} + \beta_2 age_{it} + \beta_3 poorhealth_{it} + \beta_4 married_{it} \\ & + \beta_5 onincome_{it} + \beta_6 highereduc_{it} + \beta_7 homeowner_{it} + \beta_8 householdsize_{it} \\ & + \beta_9 arrears_{it} + \beta_{10} 1stincomequintile_{it} + \beta_{11} 2ndincomequintile_{it} \\ & + \beta_{12} 3rdincomequintile_{it} + \beta_{13} 4thincomequintile_{it} + \beta_{14} \text{internetaccess}_{it} \\ & + \varepsilon_{it} \end{aligned} \tag{3}$$

Fig. 1 visualises the models performed in different data contexts below.

4. Results

4.1. Descriptive findings

Before proceeding to the econometric findings, Table 2 reveals descriptive statistics of the data.

Poverty in different forms, income inequality, and the share of income groups in annual equivalised household disposable income are demonstrated in Figs. 2–4below, respectively.

According to Fig. 2, while the poverty rate hovered above 20% between the years of 2016 and 2025, it was observed that the average rate of social exclusion, also known as the at-risk-of poverty rate, was around 31%. On the other hand, the energy poverty rate in the form of inadequate heating has been below 20% for the last three years. While it has decreased, this rate is still quite high, and therefore, it should be properly addressed.

Fig. 3 visualised the income inequality issue in Türkiye. It was observed that the average Gini coefficient has been around .41 over the ten years. This can be considered a moderately high value.

Fig. 4 visualised income inequality in Türkiye in a different sense. It was observed that while the highest share of income went to the top of the income distribution, the lowest share of it went to the bottom of the income distribution. This clearly demonstrates a relatively serious income gap between individuals in Türkiye.

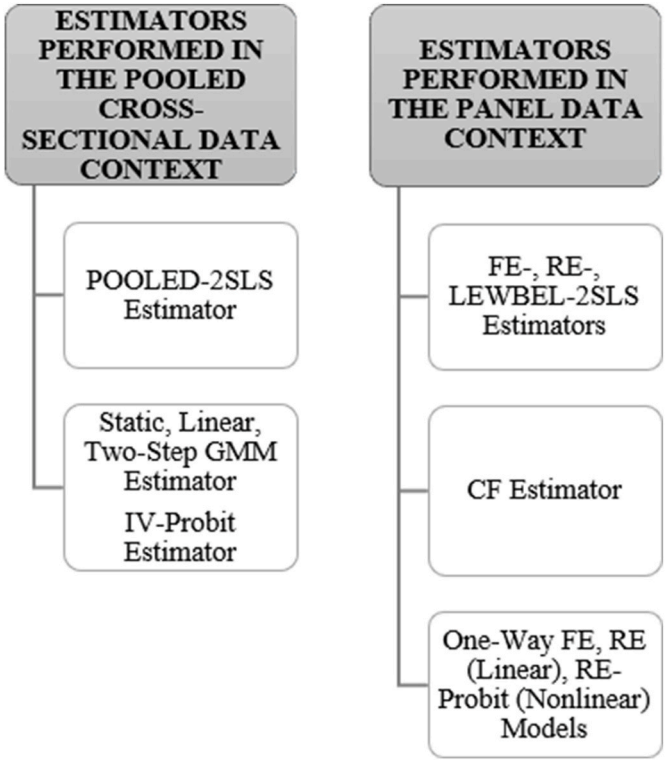

Fig. 1. Visualization of the models used in this study.

Table 2
Descriptive statistics.

Variables	Proportion	Std. Err.	Logit [95% conf. Int.]
Personal income inequality.			
0	.5000	.0022	4957 .5043
1	.4999	.0022	.4957 .5043
Fuel poverty			
0	.7947	.0018	.7912 .7981
1	.2053	.0018	.2019 .2088
Age (65+)			
0	.8797	.0014	.8769 .8825
1	.1203	.0014	.1175 .1231
Poor health			
0	.8954	.0013	.8928 .8980
1	.1045	.0013	.1019 .1072
Married.			
0	.3134	.0020	3095 .3174
1	.6866	.0020	.6826 .6905
On income			
0	.4598	.0022	.4556 .4641
1	.5401	.0022	.5359 .5444
Higher education.			
0	.8692	0015	.8663 .8721
1	.1307	.0015	.1279 .1337
Homeowner			
0	.3757	.0021	.3716 .3799
1	.6243	.0021	.6201 .6284
Arrears on instalments			
0	.8189	.0017	.8156 .8222
1	.1810	.0017	.1778 .1844
1st income quintile			
0	.80	.0017	.7965 .8034
1	.20	.0017	.1966 .2035
2nd income quintile			
0	.80	.0017	.7966 .8034
1	.20	.0017	.1966 .2034
3rd income quintile			
0	.80	.0017	.7966 .8034
1	.20	.0017	.1966 .2034
4th income quintile			
0	.80	.0017	.7965 .8034
1	.20	.0017	.1966 .2034
5th income quintile*			
0	.80	.0017	.7966 .8034
1	.20	.0017	.1966 .2034
***Ref. Cat.**			
Internet access			
0	.3132	.0020	.3092 .3172
1	.6868	.0020	.6828 .6908
Arrears on utility bills			
0	.7657	.0018	.7621 .7693
1	.2342	.0018	.2306 .2379
Leaky roof, damp walls, rot in window frames, etc.			
0	.6430	.0021	.6389 .6471
1	.3569	.0021	.3529 .3611
Continuous variables	**Mean**	**Std. dev.**	**Min Max**
Household size	3.71	1.8747	1 16

Note: Authors' own calculations based on TurkStat (2022).

4.2. Econometric findings

This section will be devoted to reporting the findings obtained from the econometric models. According to this, the findings obtained from the Pooled-2SLS, static, two-step GMM, and IV-Probit estimators will be reported by pooling the data in Table 3. These models will be used as the first robustness checks of the baseline panel estimator, FE-2SLS. The FE-2SLS estimator will be used as the baseline model to prevent omitted variable bias that results from time-constant unobserved heterogeneity (Joshi and Wooldridge, 2019; Wooldridge, 2010). Panel data findings with robustness checks such as the RE-2SLS, CF, and Lewbel-2SLS estimators will be reported in Table 4. The use of various estimators under different data and model assumptions is expected to provide a better understanding of the nature of the relationship between personal income inequality and fuel poverty in Türkiye. The statistically significant findings of the pooled and panel data estimators will be reported after the relevant tables are demonstrated. According to this, Table 3 and Table 4 are as follows.

Pooled and panel data estimators in Table 3 and Table 4 suggested that fuel poverty decreased the probability of individuals living in a relatively high-inequality state. Being 65 years of age and older and an increase in the household size decreased the probability of individuals living in a relatively high-inequality state, according to both pooled data estimators and the RE-2SLS estimator. Poor health status, higher educational status, and homeownership increased the probability of individuals living in a relatively high-inequality state, according to both pooled data estimators and the RE-2SLS estimator. Being married increased the probability of individuals living in a relatively high-inequality state, according to both FE-, and the Lewbel-2SLS estimators. Being in arrears on instalments and internet access at home increased the probability of individuals living in a relatively high-inequality state, according to both pooled and panel data estimators. While positioning in the 1st income quintile increased the probability of individuals living in a relatively high-inequality state, according to bothpooled-2SLS, static, two-step GMM, and panel data estimators, it decreased the probability of individuals living in a relatively high-inequality state, according to the pooled IV-Probit estimator only. On the other hand, positioning in the 2nd, 3rd, and 4th income quintiles decreased the probability of individuals living in a relatively high-inequality state, according to each estimator. It is noteworthy to mention that the CF estimator revealed the identical findings as the FE-2SLS estimator. The findings obtained from the Lewbel-2SLS estimator were mostly consistent with those obtained from the other estimators. Finally, overidentifying restrictions tests and weak-instrument-robust inferences suggested that the instrument variables were both valid and strong, respectively.

Table 5, on the other hand, reports the relationship within the first- and third-income quantiles to prove that a heterogeneous personal income inequality-fuel poverty relationship exists across different income groups. Since the FE- and RE findings from the 2nd income quantile were not significant according to the F and Wald chi-square statistics (F statistic: .9963 in the FE estimator; Wald chi-sq. Statistic: .9814 in the RE estimator), they were not included in the study to save space.

Table 5 suggested that while fuel poverty increased the probability of individuals living in a relatively high-inequality state in the 1st income quantile, it decreased the probability of it in the 3rd income quantile, according to each estimator. Similarly, while an increase in household size increased the probability of individuals living in a relatively high-inequality state in the 1st income quantile, according to both RE and RE-Probit estimators, it decreased the probability of it in the 3rd income quantile, according to the same estimators. While being in arrears on instalments increased the probability of individuals living in a relatively high-inequality state in the 1st income quantile, according to both RE and RE-Probit estimators, it decreased the probability of it in the 3rd income quantile, according to the RE-Probit estimator only. While being married and homeowners decreased the probability of individuals living in a relatively high- inequality state in the 1st income quantile, according to each estimator, they increased the probability of it in the 3rd income quantile, according to the same estimators. While having an income decreased the probability of individuals living in a relatively high-inequality state in the 1st income quantile, according to each estimator, it increased the probability of individuals living in a relatively high-inequality state in the 3rd income quantile, according to the RE and RE-Probit estimators only. Similarly, higher education and internet access at homedecreased the probability of individuals living in a relatively high-inequality state in the 1st income quantile, according to the RE and RE-Probit estimators only. However, while higher education increased the probability of individuals living in a relatively high-inequality state in the 3rd income quantile, according to the RE and RE-Probit estimators only, internet access at home increased the probability of it in the 3rd income quantile, according to each estimator.

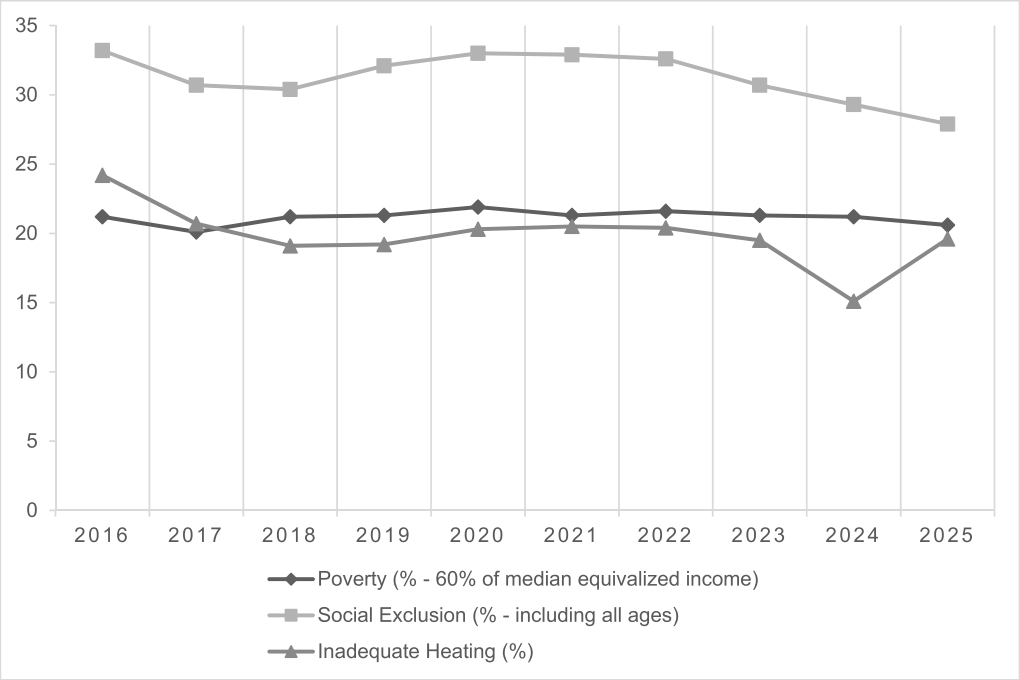

Fig. 2. Poverty with Its Different Definitions in Türkiye **Source:** Authors' own calculations based on (TurkStat Press Release, 2025b, 2025c). Income data for poverty refer to the previous reference year [2015-2024].

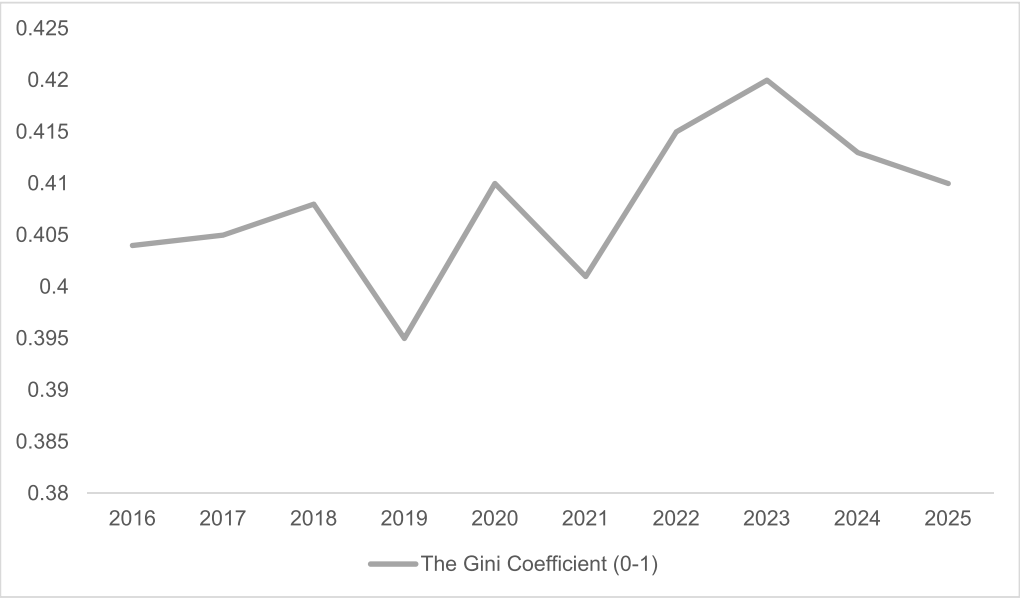

Fig. 3. Income Inequality in Türkiye **Source:** Authors' own calculations based on TurkStat Press Release, 2025a. Income data refer to the previous reference year [2015-2024].

4.2.1. Discussion

Fuel poverty is, on average, negatively related to individuals' relative exposure to income inequality on a micro scale in Türkiye both in pooled and panel data contexts. While this finding is partly in contradiction with Acheampong et al. (2021) and Song et al. (2023), it is fully in contradiction with Adom et al. (2021) and Nguyen and Nasir (2021). On the one hand, both Adom et al. (2021) and Nguyen and Nasir (2021) found that energy poverty leads to an increase in income inequality at the macro scale, which is not the case at the micro scale for this study. On the other hand, Acheampong et al. (2021) and Song et al. (2023) argued that global income inequality rises when clean energy access is provided; from another perspective, a decline in energy poverty leads to income inequality. These findings may imply possible heterogeneity in income level, and they may point out possible (un)affordability of clean energy. They argue that global and regional disparities in income and the resulting inability to afford the cost of clean energy might play a significant role in this regard. These findings specifically highlight the importance of energy being affordable, rather than merely available, to ensure a fair distribution of income.

In this study, the overall negative relationship may be explained by the inability of the personal income inequality indicator to fully capture the distributional dynamics at the bottom of the income distribution, or

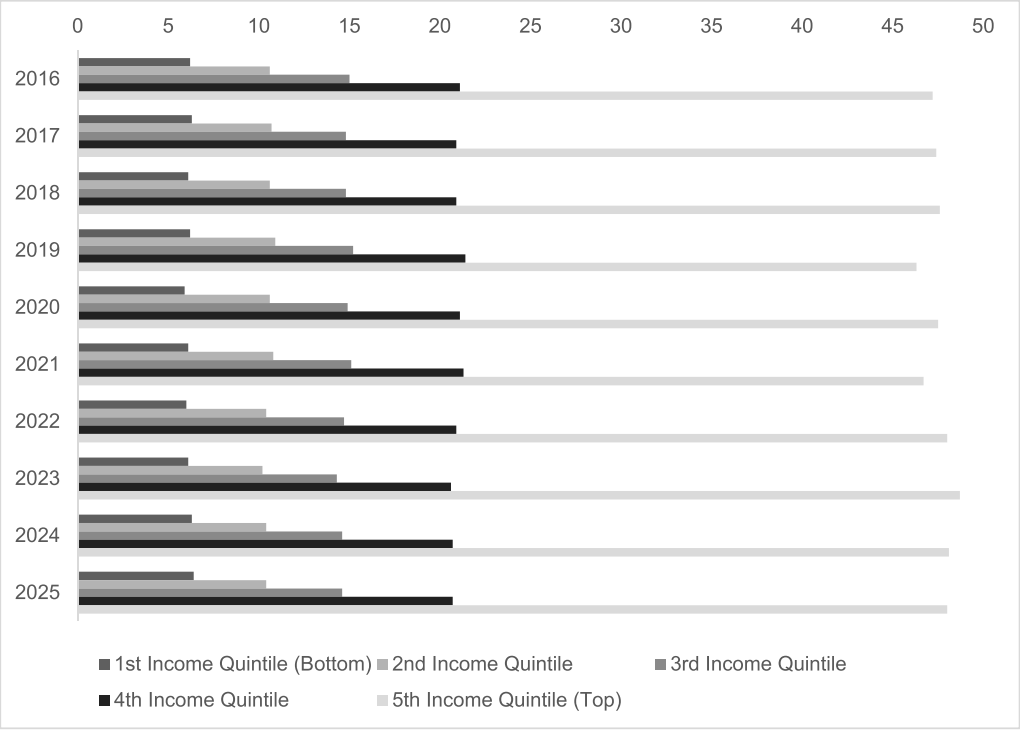

Fig. 4. Share of Income Groups in Annual Equivalized Household Disposable Income (%) **Source:** Authors' own calculations based on TurkStat Press Release, 2025a. Income data refer to the previous reference year [2015-2024].

the insensitivity of this indicator to the bottom end. Bardazzi et al. (2021) argued the same for the expenditure-based energy poverty indicators since they found a negative sign when they looked at the relationship of income inequality to energy poverty. If the negative impact at the top of the income distribution is greater than the positive impact at the bottom end of it, the overall finding could be expected to be negative. However, this finding cannot explain the possible heterogenous impact of fuel poverty in the overall distribution. Bardazzi et al. (2021) did not discuss the negative relationship, especially with respect to the possible heterogeneity. Therefore, heterogeneity was checked for the relationship of fuel poverty to personal income inequality across the income groups in this study, and its existence was confirmed by the one-way panel models estimated within three income categories. This shows that the relationship was not uniform across different income levels.

According to this, while fuel poverty leads to an increase in the probability of individuals living in a relatively high-inequality state at the bottom of the income distribution, it leads to a decrease in the probability of individuals living in a relatively high-inequality state at the top of it. The positive relationship observed at the bottom of the income distribution can be explained by the combination of budget constraints, lack of dwelling insulation, and lack of access to numerous opportunities such as employment, health, and education. The poorest people are more likely to allocate a greater portion of their income to heating, particularly because of inadequate income and poor insulation (David and Kod'ousková, 2026), and this situation could have adverse consequences on income distribution (Hussain et al., 2024). The implication of the finding for this study could be that energy poverty amplifies individuals' relative exposure to income inequality at the bottom part of the income distribution since these individuals are the most disadvantaged. This finding is quite similar to what Jachimowicz et al. (2020) found in their article, which examined the impact of income inequality on financial stress among low-income individuals, except the fact that income inequality is the dependent variable in this study. While they argue that income inequality amplifies financial stress *only for the poor*, this study argues that fuel poverty deepens the probability of individuals living in a relatively high-inequality state *at the bottom of the income distribution*. On the other hand, the negative relationship observed at the top could be explained by the compositional concentration of energy-poor, upper-income individuals within relatively homogeneous segments. To put it more plainly, since the personal income inequality index used in this study is the highest at the highest end (Davies, 2021), the reasonable explanation is that although energy poverty is observed at the higher-income levels (Maier and Dreoni, 2026), it appears to be concentrated in the lower and more homogeneous segments of the top end of the income distribution. Therefore, it may reduce the probability of individuals living in a relatively high-inequality state at the top. Homogeneity is more likely to appear in (low) incomes, (poor) employment status, homeownership, dwelling types and (poor) dwelling quality in this segment (Kargın Akkoç, 2026; Korkmaz and Senyel Kurkcuoglu, 2025).

According to the overall panel findings, the relationship of being married to personal income inequality is positive in the FE-2SLS, CF, and Lewbel estimators. Nie and Xing (2019) argue that education may determine the impact of marriage on overall income inequality, meaning that if spouses are highly educated, inequality will increase. This situation is also known as homogamy (Shen, 2021). In this case, homogamy could also be one of the main factors that increases individuals' relative exposure to income inequality. The relationship of being in arrears on instalments to personal income inequality is also positive in all estimators. This finding is consistent with De Vita and Luo (2021) finding. The main reason could be that lower-income individuals are less likely to afford these debts, and they are more likely to face financial obligations such as interest rates and penalties. These obligations may create a burden on individual budgets, leave these individuals vulnerable to economic shocks, make them financially unstable, and impair wealth accumulation. As a result of these adverse conditions, incomes of those who are located at the bottom of the income distribution may be volatile or even decrease, increasing personal income inequality (Birdal et al., 2023; De Vita and Luo, 2021; Mashigo, 2006; Scott and Pressman,

Table 3
POLS-IV, static, two-step GMM and pooled IV-probit estimators.

Variables	Robustness Checks		
Dependent variable: Personal Income Inequality	**Pooled-2SLS Estimator**	**Pooled Static, Two-Step GMM Estimator**	**Pooled IV-Probit (Bootstrap)**
Fuel poverty	−.0487*	−.0465*	−.4650*
	(.0176)	(.0174)	(.1639)
Age (65+)	−.0148*	−.0148*	−.1315*
	(.0041)	(.0041)	(.0326)
Poor health	.0087**	.0085**	.0888**
	(.0043)	(.0043)	(.0407)
Married	.0022	.0023	.0162
	(.0029)	(.0029)	(.0249)
On income	.0023	.0023	.0161
	(.0027)	(.0027)	(.0217)
Higher education	.0183*	.0183*	.1525*
	(.0042)	(.0042)	(.0389)
Homeowner	.0066**	.0066**	.0479***
	(.0027)	(.0027)	(.0250)
Household size	−.0015**	−.0015**	−.0136**
	(.0006)	(.0006)	(.0069)
Arrears on instalments	.0129*	.0126*	.1344*
	(.0036)	(.0036)	(.0382)
1st income quintile	.0334*	.0325*	−2.9187*
	(.0069)	(.0069)	(.3714)
2nd income quintile	−.8790*	−.8792*	−7.2591*
	(.0046)	(.0046)	(.3587)
3rd income quintile	−.9861*	−.9863*	−9.7334*
	(.0019)	(.0019)	(.3913)
4th income quintile	−.5896*	−.5898*	−6.3562*
	(.0056)	(.0056)	(.3528)
Internet access at home	.0099*	.0101*	.0827*
	(.0029)	(.0029)	(.0253)
_cons/b0	.9822*	.9819*	6.0471*
	(.0050)	(.0050)	(.3568)
Model Diagnostics			
1st stage F statistic	324.87 > 10 (Rule of thumb)	-	-
Weak-instrument-robust inference Anderson-Rubin Wald F test Anderson-Rubin Wald Chi-sq test Stock-Wright LM S statistic	P-value: .0155 P-value: .0154 P-value: .0147	-	-
Montiel-Pflueger robust weak instrument test Effective F statistic	309.96 > 8.04 (2SLS- 5% of worst-case bias 309.96 > 21.33 (Limited Information Maximum Likelihood (LIML) – 5% of worst-case bias)	-	-
Weak identification test Kleibergen-Paap rk Wald F statistic	324.87 > 19.93 (10% maximal IV size)	-	-
Hansen-J statistic	Chi-sq (1) P-value: .2903	Chi2 (1) = 1.12 p-value: .2903	-

Note: * denotes .01 significance level. ** denotes .05 significance level. *** denotes .10 significance level. Cluster-robust standard errors are in parentheses. Bootstrapped standard errors were used in the IV-Probit estimator. 200 bootstrap replications were performed. Some parameters were not estimated in 62 bootstrap replicates.

2013). In addition, while the American Public Health Association ([APHA], 2021) argues that debt leads individuals to ill health, Krumer-Nevo et al. (2017) suggest that it leads individuals to financial exclusion. Individuals' relative exposure to income inequality may also increase because of this. Since inequality is driven by the large

Table 4
Panel findings.

Variables				
Dependent variable: Personal income inequality	FE-2SLS Estimator (Baseline)	Lewbel-2SLS Estimator	CF Estimator	RE-2SLS Estimator
Fuel poverty	−.1726**	−.0829**	−.1726**	−.0539*
	(.0779)	(.0357)	(.0759)	(.0183)
Age (65+)	.0120	.0159	.0120	−.0144*
	(.0143)	(.0138)	(.0140)	(.0041)
Poor health	−.0006	−.0007	−.0006	.0075***
	(.0056)	(.0055)	(.0055)	(.0043)
Married	.0256**	.0254**	.0256**	.0019
	(.0117)	(.0115)	(.0114)	(.0029)
On income	.0004	.0014	.0004	.0026
	(.0052)	(.0050)	(.0051)	(.0027)
Higher education	.0137	.0158	.0137	.0219*
	(.0230)	(.0227)	(.0228)	(.0042)
Homeowner	−.0035	−.0029	−.0035	.0064**
	(.0079)	(.0078)	(.0077)	(.0028)
Household size	−.0024	−.0032	−.0024	−.0015**
	(.0027)	(.0025)	(.0025)	(.0007)
Arrears on instalments	.0112**	.0073***	.0112**	.0125*
	(.0052)	(.0042)	(.0050)	(.0036)
1st income quintile	.1298*	.1219*	.1298*	.0414*
	(.0104)	(.0087)	(.0102)	(.0069)
2nd income quintile	−.7333*	−.7385*	−.7333*	−.8662*
	(.0089)	(.0079)	(.0088)	(.0047)
3rd income quintile	−.8142*	−.8173*	−.8142*	−.9692*
	(.0073)	(.0069)	(.0072)	(.0021)
4th income quintile	−.4934*	−.4955*	−.4934*	−.5816*
	(.0076)	(.0074)	(.0075)	(.0055)
Internet access at home	.0151*	.0161*	.0151*	.0107*
	(.0041)	(.0039)	(.0040)	(.0029)
Constant	-	-	-	.9735*
				(.0051)
Fuelpov_residual	-		.1715**	-
			(.0758)	
Sigma_u	-		.1733	.0696
Sigma_e	-		.2444	.2472
rho	-		.3345	.0734
Model Diagnostics				
1st stage F statistic	49.14 > 10 (Rule of thumb)	-	-	-
Weak identification test Kleibergen-Paap Wald rk F statistic	49.14 > 19.93 (10% maximal IV size)	15.27 > 11.51 (10% maximal IV relative bias) 15.27 > 14.60 (25% maximal IV size)	-	-
Weak-instrument-robust inference Anderson-Rubin Wald F test Anderson-Rubin Wald Chi-sq test Stock-Wright LM S statistic	P-value: .0741 P-value: .0740 P-value: .0723	-	-	-
Endogeneity test	Chi-sq (1) P value: .0247	-	-	-
Hansen-J statistic	Chi-sq (1) P-value: .7523	Chi-sq (14) P-Value: .3144	-	-
Hansen-J statistic (suspect orthogonality conditions were excluded)	-	Chi-sq (12) P-value: .3238	-	-
C Statistic (exogeneity/ orthogonality of suspect instruments)	-	Chi-sq (2) P-value: .3111	-	-
Sargan-Hansen statistic	-		-	Chi-sq (1) P-value: .3041

Note: * denotes .01 significance level. ** denotes .05 significance level. *** denotes .10 significance level. Cluster-robust standard errors were used in the FE-2SLS, Lewbel-2SLS and the CF estimators. Robust standard errors were used in the RE-2SLS estimator. The Lewbel-2SLS method was applied with generated instruments and external instruments.

differences in income between the rich and the poor (Granö, 2024), it could be expected that being positioned at the bottom of the income distribution leads to an increase in individuals' relative exposure to income inequality due to their increased relative distance to the median. This also reflects the absence of upward mobility at the lowest end of the income distribution (The Organization of Economic Co-operation and Development [OECD] 2018). On the other hand, individuals' relative exposure to income inequality is observed to decline in higher income brackets due to their decreased relative distance to the median. Finally, access to the ICT services, such as the Internet, may lead to an increase in individuals' relative exposure to income inequality overall due to their increased relative distance to the median and their inability to monetise this technology (Afzal et al., 2022).

In the previous paragraph, the overall trend observed in the relationship between personal income inequality and its determinants was discussed. However, in addition to the relationship of fuel poverty to personal income inequality, the relationship of being married, obtaining income, higher education, homeownership, household size, being in arrears on instalments, and internet access at home to personal income inequality is also found to be heterogeneous across income groups inTable 5. It is expected from the relevant literature that the poorest can benefit from marriage if governments support individuals who are going to marry to improve the economic situation of these individuals and reduce inequality (Randles, 2012). On the other hand, marriage could widen the income gap at the top through much higher incomes, possibly because of the presence of secure jobs, advanced education, and strong family background of partners. Similarly, obtaining a stable and secure income at the bottom may help reduce individuals' relative exposure to income inequality , as the poorest in this segment may catch up with the better off on average (Mutlugün, 2024). On the other hand, it may increase individuals' relative exposure to income inequality at the top, probably because of the presence of a high level of income in this segment. In addition, increasing educational attainment at the bottom may lead to a reduction in relative exposure to income inequality, as it is more likely to increase income in the lowest segment (Şenol and Orhan, 2021). On the other hand, higher education may lead to an increase in the income gap at the top, probably because of the presence of a higher relative advantage in terms of income at the highest end. Furthermore, the poorest at the bottom may benefit from homeownership, which may reduce their relative exposure to income inequality, as it rules out rental costs (Cima and Kopecky, 2025). On the other hand, homeownership levels at the top may lead to an increase in the relative exposure to income inequality, probably because of increased relative income advantage at the highest end due to reduced housing costs. Finally, improved access to the internet at the lowest segment may help reduce their relative exposure to income inequality, probably because of increased job opportunities and thereby, increased and equalised income (Ndjobo and Otabela, 2023). On the other hand, increased access to the internet may lead to an increase in the relative exposure to income inequality at the top, probably because of increased relative income advantage at the highest end. This may result from the digital divide that may appear because of high skills at the highest end (Zhang et al., 2025). On the other hand, an increase in household size may lead to a further decline in incomes and an increase in living costs at the lowest end (Bitana et al., 2024). This may result in increased relative disadvantage at the lowest segment and distort their relative position in the income distribution. On the other hand, an increase in household size may

Table 5
FE (Linear) vs. RE (Linear-Nonlinear: Probit) Estimator Findings.

Variables	FE and RE Estimators					
Dependent variable: Personal income inequality	FE Estimator		RE Estimator		RE-Probit Estimator (Marginal Effects)	
	1st Income Quantile	3rd Income Quantile	1st Income Quantile	3rd Income Quantile	1st Income Quantile	3rd Income Quantile
Fuel poverty	.0347**	−.0451***	.1321*	−.0711*	.1401*	−.0643*
	(.0140)	(.0238)	(.0083)	(.0164)	(.0083)	(.0120)
Age (65+)	.2246*	.0186	.0138	−.0092	.0127	−.0077
	(.0539)	(.0303)	(.0155)	(.0129)	(.0148)	(.0116)
Poor health	−.0005	−.0099	.0059	−.0182	.0045	−.0166
	(.0145)	(.0164)	(.0112)	(.0132)	(.0115)	(.0116)
Married	−.1136*	.0587*	−.0333*	.0196**	−.0291*	.0187**
	(.0437)	(.0199)	(.0096)	(.0079)	(.0096)	(.0073)
On income	−.0499*	.0236	−.0509*	.0272*	−.0542*	.0291*
	(.0133)	(.0146)	(.0084)	(.0078)	(.0083)	(.0069)
Higher education	−.0953	−.0284	−.0632**	.1105*	−.0556**	.1265*
	(.1055)	(.0539)	(.0283)	(.0076)	(.0259)	(.0089)
Homeowner	−.0776*	.0346**	−.0473*	.0393*	−.0457*	.0421*
	(.0284)	(.0137)	(.0091)	(.0073)	(.0089)	(.0069)
Household size	.0044	−.0046	.0390*	−.0295*	.0428*	−.0302*
	(.0066)	(.0097)	(.0020)	(.0031)	(.0022)	(.0027)
Arrears on instalments	.0133	.0097	.0185**	−.0071	.0200**	−.0161***
	(.0095)	(.0123)	(.0079)	(.0101)	(.0085)	(.0092)
Internet access at home	.0128	.0205***	−.0506*	.0708*	−.0659*	.0809*
	(.0103)	(.0122)	(.0077)	(.0097)	(.0081)	(.0082)
_cons	.7329*	.7657*	.4862*	.7558*	-	-
	(.0466)	(.0436)	(.0149)	(.0154)		
Sigma_u	.4196	.3533	.2850	.2751	-	-
Sigma_e	.3706	.2859	.3706	.2859	-	-
rho	.5617	.6042	.3716	.4807	-	-
Number of observations	17.478	17.474	17.478	17.474	17.478	17.474
Number of clusters	6765	6475	6765	6475	6765	6475

Note: * denotes .01 significance level. ** denotes .05 significance level. *** denotes .10 significance level. Cluster-robust standard errors are in parentheses. 1st income quantile (in real terms): 226.19 TL – 12.965,97 TL. 3rd income quantile (in real terms): 21.992,27 TL – 725.593,37 TL.

decrease individuals' relative exposure to income inequality at the top of the income distribution, probably because of reduced incomes at the highest end due to the increased cost of living (Ebert, 1995). Finally, arrears on instalments at the lowest end are more likely to increase individuals' relative exposure to income inequality , probably because of the credit cards' and loan payments' relatively higher burden on individuals' budgets (De Vita and Luo, 2021). Both RE and RE-Probit estimators in Table 5 support these findings.

4.2.2. Policy implications

It is understood from this study that it may not always be true to directly say that fuel poverty leads to income inequality. The negative relationship may seem counterintuitive, but it may imply that the relationship is much more nuanced and is heterogeneous across income categories. Therefore, it is crucial to look beyond what is seen using various techniques and implement relevant policies based on changing needs because one-size-fits-all policies are not efficient to handle this issue. In this case, energy policies should go hand in hand with social policies to provide a more sustainable future for all individuals.

The positive relationship between personal income inequality and fuel poverty at the bottom implies that policies that aim at affordable and clean energy may also help reduce individuals' relative exposure to income inequality in an overall income distribution. The poorest can escape fuel poverty if they are supported with adequate (increased) income for energy costs, proper insulation, and the provision of efficient energy (Jové-Llopis and Trujillo-Baute, 2024). Thus, income inequality will be reduced at the bottom. More specifically, the poorest residing in poor-quality dwellings may be supported through government-backed retrofits and energy-efficient heating systems such as heat pumps and solar heating systems to achieve clean and affordable energy at home. In addition, low-interest bank loans may be provided for proper insulation to curb individual energy poverty in middle and lower-middle segments. It is also of utmost importance to help the most vulnerable heat their homes through energy vouchers and means-tested heating benefits in winter. Considering that they may face multiple deprivations to sustain their lives, the importance of government-backed benefits and decent job opportunities will be better understood. Progressive pricing could be a relevant option to reduce energy poverty, especially for the poorest segment, because they are the ones who suffer from inadequate and inefficient heating the most. However, this policy option particularly requires a proper means test and/or income threshold to properly target the most vulnerable and those who genuinely need financial assistance. At this point, the implication is that it is vital to determine this policy not just by considering a common, minimum required energy consumption threshold and a specific energy source (Emre, 2025), but also by allowing for various energy sources, determining a required income threshold (Jové-Llopis et al., 2025) for different household types, and categorizing the dwelling types for the most vulnerable to help them maintain a decent standard of living. It is noteworthy to consider that high energy consumption does not automatically mean someone is better off. For instance, the elderly and the patients usually require more energy at home (Chard and Walker, 2016). If the main caregiver is a pensioner, for instance, it could be quite hard to make a good living. Finally, the most vulnerable individuals could alleviate their fuel poverty by receiving support from energy advisors found in the cities to identify the program best suited to their needs based on their household type and consumption patterns.

On the other hand, awareness campaigns should be first launched for the relatively lower segments at the top to help them understand the importance of energy efficiency in reducing their superfluous costs because of a possible poor insulation problem. The implication is that energy poverty may also appear at higher income levels due to the old, large houses, poor insulation, energy loss in buildings, and inefficient heating systems. Therefore, they should be first targeted at the top. This means that it should be compulsory to conduct building-based energy audits in the lower segment of the highest end. Providing retrofit incentives with the optimum cost for the higher-income, energy-poor individuals is also required to alleviate energy poverty in this segment (Aruta et al., 2025). Obtaining energy performance certificates for the buildings (Nunes and Lopes, 2024) is also required to improve housing quality and reduce energy poverty by reducing energy costs of individuals in this segment at the top. This may provide an improvement in economic welfare, although individuals' relative exposure to income inequality may increase if energy poverty decreases at the top. This increase in personal income inequality is not driven by the worsening condition of the lower segments at the top; rather, it is a result of them capturing efficiency gains associated with greater economic prosperity because of a decline in energy poverty. This brings to mind the traditional economic theory suggesting that efficiency and equality are fundamentally in conflict (Choi, 2019). At this point, it is important to differentiate between welfare loss and an increase in relative exposure to income inequality, and welfare gains and an increase in relative exposure to income inequality. The key point here is that the rise in inequality should not be viewed as an adverse condition; for in such a scenario, deprivation would have improved, welfare loss would have decreased, and individuals would likely no longer identify themselves as energy-poor.

This study particularly focuses on the nature of the relationship between personal income inequality and fuel poverty in Türkiye. The econometric analyses reveal that this relationship is heterogeneous across income groups. However, the findings are not limited to this relationship. The study also identifies other variables whose relationship with individuals' relative exposure to income inequality -apart from fuel poverty-is heterogeneous. At this point, the suggested policies should primarily target the bottom part of the income distribution. The findings of the heterogeneity analysis imply that governments should support soon-to-wed couples whose total income is below a specific threshold to encourage marriage and reduce their relative exposure to income inequality in an overall income distribution. At this point, determining a specific income threshold that could help improve individuals' relative position in the income distribution comes into prominence. In addition, those who are vulnerable to income inequality should also be properly targeted according to the sub-groups (those with poor health and low educational level; those who have precarious/insecure jobs, etc.) while implementing this policy. Furthermore, inequalities in access to opportunities such as higher education should be narrowed in favour of the poor through awareness campaigns regarding the importance of education to increase their chances of finding a decent job in the future. It is also of the utmost importance that the government should support those who want to receive decent higher education through wide-ranging scholarships and interest-free loans (Furuta, 2026; Gupta et al., 2026). The poor should also be supported by the government and banks through interest-free or low-interest mortgage credits when they intend to buy a house and reduce their costs, such as rent. Additionally, vulnerable individuals such as those who need adequate income, those with children and who have extended families, and those who are insolvent should be supported through employment centres to find a proper job if they are unemployed or have precarious jobs. In addition, public retirement pensions should also be increased in line with the economic conditions; more comfortable living conditions should be provided for the vulnerable pensioners by reducing their relative exposure to higher income inequality (Doctrinal, 2024). Alternatively, palliative income benefits and debt restructuring programs may be provided for the most vulnerable to recover from debts and reduce their exposure to higher income inequality. Finally, internet access should be expanded at the bottom part of the income distribution to especially increase opportunities regarding job search and reduce their relative exposure to higher income inequality (Denzer et al., 2021). The prevalence of these services depends largely on boosting affordability through corporate discount campaigns and government support targeting the most vulnerable groups. Besides, to improve overall societal well-being, fair wealth and income taxes should be implemented according to the

income categories and forms for which individuals' relative exposure to income inequality increases (Delestre et al., 2024).

5. Conclusion

This study used micro-panel data to mainly capture more nuanced information on the relationship between personal income inequality and fuel poverty in Türkiye within different data contexts, considering potential endogeneity of fuel poverty. The importance of addressing endogeneity manifests itself in the Sustainable Development Goals, as each goal is interrelated. All estimators used in the analyses referred to the same finding that fuel poverty is, on average,negatively related to personal income inequality in Türkiye. The heterogeneity analysis, on the other hand, reveals that fuel poverty appears in different income brackets, and its relationship to the individuals' relative exposure to income inequality differs across the income groups. Yet, it is found that the most vulnerable particularly suffer from the adverse consequences of fuel poverty, and as a result, their relative position in the income distribution deteriorates. Therefore, the microeconomic analysis once again demonstrates that the policies should target the bottom end of the income distribution first to tackle fuel poverty and improve individuals'relative position in the income distribution.

The main contribution of the study was to measure income inequality on a micro scale, revealing the individuals' relative position in the income distribution. Another contribution of the study was to examine the micro-heterogeneous relationship of fuel poverty to income inequality to find out whether this relationship differs across income categories. The final contribution of the study was to suggest instruments for fuel poverty on a micro level for the first time in the literature while examining its relationship to personal income inequality. These contributions are expected to partly fill the gap on the microeconomic perspective in both domestic and international literature.

The main drawback of this study was that the bivariate probit model could not be used as a robustness check for the LPM-2SLS estimator. The reason was that some technical problems, such as poor convergence, were encountered when using this model with panel data, due to perfect or quasi-perfect prediction issues (Nahhas, 2025; Villa-Cox et al., 2017). Instead, a pooled IV-Probit model was used to take the binary characteristic of the dependent variable into account. Although supported by the theoretical literature, the selection of instrumental variables has also been constrained by data limitations. Therefore, in the initial phase, evaluating the instrumental variables used to explain fuel poverty at the micro level as a suggestion is of significant importance for the further development of the relevant literature through other studies. The lack of regional and urban-rural data was another problem; the possible changes to emerge in this relationship according to the regional characteristics could not be observed because of this constraint. Considering that both energy poverty and income inequality differ across the regions of the country, the lack of spatial information is more likely to mask related dynamics regarding the relationship.

The model included some context-specific variables that are expected to be closely related to the topic, based on the relevant literature. More importantly, this study conceptualized fuel poverty and income inequality adopting a socioeconomic vulnerability perspective, trying to look beyond the energy access and summary inequality statistic issues. This perspective was adopted to reveal the relevant mechanism that deepens individuals' vulnerable positions in an income distribution. The variables were selected based on their relationship to the concepts of social exclusion/vulnerability, financial situation, and material deprivation. On the other hand, technical variables such as dwelling age, size and type; heating system; and primary fuel type were deliberately excluded from the models, owing to their close relationship with spatial energy structures and planning, housing technologies and infrastructure, forms of urbanisation and residential energy choices/consumption, rather than individual subjective vulnerability (Çebi Karaaslan et al., 2022). This approach can be considered a theoretical boundary of this study and should be addressed in future research, considering the research focus.

Keeping these issues in mind, first, it would be better if future studies could especially integrate the bivariate probit model into the analysis, if applicable, since this is the main technical limitation of the study. Second, they could re-examine this relationship on a regional basis, as both energy poverty and income inequalities were more likely to differ across the regions of Türkiye. Additionally, several variables, namely the main heating system, fuel and dwelling types, and monthly housing expenditures, could be added to the model according to the regional characteristics. Third, it is noteworthy to look at the energy poverty issue from the expenditure perspective as energy expenditures in different income groups and their relationship to income inequality may reveal more detailed information regarding individual standard of living and enable more concrete policy conclusions related to clean and efficient energy use. Fourth, income inequality could be re-measured through aggregate measures such as the Gini coefficient and the Theil index to understand whether the relationship changes when a different measurement method is used. Fifth, doing spatial analysis is equally important to advance this relationship by particularly focusing on geographical and infrastructural causes of social exclusion and socioeconomic vulnerability. Sixth, a threshold analysis could be applied to understand which individuals are the most vulnerable in the country, especially in terms of income, how this problem affects different definitions of energy poverty and income inequality, and what strategy should be used to improve overall living standards. Seventh, comparative research with cluster analysis is required to position the energy poverty situation of Türkiye in a wider context and fight against both energy poverty and income inequality, as energy poverty may reveal itself in different ways in different countries. Finally, examining the relationship between energy poverty and income inequality through dynamic modelling in the next step may contribute to a better and more detailed understanding of the issue as compared to the static modelling.

CRediT authorship contribution statement

Simge Günay: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Bekir Kayacan:** Conceptualization, Methodology, Resources, Supervision, Validation, Writing – review & editing. **Meltem Ucal:** Conceptualization, Methodology, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare no competing interests.

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Data availability

The data that has been used is confidential.

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