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Assessing the impact of marketization on energy poverty

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Abstract
In conjunction with economic growth, improving the quality of life for its citizens is a central concern for the Chinese government. Energy poverty, a topic closely linked to people's quality of life, has garnered global attention. This study examines the relationship between marketization and energy poverty by constructing provincial-level panel data using the fixed effect model. To address endogeneity, the instrumental variable method is further employed. The study obtains two major findings. First, the study reveals a significant upward trend in marketization in China in recent years, with a concomitant decrease in energy poverty. Here, the causal (and negative) effects of marketization on energy poverty are identified. Second, the mechanism analysis shows that this effect operates through (i) improvements in the quantity of energy supply (rather than energy supply efficiency), (ii) the accumulation of human capital that promotes the use of clean energy, and (iii) an increase in people's income. This study makes three key contributions. First, it empirically analyzes the impact of marketization on energy poverty from a macro-perspective. Second, it systematically discusses the pathways through which marketization operates. Third, drawing on several theories, it provides a deeper understanding of the theoretical connection between marketization and energy poverty.

Keywords Energy poverty · Marketization · Instrumental variable · China

1 Introduction

Persistent energy poverty is one of the three major challenges that the world's energy systems are currently facing, which hampers economic development and the improvement of livelihoods. Therefore, the concept of energy poverty has garnered the attention of numerous countries and international organizations since its emergence (Lin & Wang, 2020). The primary causes of energy poverty are consistently identified as high energy prices and low per capita income (Primc et al., 2019). However, to date, there is no universally accepted definition of energy poverty. The most commonly used definition comes from The International Energy Agency, which defines energy poverty as the lack of access to electricity services or reliance on traditional biomass energy sources (IEA, 2010). As the world's environmental issues become more prominent, increasing research is focusing on the utilization of alternative and green energy sources, such as biomass solid fuels (Mardoyan & Braun,

Extended author information available on the last page of the article

2015) and biomass diesel (Maroušek et al., 2023a). Consequently, the concept of energy poverty is also gradually becoming intertwined with modern clean energy access (Barroco et al., 2021).

Energy poverty has a substantial negative impact on social and economic development. Pan et al. (2021) state that energy poverty has a substantial negative effect on public health. Hassan et al. (2022) indicate that energy poverty intensifies pressure on the environment. Furthermore, the detrimental effects of energy poverty on education and subjective well-being have also received extensive attention (Churchill et al., 2020). Following the COVID-19 pandemic and the subsequent global turbulence, the uncertainty surrounding energy prices have risen (Vochozka et al., 2020a), particularly because international energy prices are closely linked to exchange rates (Vochozka et al., 2020b). This linkage affects the relative cost of energy and escalates the risks associated with energy poverty owing to its unaffordability.

Current research on energy poverty is being conducted at micro- and macro-levels. At the micro-level, researchers have focused on the relationship between energy poverty and various factors such as education (Oum, 2019), health (Liu & Hu, 2023), gender equality (Nguyen & Su, 2021), family dynamics (Qurat-ul-Ann & Mirza, 2021), employment (Bienvenido-Huertas, 2021), and micro-level climate change responses (Yadava & Sinha, 2022). At the macro-level, research has primarily examined the linkages and impacts of energy poverty on the environment (Ansari et al., 2022) and socioeconomic development (Henry et al., 2021). These studies have deepened our understanding of the hazards associated with energy poverty and provided insights into responses to energy poverty from both macro- and micro-perspectives across various subject areas.

However, at the macro-level, there has been limited research on the relationship between energy poverty and marketization. Wang et al. (2022) discuss the mediating effect of marketization and find that marketization significantly contributes to the alleviation of energy poverty through renewable energy technologies. Another study reveals that market-based development in rural China can reduce the incidence of energy poverty (Ren et al., 2022). To further provide a comprehensive overview of the current state of research on energy poverty and marketization, we summarize recent studies in Table 1. Nevertheless, to the best of our knowledge, there are few studies that directly and systematically examine the relationship between marketization and energy poverty at the macro-level. Marketization is often understood as the process of shifting goods and services provided through bureaucratic and political means to market-based arrangements (Crouch, 2009). It is considered a powerful tool for poverty reduction (Araujo & Pels, 2015) and is deemed to play a vital role in promoting socioeconomic development. In Asia, marketization reforms in Vietnamese agriculture have significantly increased rice and agricultural productivity (Kompas et al., 2012). Laos has improved the livelihoods of its people through a degree of marketization in the resource sector (Rigg, 2006). However, there are also dissenting views in the discussion of the role of marketization. Market-based reforms in Ethiopia exacerbate inequality (Mulugeta, 2006), and in the US, market-based reforms in education have not yielded the expected results (Bartlett et al., 2002). These varying outcomes suggest that the impact of marketization in a specific field remains unclear. Therefore, the central question of interest in this paper is: What role does marketization, closely associated with economic development and poverty reduction, play in reducing energy poverty? To explore this question, we conducted our study in China. This choice is based on the fact that China has undergone a comprehensive transition from a planned economy to a market economy. Studying China's market-oriented development path can more clearly demonstrate the benefits and drawbacks of market-oriented development on the social and economic aspects of society.

Table 1 Review of relevant literature

Theme	Elements	Author Information	Outline
Energy poverty	Factors affecting energy poverty	Shettima et al., 2023	This study explores the impact of violent conflict on energy poverty in sub-Saharan Africa, empirically revealing that violent conflict exacerbates energy poverty
	Energy poverty measurement	Dagher et al., 2023	This study measures the incidence of energy poverty in Lebanon using three energy poverty measures and finds that the incidence of energy poverty in Lebanon is very high
	Factors affecting energy poverty	Yin et al., 2023	This study discusses the impact of financial inclusion on energy poverty in China, suggesting that the development of financial inclusion can effectively reduce energy poverty in the country
	Factors affecting energy poverty	Shi et al., 2023	This study examines the impact of household labor mobility on energy poverty in China and finds that household mobility in China reduces the incidence of energy poverty
Marketization	Role of marketization	Yan et al., 2023	This study discusses the industrial upgrading effect of marketization on Information and Communication Technology (ICT) investment, pointing out that a more favorable marketization environment can enhance the positive impact of ICT investment on industrial structure upgrading
	Role of marketization	Hazan et al., 2023	This study discusses the relationship between marketization and female childbearing, noting that marketization can promote childbearing among highly educated women
	Role of marketization	Zhang et al., 2022	This study explores the relationship between marketization and the R&D efficiency of enterprises and suggests that the development of marketization can effectively enhance the R&D efficiency of enterprises
Energy poverty and marketization	The role of marketization in regulating energy poverty	Wang et al., 2022	This study discusses the role of marketization in mitigating energy poverty through renewable energy sources. The results of the study indicate that increased marketization can effectively contribute to the alleviation of energy poverty through renewable energy sources
	The impact of marketization on rural energy poverty from a unilateral perspective	Ren et al., 2022	This study discusses the role of marketization in alleviating rural energy poverty in China, highlighting an inverted U-shaped relationship between marketization and the alleviation of rural energy poverty in China

China's marketization reform involves fundamental institutional changes in economic, legal, social, and political systems (Fan et al., 2003). These reforms have facilitated rapid economic development in China by enhancing total factor productivity (Yao and Wang, 2003), improving resource allocation efficiency (Hsieh & Klenow, 2009), and expanding market potential (Lv & Zhu, 2016).

In summary, current research on energy poverty has placed less emphasis on the impact of socioeconomic development on energy poverty from a macro-perspective, particularly in our increasingly open and inclusive world where the market economy has become the mainstream of global economic development. Motivated by the lack of empirical evidence regarding the socioeconomic role of marketization at the macro-level, we explore the impact of marketization on energy poverty. Our primary focus revolves around addressing the following questions: (i) Can marketization alleviate the occurrence of energy poverty? and (ii) If so, through what mechanisms does marketization impact energy poverty? To investigate the relationship between marketization and energy poverty, we consider China as a case study, constructing panel data from 2002 to 2016 using a two-way fixed effects model. We use the marketization gene as an instrumental variable to address endogeneity concerns in the model. Furthermore, we delve into the underlying mechanisms connecting marketization and energy poverty, offering relevant recommendations based on our empirical findings. These suggestions can serve as references for other countries in their pursuit of market-based development and the mitigation of energy poverty.

The primary marginal contributions of this study are as follows: First, it directly analyzes the impact of marketization on energy poverty from a macro-perspective. This differs from previous studies, which often treated marketization as an intermediary pathway or discussed it solely from either a rural or urban perspective. This approach fills a gap in the current discourse on the relationship between marketization and energy poverty. Second, the study broadens our understanding of the role of marketization and systematically examines its impact through three dimensions: energy supply, human capital, and disposable income. Finally, drawing on the Capacity Approach theory, Sustainable Development theory, and Green Development theory, this study further develops the theoretical foundations underlying the relationship between marketization and energy poverty. Additionally, it enhances our understanding of how these theories manifest in the real world.

2 Theoretical frameworks and hypotheses

Marketization is an essential tool for fostering economic growth and optimizing resource allocation. It also serves as a significant means to combat poverty (Araujo & Pels, 2015). Poverty is multifaceted (Dou et al., 2022), and the eradication of energy poverty is an important dimension and aspect of the broader poverty eradication efforts. In recent years, as the world has progressively opened up, marketization has become unavoidable, and its potential impact on poverty reduction may be substantial. With this in mind, we propose the following hypothesis:

H1: The development of marketization significantly reduces the incidence of energy poverty.

With the development of marketization, the emergence of various market production practices will inevitably drive the supply of energy to meet its increasing demand. Furthermore, with increased economic development, more countries and regions have begun to prioritize the establishment of sustainable communities, and marketization can effectively

contribute to the development of sustainable communities (Zhou, 2015). A sustainable community is a settlement within an appropriate geographic area and population size, characterized by a shared eco-cultural consciousness and ecological development that fosters a pleasant environment, social harmony, and economic efficiency (Haight, 2001). An important measure in building sustainable communities is the efficient and clean use of energy (Karaca et al., 2023), which encompasses both energy efficiency and energy supply.

At the energy supply level, economic growth due to market development has boosted China's energy sector, with investment in the energy industry increasing from 426.194 billion yuan (59.88 billion USD[1]) in 2002 to 3,225.906 billion yuan (453.28 billion USD) in 2017, and electricity supply increasing from 165.4 billion kWh in 2002 to 853.45 billion kWh in 2021.[2] Furthermore, market-oriented reforms have enhanced the efficiency of China's agricultural production, primarily through the implementation of the "household contract responsibility system," granting industrial operators greater autonomy in their operations. Additionally, China has established numerous special economic zones to attract foreign investment, and all these reforms have significantly improved the efficiency of resource allocation in the country (Sachs & Woo, 1994). In summary, the increase in energy supply and the improvement in energy efficiency are effective in meeting the energy demands of the population and allocating energy resources more efficiently. Consequently, this can help reduce energy poverty. Therefore, we propose the following hypothesis:

H2a: Marketization can promote the supply of energy, which includes supply quantity and supply efficiency.

The green premium represents the additional cost incurred when upgrading an existing fossil energy source or technology to a zero-emissions fuel or technology. It can be understood as the extra cost borne by consumers for fuel or technology that reduces greenhouse gas emissions (Gates, 2021). The improvement in marketization has facilitated the emergence of green premiums, as marketization can effectively promote the accumulation of human capital, thereby increasing people's awareness of the significance of clean energy. Some studies have indicated that green premiums can contribute to reducing the prevalence of energy poverty (Saunders et al., 2012). Furthermore, market economy intervention can better align with the growing clean energy needs as human capital increases. It can drive the development and utilization of new clean energy sources such as biogas (Bencoova et al., 2021) and biodiesel (Maroušek et al., 2023b), reducing reliance on traditional high-pollution energy sources and energy prices. Consequently, this intervention can alleviate the incidence of energy poverty. In light of this, we propose the following hypothesis:

H2b: The facilitative impact of marketization on human capital makes individuals more inclined to embrace the green premium for utilizing clean energy, thereby reducing the incidence of energy poverty.

One of the primary causes of energy poverty is low disposable income, and the income-boosting effect of marketization is particularly pronounced in China. With a nearly 22.8-fold increase in per capita disposable income over the course of the 40 years of market-oriented reforms in China, marketization has undeniably played a substantial role in income growth. The mitigating effects of increased income on energy poverty have also been extensively documented (Nguyen & Su, 2022). Furthermore, efficiency is a central objective of marketization. Marketization's pursuit of efficiency drives the adoption of technologies such as big data technologies (Kovacova & Lăzăroiu, 2021), AI technology (Durana

[1] Full text is based on 2023 U.S.–China exchange rates.

[2] https://data.stats.gov.cn/easyquery.htm?cn=C01

et al., 2021), and automated intelligent technology (Zvarikova et al., 2021). These technologies can enhance production and market efficiency, consequently reducing the cost of energy usage and diminishing the likelihood of energy poverty. Therefore, we propose the following hypothesis:

H2c: An important goal of marketization is to foster economic development and elevate people's incomes. This increase in income enhances their purchasing power, ultimately improving energy access and reducing the prevalence of energy poverty.

3 Methodology

3.1 Data

Regarding the data, owing to data availability constraints (the Energy Poverty Index data covers the period from 2002 to 2017, while some control variables data only extends until 2016), we select the study period as 2002–2016. During this time frame, we construct a provincial panel dataset for China to empirically examine the influence of marketization on energy poverty.

The data used in this study have been primarily sourced from the Chinese Statistical Yearbook (2003–2017) and the Statistical Yearbook (2003–2017) from 30 provinces, excluding Tibet, Hong Kong, Macau, and Taiwan. This is because the statistical data of Tibet are scarce, and the statistical caliber used in Hong Kong, Macau, and Taiwan is inconsistent with that of mainland China. The marketization gene data are obtained from Zhang (1993). In some cases where provinces lack data on the first trade port, we substitute it with the trade time of their respective capital cities.

3.2 Study models

Following the discussion in Sect. 1, this study further investigates the impact of marketization on energy poverty, using China as a case study. We estimate a fixed effect model as follows:

$$\mathrm{EPI}_{it} = \beta_0 + \beta_1 \mathrm{MI}_{it} + \beta_2 X_{it} + u_i + \delta_t + \varepsilon_{it} \tag{1}$$

where EPI_{it} (the index of energy poverty) represents the energy poverty level in each province i,[3] in year t; MI_{it} (the index of marketization) refers to the marketization of province i in year t; X_{it} is a vector of province-level control variables, including the energy price index, condition of social security, creation ability, unemployment ratio, and investment in fixed assets of energy equipment; u_i captures the province fixed effects that remain constant through the year; δ_t captures the year's fixed effect that is similar to all provinces; and ε_{it} is a random error term. The coefficient of MI_{it}, β_1 is the focus of our study.

Although our measurement of marketization is comprehensive and we diligently control for other factors that may influence energy poverty, there are still two potential pathways that could lead to endogeneity. First, we assume that the growth of marketization influences energy poverty. However, it is plausible that fluctuations in energy poverty could also impact marketization. Energy poverty is closely tied to income inequality (Nguyen &

[3] Province is an administrative unit of China; it is the largest first-level administrative region in China, directly under the Central People's Government of China.

Nasir, 2021), and income disparity can affect purchasing power (Bergh & Nilsson, 2014), thereby influencing the development of marketization. This introduces the possibility of reverse causality. Second, owing to the complexity of our estimation, it is not feasible to account for all potential scenarios, and some information may be challenging to capture. Consequently, omitted information related to marketization might be included in the random error, leading to omitted variables that can cause endogeneity. In light of these considerations, we directly estimate Eq. (1) using instrumental variable methods in our baseline results, contrasting with our initial baseline model using the fixed effect model without instrumental variables. To address the endogeneity issue, we employ the marketization gene as an instrumental variable, which has been verified as a valid instrumental variable for marketization in the existing literature (Li et al., 2020). The "marketization gene" refers to the opening time of the first local trade port. Owing to the historical dependence of the economic system, marketization gene affects marketization by influencing the business environment. We discuss the exogeneity of the marketization gene in Sect. 4.3.1. The regression model for the first stage is as follows:

$$\mathrm{MI}_{it} = \beta_0 + \beta_1 OY_{it} + \beta_2 X_{it} + u_i + \delta_t + \varepsilon_{it} \tag{2}$$

where MI_{it} denotes the marketization index of each province for each year, and OY_{it} (number of years since the opening of the first trade port) denotes the market-oriented gene. The rest of the indicators are consistent with those in Eq. (1).

3.3 Study variables

3.3.1 Marketization

There is no universally accepted standard for measuring marketization; therefore, we utilize the marketization index from the "Marketization Index by Provinces in China," compiled by the Beijing National Economic Research Institute (Wang et al., 2019). Notably, the published marketization index is not directly comparable owing to calculations based on different base periods that change every few years. Thus, we adjust the marketization index to ensure comparability across different time periods. This index accounts for various factors, including the government–market relationship, development of the non-state-owned economy, level of market development, factor market's development, market system, and legal environment. It offers a comprehensive reflection of China's marketization development and has been frequently employed in recent studies. Prior to the widespread use of the marketization index, the ratio of the non-state industrial economy was commonly used as a proxy for assessing marketization. We employ both measures for robustness. Figure 1 illustrates the overall trend in China's marketization index development (refer to Figure 4 for the trends in each province). In general, China's marketization index exhibited an upward trajectory, increasing from 5.16 in 2002 to 9.14 in 2016, followed by a temporary decline around 2009, possibly due to the impact of the 2008 global financial crisis. Subsequently, the index resumed its upward trend, with an average annual growth rate of 5%.

3.3.2 Energy poverty

Energy poverty has been a widely discussed issue, but its measurement is challenging owing to its dynamic, private, and multidimensional nature (Thomson & Liddell, 2015). Generally, three main methods are employed to measure energy poverty at the

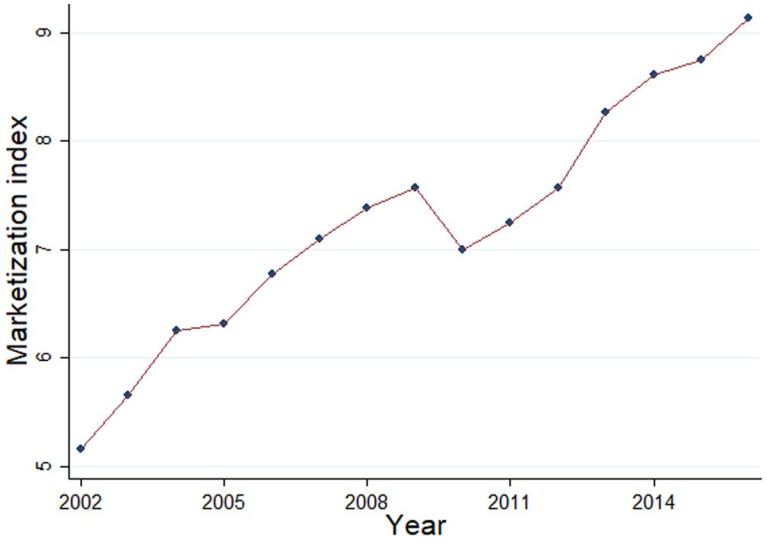

Fig. 1 Evolution of the marketization index

macro-level: technological, physical, and economic thresholds (Nguyen & Nasir, 2021). However, each of these methods assesses energy poverty from a single or limited perspective, which may not provide a precise reflection of the phenomenon. Therefore, it becomes essential to comprehensively and systematically evaluate energy poverty. Zhao et al. (2021) have devised an integrated index system comprising four aspects: energy service availability, energy consumption cleanliness, energy management completeness, and household energy affordability and efficiency. This system encompasses 17 measurement indicators and accounts for energy supply and energy quality, offering a comprehensive depiction of China's energy poverty. Therefore, we adopt this index as our proxy for energy poverty.

Figure 2 illustrates the changes in China's energy poverty index. According to the figure, China's energy poverty index exhibited a fluctuating downward trend, decreasing from 0.49 in 2002 to 0.42 in 2016. Prior to 2006, China's energy poverty level experienced an upward trend, but thereafter, the country's energy poverty index exhibited a rapid and stepwise decline (refer to Figure 5 for the trends in each province).

3.3.3 Control variables

We introduce the price index of energy (**PI**), social security spending as a share of GDP (**SS**), number of patents accepted (**IN**), unemployment rate (**UR**), and investment in fixed assets of energy equipment (**IF**). These variables represent the influence of price, innovation, employment, and energy facilities. Notably, in our baseline analysis, we do not control for population and GDP, as the calculation of the marketization index already incorporates information related to them. However, to enhance the robustness of our results, we include them as controls in the Appendix. Table 2 provides a detailed description and summary of all variables, with standard deviations presented in parentheses.

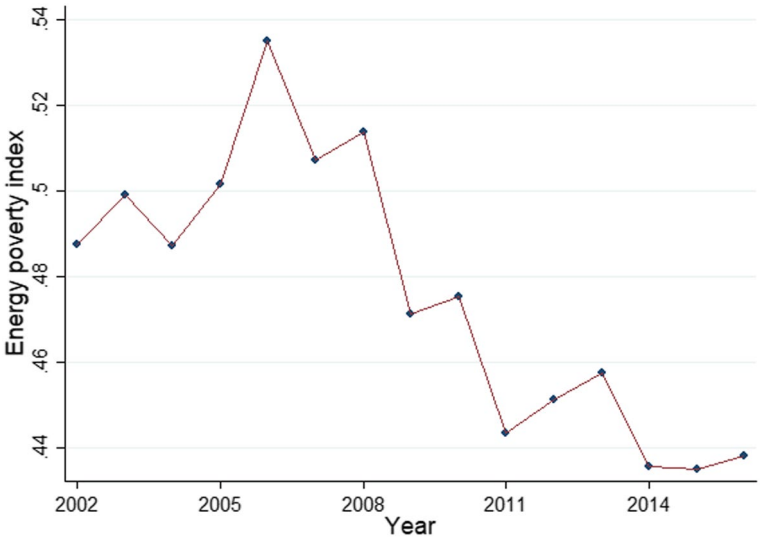

Fig. 2 Evolution of the energy poverty index

4 Results

4.1 Descriptive statistics

The average energy poverty index (**EPI**) for each province in China over the 15 years is 0.48, and the average marketization index is 7.25. The EPI exhibits significant regional variation, with an increasing trend from the east to the center and the west. Specifically, the average EPI for the three regions is 0.38, 0.50, and 0.55, respectively. In contrast, the marketization index (**MI**) follows the opposite pattern, decreasing from the east to the center and the west. The average MI for the three regions is 9.40, 6.79, and 5.44, respectively. Regarding energy prices, the average energy price (**PI**) for Chinese provinces over the years is 193.73. The annual average SS for each province is 3%. Regarding social innovation, the average annual IN in China's provinces is 41,000, with a noticeable upward trend over time, reflecting the growth in China's overall innovation capacity. The average annual UR for all provinces is 4%, displaying little fluctuation and indicating a generally stable employment market in China. The average IF by province for each year is 196.16 billion yuan (27.56 billion USD). The average number of years since the opening of the first commercial port (**OY**) in each province is 129.5 years. Additionally, the average total road and railroad mileage (**WY**) for each province in each year is 120,000 km. Concerning administrative divisions, the average number of county-level administrative districts (**CTS**) in each province for each year is 92.78. The average number of universities and high schools per year (**SC**) in each province is 558.04. The average annual per capita electricity consumption (**ECC**) in each province is 3,285.98 kWh/person, showing an increasing trend over the years. The average proportion of non-publicly owned industries above the scale (**PS**) in each province is 59%, mirroring the geographic distribution characteristics. Specifically, it averages 72% in the east, 58% in the center, and 46% in the west. Concerning resource endowment, the average annual coal reserves (**CR**) of each province are 96.42 million tons, and the average forest reserve (**FS**) is 36,676.35 million cubic meters. Regarding

Table 2 Summary statistics

Variable	Definition	Mean
EPI	The index of energy poverty	0.48 (0.14)
MI	The index of marketization	7.25 (2.56)
PI	The index of energy price	183.73 (48.68)
SS	Social security spending as a share of GDP (%)	2.91 (1.74)
IN	Number of patents accepted (1000 items)	41.00 (76.00)
UR	Ratio of unemployment (%)	3.62 (0.70)
IF	Investment in fixed assets of energy equipment (billion yuan/USD)	196.19/27.57 (155.88/21.90)
OY	Number of years since the opening of the first trade port (years)	129.50 (26.03)
WY	Total rail and road mileage (million km)	12.00 (7.30)
CTS	Number of county-level administrative districts	92.78 (44.94)
SC	Number of universities and high schools in each province	558.04 (253.32)
ECC	Electricity consumption per capita (kWh/person)	3285.98 (2239.44)
PS	Proportion of non-public industrial economy above designated size (%)	58.79 (19.25)
CR	Coal reserves (million tons)	96.42 (205.51)
FS	Forest stock (million cubic meters)	36,676.35 (46,837.62)
ADA	Agricultural disaster area (1000 hectares)	1229.68 (1056.91)
EGC	Electricity generation per capita (100 million kWh/10,000 people)	0.34 (0.27)
SE	Power supply efficiency	0.65 (0.23)
CLE	Natural gas supply (billion cubic meters)	17.78 (25.34)
HC	Human capital (1000 yuan/USD)	253.54/35.62 (146.70/20.61)
DI	Per capita disposable income by province (yuan/USD)	12,581.04/1767.79 (8688.21/1220.80)
GDP	GDP by province (billion yuan/ USD)	13,117.33/1843.15 (13,381.16/1880.22)
POP	Population by province (ten thousand people)	4416.03 (2682.09)

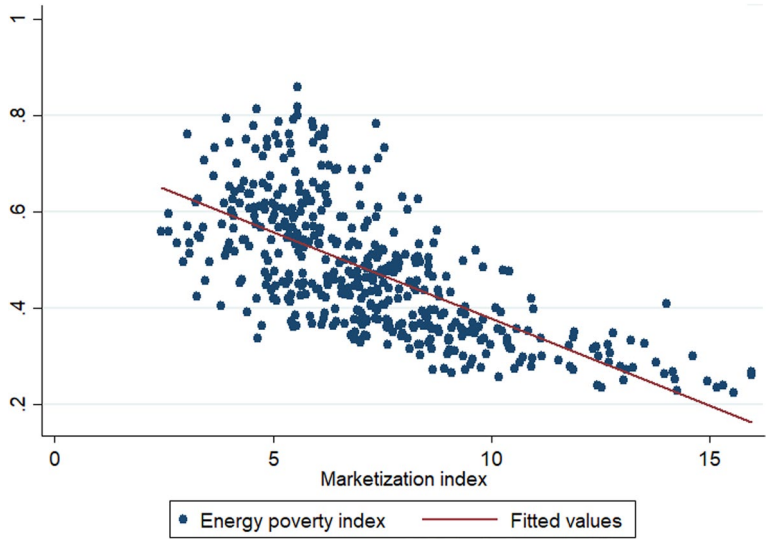

Fig. 3 Energy poverty index and marketization relationship

agricultural disasters, the average annual agricultural disaster area (**ADA**) of each province is 1,229.68 thousand hectares. Regarding energy supply, the average power generation (**EGC**) of each province each year is 0.34 billion kWh/10,000 people, and the average energy supply efficiency (**SE**) each year is 0.65. The average natural gas supply (**CLE**) of each province per year is 1.778 billion cubic meters. Furthermore, the average human capital (**HC**) for each year is 253.5 thousand yuan (35.61 thousand USD). Regarding residents' income, the average disposable income (**DI**) of each province is 12,581.04 yuan (1,767.79 USD) per capita, demonstrating an overall upward trend year by year. The average GDP of each province per year is 1,311.733 billion yuan (184.31 billion USD), and the average population (**POP**) is 44,160,300. These statistics provide a comprehensive overview of the various factors considered in the study across different regions and years.

4.2 Baseline results

We initially create a scatter plot illustrating the relationship between the marketization index and the energy poverty index, as depicted in Fig. 3. This plot clearly demonstrates a noticeable negative correlation between the energy poverty index and market-oriented development, providing initial support for Hypothesis 1. Table 3 presents the baseline results of the relationship between energy poverty and marketization in China. Columns (1–3) display the outcomes without the inclusion of instrumental variables, while Columns (4–6) reveal the results derived from a fixed effects model employing instrumental variables. Upon conducting the estimation using the instrumental variables method, we observe statistically significant relationships between marketization and energy poverty in Columns (4–6). The first-stage regression results can be found in the Appendix. In Column (6), which incorporates both control variables and controls for time fixed effects, the coefficient of marketization is −0.0311. This suggests that a one-unit increase in the marketization index is associated with a decrease in 0.0311 in

Table 3 Baseline results

	(1)	(2)	(3)	(4)	(5)	(6)
Regression methods	FE	FE	FE	IV-FE	IV-FE	IV-FE
Variables	EPI	EPI	EPI	EPI	EPI	EPI
MI	−0.0158***	−0.00692	−0.00922	−0.0231***	−0.0298***	−0.0311**
	(0.00336)	(0.00622)	(0.00739)	(0.00497)	(0.0103)	(0.0123)
PI		−5.05e−05	0.000692		0.000196	0.000473
		(0.000167)	(0.000562)		(0.000189)	(0.000463)
SS		−0.00227	0.00465		0.000307	0.00335
		(0.00326)	(0.00686)		(0.00624)	(0.00701)
IN		−7.23e−05	0.000126		0.000270	0.000362*
		(0.000122)	(0.000142)		(0.000188)	(0.000209)
UR		0.0249*	0.00472		0.0217	0.00745
		(0.0131)	(0.0102)		(0.0137)	(0.0112)
IF		−3.40e−05	3.14e−06		−4.48e−05	−4.37e−05
		(3.91e−05)	(4.71e−05)		(4.52e−05)	(5.87e−05)
Constant	0.591***	0.462***	0.433***	0.643***	0.575***	0.563***
	(0.0244)	(0.0708)	(0.0991)	(0.0360)	(0.0736)	(0.0639)
Province fixed effect	YES	YES	YES	YES	YES	YES
Time fixed effect	NO	NO	YES	NO	NO	YES
Observations	450	450	450	450	450	450
R-squared	0.145	0.192	0.351			
Number of provinces	30	30	30	30	30	30

Table 3 presents the baseline regression results, with Columns (1)–(3) displaying the outcomes without the instrumental variable, while Columns (4)–(6) exhibit the results with the instrumental variable. In all columns, the marketization index (MI) is the key explanatory variable. Upon introducing the instrumental variable, the regression coefficient of marketization on energy poverty in Columns (4)–(6) becomes significantly negative. Specifically, Column (4) showcases the regression outcomes without the inclusion of control variables and time fixed effects; Column (5) presents the regression results with control variables, such as the energy price index, social security, social innovation, unemployment rate, and energy infrastructure development, while not accounting for time fixed effects; and Column (6) exhibits the regression findings with both control variables and the incorporation of time fixed effects. ***, **, and * denote significance at 1%, 5%, and 10% levels, respectively

the energy poverty index. This finding aligns with the conclusions of Lyu et al. (2023) and Ren et al. (2022), who argue that marketization effectively alleviates energy poverty. They emphasize that any impediments to the marketization process would hinder efforts to alleviate energy poverty, providing further support for Hypothesis 1.

4.3 Robustness check

To ensure the robustness of our results, we conduct several sensitivity analyses, which include exclusive restriction, variable substitutions, and additional control variables. The outcomes of these robustness checks are displayed in Tables 4, 5, 6 and 7.

Table 4 Exclusive restriction

	(1)	(2)	(3)
Regression methods	FE	FE	FE
Variables	WY	CTS	SC
OY	0.178	0.0253	0.806
	(0.302)	(0.100)	(3.603)
Constant	−22.28	91.32***	522.7
	(34.17)	(11.53)	(415.6)
Controls	YES	YES	YES
Province fixed effect	YES	YES	YES
Time fixed effect	YES	YES	YES
Observations	450	450	450
R-squared	0.757	0.318	0.418
Number of provinces	30	30	30

Table 4 provides results from the exclusive restriction analysis. Columns (1) to (3) employ fixed effects models with control variables, accounting for both time and province fixed effects, with OY (marketization gene) as the core variable in each column. Column (1) examines whether the marketization gene reduces energy poverty by promoting road construction. The results indicate that the coefficient of OY is not statistically significant, suggesting that road construction is not an effective pathway for the marketization gene to impact energy poverty. Column (2) explores whether the marketization gene reduces energy poverty by increasing the number of local towns. Here again, the results show that the coefficient of OY is not statistically significant, indicating that an increase in the number of towns is not an effective pathway for the marketization gene to influence energy poverty. Column (3) investigates whether the marketization gene alleviates energy poverty by increasing the number of local schools. Once more, the regression results for OY do not reach statistical significance, rejecting this scenario. ***, **, and * denote significance at the 1, 5, and 10% levels, respectively

4.3.1 Exclusive restriction

To assess the validity of the instrumental variable, an exclusive restriction test is conducted. The marketization gene can influence energy poverty through its impact on local marketization development, but the establishment of commercial ports may also affect energy poverty by improving local transportation, urbanization, and education. In terms of transportation, the presence of commercial ports may lead to increased commercial exchanges, which could promote road construction. Improved road infrastructure might reduce energy access costs and enhance energy availability. We use the total rail and road mileage as a proxy variable for road construction because coal needed for power generation is mostly transported by rail, whereas road transport is not only an important supplement for transporting coal but also improves commuting efficiency. The construction of commercial ports due to the proliferation of commerce and the movement of people will also promote urbanization, attracting people from the countryside to move to the cities, thus potentially alleviating rural energy poverty. At the educational level, the construction of commercial ports brings new educational concepts and promotes the development of local education, which in turn may promote the accumulation of human capital and a change in

Table 5 Alternative measure for energy poverty

	(1)	(2)	(3)	(4)
Regression methods	FE	FE	IV-FE	IV-FE
Variables	ECC (log)	ECC (log)	ECC (log)	ECC (log)
MI	−0.0932**	−0.104***	0.303***	0.193**
	(0.0343)	(0.0286)	(0.0364)	(0.0847)
Constant	7.652***	7.748***	5.609***	5.987***
	(0.190)	(0.357)	(0.255)	(0.480)
Controls	NO	YES	NO	YES
Province fixed effect	YES	YES	YES	YES
Time fixed effect	YES	YES	YES	YES
Observations	450	450	450	450
R-squared	0.901	0.910		
Number of provinces	30	30	30	30

Table 5 presents the results after substituting the energy poverty index with per capita electricity energy consumption for each province. Columns (1) and (2) display the results using the fixed effects model without the instrumental variable, while Columns (3) and (4) reveal the results after incorporating the instrumental variable. All columns control for time and province fixed effects. Columns (1)–(3) do not include additional control variables, while Columns (2)–(4) do. It is essential to note that electricity energy consumption per capita differs from the energy poverty index. In this context, greater energy poverty is associated with lower per capita electricity consumption in each province. Initially, in Columns (1) and (2), the coefficient of marketization is significantly negative, which contradicts the baseline findings. This inconsistency may arise from endogeneity issues. However, after introducing the instrumental variable in Columns (3) and (4), the coefficients for marketization become positive and statistically significant at the 1% level. This indicates a significant positive relationship between marketization and per capita electricity energy consumption. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively

the concept of energy consumption, thus alleviating energy poverty. The regression results are shown in Table 4, and Columns (1–3) represent the effects of the marketization gene on road construction, urban development, and education, respectively. Column (1) shows the impact of the marketization gene on the development of road construction. After adding control variables and controlling for time and province fixed effects, it is revealed that the marketization gene does not have a significant effect on the development of road construction. Column (2) shows the effect of the marketization gene on urbanization development, and the results show that the marketization gene does not significantly contribute to local urbanization development. Column (3) shows the development of the marketization gene on education, and the results show that the marketization gene does not have a significant effect on education. By exclusive restriction of the marketization gene, other paths through which the marketization gene may have impacted energy poverty are pinched-off, which increases our confidence in the marketization gene as an instrumental variable.

4.3.2 Alternative measure for energy poverty

Electricity consumption per capita is a commonly used variable in the existing literature to gauge energy poverty (Nguyen & Nasir, 2021). In this study, we utilize per capita electricity consumption as a replacement for the energy poverty index. It is essential to note that unlike the energy poverty index, electricity consumption per capita is a positive indicator. This means that higher values of electricity consumption per capita indicate lower levels of

Table 6 Alternative measure for marketization

	(1)	(2)	(3)	(4)
Regression methods	FE	FE	IV-FE	IV-FE
Variables	EPI	EPI	EPI	EPI
PS	0.000802	0.000761	−0.00209**	−0.00637
	(0.000840)	(0.000865)	(0.000817)	(0.00463)
Constant	0.450***	0.340***	0.584***	0.705***
	(0.0383)	(0.0833)	(0.0478)	(0.188)
Controls	NO	YES	NO	YES
Province fixed effect	YES	YES	YES	YES
Time fixed effect	YES	YES	YES	YES
Observations	450	450	450	450
R-squared	0.327	0.351		
Number of provinces			30	30

Table 6 presents the results after replacing the marketization proxy variable with PS as the core variable. Columns (1) and (2) display the results using the fixed effects model, while Columns (3) and (4) show the results after implementing the instrumental variable. All columns control for time and province fixed effects, with Columns (1)–(3) excluding control variables, and Columns (2)–(4) including them. Upon resolving the endogeneity issue, the coefficients of the marketization proxy variable in Columns (3) and (4) all display negative values, consistent with the baseline regression results. However, notably, in Column (4), the proxy variable for marketization loses its significance after introducing the control variables. This outcome might be attributed to the limitation of using the percentage of non-publicly owned industrial economy above the scale as a marketization proxy, which may not fully capture the extent of marketization development. ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively

energy poverty. In Table 5, all columns exhibit statistical significance. However, the coefficient of the marketization index is negative before introducing the instrumental variable, which might be attributed to endogeneity issues. After employing the instrumental variable and controlling for other relevant variables, Column (4) demonstrates a coefficient of 0.193 for marketization. This implies that a higher degree of marketization is associated with a lower degree of energy poverty.

4.3.3 Alternative measure for marketization

Prior to the introduction of the marketization index, the proportion of the non-public economy was commonly employed (Jiang, 1998). In this context, we substitute the marketization index with the proportion of the non-public industrial economy above the designated size. In Table 6, all columns show negative results after addressing endogeneity issues, which aligns with the baseline findings. Although the result in Column (4), after adding control variables and using the instrumental variable, is not statistically significant, the impact of the marketization proxy on energy poverty remains consistent with that of the marketization index. One possible explanation for this phenomenon is that the level of marketization is a multifaceted indicator, and the proportion of the non-public industrial economy above the designated size may not comprehensively reflect the degree of marketization. Consequently, its effect on energy poverty diminishes when additional control variables are incorporated. Consequently, the use of this indicator has significantly decreased since the advent of the marketization index.

Table 7 New controls

	(1)	(2)	(3)
Regression methods	IV-FE	IV-FE	IV-FE
Variables	EPI	EPI	EPI
MI	−0.0364***	−0.0316**	−0.0367***
	(0.0112)	(0.0124)	(0.0114)
CR	8.97e–05		9.15e–05
	(0.000108)		(0.000108)
FS	2.70e–06*		2.62e–06*
	(1.43e–06)		(1.37e–06)
ADA		−5.32e–06	−3.67e–06
		(5.91e–06)	(5.06e–06)
Constant	0.510***	0.579***	0.522***
	(0.0628)	(0.0627)	(0.0599)
Other controls	YES	YES	YES
Province fixed effect	YES	YES	YES
Time fixed effect	YES	YES	YES
Observations	450	450	450
Number of provinces	30	30	30

Table 7 presents the regression results after the inclusion of new control variables. All columns incorporate additional control variables, with time and province fixed effects also accounted for. In Column (1), resource endowment control variables are added to address provincial differences in coal and forest resources. The coefficient of the marketization index is −0.0364, and it is significant at the 1% level. In Column (2), the natural disaster control variable is introduced, and the regression coefficient of marketization is −0.0316, significant at the 5% level. Column (3) includes both natural disaster and resource endowment control variables, and the coefficient of the marketization index is −0.0367, remaining significant at the 1% level. ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively

4.3.4 New controls

Finally, we consider some new factors. Energy poverty is closely linked to energy access, which, in turn, is affected by energy resources. Regions with abundant energy resources often have more accessible energy. To account for the impact of resource disparities on energy poverty, we include the coal and forest reserves of each province in the model, representing the availability of electricity and biomass energy. The results are presented in Column (1) of Table 7, where the coefficient of marketization is significant, with a regression coefficient of −0.0364. Additionally, natural disasters can influence energy consumption; regions with a higher frequency of natural disasters tend to consume less energy (Lee et al., 2021), thus impacting energy poverty. To control for the influence of natural disasters on energy poverty, we add the agricultural disaster area of each province as a control variable in the model, as shown in Column (2). In this case, the coefficient of marketization remains significant, with a coefficient of −0.0316. Column (3) presents the results considering the impact of both resources and disasters on energy poverty simultaneously; the coefficient of marketization remains significant, with a coefficient of −0.0367. Therefore, the findings in Table 7 indicate the robustness of our results.

4.4 Underlying mechanisms

We have previously discussed the definition of energy poverty concerning the quantity and quality of energy supply. To delve further into the role of marketization in addressing energy poverty, we investigate the impact of marketization on both the quantity and quality of energy supply, starting from the perspective of energy poverty measurement. Simultaneously, we consider the influence of marketization on income to identify ways in which the development of marketization can contribute to the reduction of energy poverty.

4.4.1 Supply

Supply level encompasses the exploration of the quantity and efficiency of energy supply, representing aspects of both energy quantity and quality. As energy supply increases, energy poverty is expected to decrease, and improvements in energy efficiency can intuitively contribute to a reduction in energy poverty as well. We utilize the per capita power generation of each province as a proxy for energy supply. For assessing energy efficiency, we employ the data envelopment analysis (DEA) method, a widely used efficiency measurement technique in the literature (Habib & Kayani, 2022). This method is nonparametric and does not necessitate assumptions about the underlying data distribution, offering a high degree of accuracy and flexibility in efficiency measurements (Habib & Mourad, 2022; Habib & Dalwai, 2023). We calculate the energy supply efficiency of each province from 2002 to 2016 using the DEA method. Input variables include total energy investment in each province and total employment in the energy industry, while output variables comprise the province's electricity output and sulfur dioxide emissions. To incorporate sulfur dioxide as a negative indicator, we perform a reciprocal transformation of the index. The results are presented in Table 8. In Panel A, Columns (1–4) display the outcomes of the relationship between marketization and energy generation. Column (4) in Panel A reveals that the coefficient of marketization is significant, with a coefficient of 0.154, suggesting that increasing energy supply quantity is an effective means through which marketization affects energy poverty. As the marketization degree of each province in China improves, it stimulates social and economic vitality, leading to increased social demand for energy. This promotes energy supply to meet rising social demand, thereby alleviating energy poverty, partially confirming Hypothesis 2a. Column (4) in Panel B presents the results of the relationship between marketization and energy supply efficiency. Surprisingly, the influence of marketization on energy supply efficiency is not significant, contradicting our expectations in Hypothesis 2a. Nevertheless, these findings are consistent with another study conducted in China (Wang & Wang, 2022), indicating that energy supply efficiency is not an effective pathway through which marketization impacts energy poverty. This could be attributed to the fact that China's energy industry has not fully undergone marketization, particularly on the energy supply side, where energy pricing and supply remain largely dependent on the government.

4.4.2 Human capital

The relationship between the environment and poverty has garnered considerable attention (Akinlo & Dada, 2021). The alignment of environmental considerations with poverty reduction represents a crucial strategic choice for the Chinese government (Qin &

Table 8 Relationship between marketization and energy supply

	(1)	(2)	(3)	(4)
Regression methods	FE	FE	FE-IV	FE-IV
Panel A dependent variable: EGC (log)				
MI	0.0309	−0.0996***	0.202***	0.177*
	(0.0272)	(0.0268)	(0.0616)	(0.0906)
Constant	−2.448***	−1.676***	−3.294***	−3.315***
	(0.365)	(0.389)	(0.536)	(0.532)
Controls	YES	YES	YES	YES
Province fixed effect	YES	YES	YES	YES
Time fixed effect	NO	YES	NO	YES
Observations	450	450	450	450
R-squared	450	450		
Number of provinces	0.822	0.873	30	30
Panel B dependent variable: SE				
MI	−0.00470	−0.0241	0.0455	−0.0258
	(0.0135)	(0.0206)	(0.0335)	(0.0345)
Constant	0.746***	0.649***	0.498	0.659***
	(0.218)	(0.210)	(0.336)	(0.247)
Controls	YES	YES	YES	YES
Province fixed effect	YES	YES	YES	YES
Time fixed effect	NO	YES	NO	YES
Observations	450	450	450	450
R-squared	0.027	0.211		
Number of provinces	30	30	30	30

Table 8 presents the mechanisms through which marketization influences energy poverty via energy supply. Panel A examines the impact of marketization on electricity generation. Columns (1) and (2) display the regression results without the instrumental variable, with Columns (1) and (3) presenting results without time fixed effects, and Columns (2) and (4) controlling for time fixed effects. Columns (3) and (4) show the regression outcomes after employing the instrumental variable. In Columns (3) and (4), the regression coefficients of marketization are significantly positive after incorporating the instrumental variable and control variables. Panel B explores the effect of marketization on energy supply efficiency. Columns (1) and (2) exhibit the regression results without the instrumental variable, with Columns (3) and (4) showing the results with the instrumental variable. Columns (1) and (3) present the results without controlling for time fixed effects, while Columns (2) and (4) control for time fixed effects. In Column (4), the regression coefficient of marketization is not significant after using the instrumental variable and controlling for the control variables. ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively

Zhang, 2022). When assessing energy poverty, energy cleanliness serves as a pivotal evaluation dimension. Greater energy cleanliness signifies higher-quality energy supply and diminished energy poverty. In the context of marketization, the influence of human capital on income becomes more pronounced. Du and Sun (2003) indicate that marketization's advancement has fostered the link between human capital and income. Within this incentivizing framework, regions exhibiting greater market development typically witness heightened human capital accumulation. In addition, regions with substantial human capital are more inclined to demand clean energy as the green

Table 9 Relationship between marketization and human capital

	(1)	(2)	(3)	(4)
Regression methods	FE	FE	FE-IV	FE-IV
Variables	CLE	CLE	CLE	CLE
MI × HC	0.00923*	0.0138**	0.0142**	0.0189*
	(0.00505)	(0.00544)	(0.00693)	(0.0102)
MI	−4.170***	−7.151***	−5.688***	−9.381**
	(1.261)	(2.241)	(2.182)	(4.348)
HC	−0.0219	−0.117	−0.0789	−0.191
	(0.0533)	(0.0853)	(0.0962)	(0.183)
Constant	3.524	37.46*	15.12	55.95
	(10.68)	(19.88)	(17.86)	(44.02)
Controls	YES	YES	YES	YES
Province fixed effect	YES	YES	YES	YES
Time fixed effect	NO	YES	NO	YES
Observations	450	450	450	450
R-squared	0.707	0.720		
Number of provinces	30	30	30	30

Table 9 presents the mechanisms through which marketization impacts energy poverty via human capital. In Columns (1)–(4), the dependent variables are clean energy supply, and the core explanatory variable is MI × HC, representing the cross-product term of marketization and human capital. Columns (1) and (2) display regression results without the instrumental variable, while Columns (3) and (4) depict results with the instrumental variable. Columns (1) and (3) lack controls for time fixed effects, while Columns (2) and (4) include controls for time fixed effects. The regression coefficients of MI × HC in Columns (3) and (4) are significantly positive after incorporating the instrumental variable and controlling for the specified control variables. ***, **, and * signify statistical significance at the 1, 5, and 10% levels, respectively

economy flourishes and industries undergo transformation (Yao et al., 2019). This is due to their increased willingness to pay a green premium.

To investigate whether marketization's progress reduces the incidence of energy poverty by bolstering human capital accumulation, thereby increasing the utilization of clean energy, we employ natural gas supply data for each province across multiple years as a proxy variable for clean energy. Concurrently, we utilize human capital data sourced from the China Human Capital Report, as published by the Central University of Finance and Economics. Table 9 presents the results elucidating the mechanisms through which marketization impacts energy poverty via human capital. After addressing endogeneity and incorporating control variables while also accounting for time and province fixed effects, the coefficient of 0.0189 for the interaction between marketization and human capital in Column (4) suggests that for each unit increase in the marketization index, there is an anticipated incremental rise of 0.0189 billion cubic meters in natural gas supply resulting from enhanced human capital—a conclusion akin to that drawn by Yi and Liu (2015). This outcome corroborates H2b, signifying the development of marketization effectively promotes increased clean energy use resulting from regional human capital accumulation, consequently mitigating the occurrence of energy poverty.

Table 10 Relationship between marketization and disposable income

	(1)	(2)	(3)	(4)
Regression methods	FE	FE	FE-IV	FE-IV
Variables	DI	DI	DI	DI
MI	2,719***	1,958***	6,276***	5,628***
	(542.6)	(562.7)	(824.0)	(887.8)
Constant	−7,426	−778.9	−24,997***	−22,529***
	(4,744)	(4,103)	(5,807)	(4,914)
Controls	YES	YES	YES	YES
Province fixed effect	YES	YES	YES	YES
Time fixed effect	NO	YES	NO	YES
Observations	450	450	450	450
R-squared	0.861	0.938		
Number of provinces	30	30	30	30

Table 10 illustrates the mechanism through which marketization impacts energy poverty via disposable income. The dependent variables in Columns (1)–(4) pertain to disposable income, while the core explanatory variable is the marketization index. Columns (1) and (2) present regression results without the instrumental variable, whereas Columns (3) and (4) depict regression outcomes with the instrumental variable. In Columns (1) and (3), regression results are presented without controlling for time fixed effects, whereas Columns (2) and (4) incorporate controls for time fixed effects. The regression coefficients of marketization in Columns (3) and (4) are notably positive after introducing the instrumental variable and adjusting for control variables. ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively

4.4.3 Disposable income

In addition to the significant impact of marketization development on the quantity and quality of energy supply, the effect on residents' income should not be overlooked. China's per capita disposable income has surged nearly 22.8 times over the course of the 40-years reform (Xinhua Network, 2018), signifying the positive influence of marketization on residents' income. Moreover, increasing income plays a role in alleviating energy poverty (Nguyen & Su, 2022). To ascertain whether income serves as the pathway through which marketization influences energy poverty, we employ per capita disposable income in each province as a proxy variable for income. The regression outcomes are presented in Table 10, where all columns reveal a significant positive impact of market-based development on income. In Column (4), after addressing the endogeneity issue and including control variables, as well as controlling for time and province fixed effects, the coefficient of disposable income is 5,628. This implies that for every unit increase in the marketization index, the population's disposable income will rise by 5,628 yuan (equivalent to 790.80 USD in 2023). This conclusion aligns to some extent with the findings of Lu and Jiang (2008) and further substantiates H2c, suggesting that income is an effective means through which marketization influences energy poverty.

5 Discussion

Based on provincial panel data from the statistical yearbook, we employed a two-way fixed effect model and instrumental variable method to provide evidence that marketization can effectively reduce the incidence of energy poverty. Our study also delves into the role of

energy supply, use of clean energy (reflecting the willingness to pay a green premium), and disposable income as the mechanisms through which marketization affects energy poverty. The findings of this paper contribute to understanding the role of marketization and the eradication of energy poverty, and also bridge the gap between these two strands of the literature.

There has been a large body of literature focusing on the factors influencing energy poverty, most of which are closely related to the development of marketization. These factors include the digital economy (Wang et al., 2023), financial markets (Cheng et al., 2023), informatization (Zou et al., 2023), and tariffs (Pereira & Marques, 2023). However, only a few articles directly focus on the relationship between marketization and energy poverty. Ren et al. (2022) use provincial panel data from rural China and demonstrate that a 1% increase in the degree of marketization reduces rural energy poverty by 0.133%. Another study suggests that marketization can influence renewable energy technologies to alleviate energy poverty, noting that the mitigating effect of renewable energy use on energy poverty increases with the degree of marketization when the marketization indicator is greater than 5.94 (Wang et al., 2022).

In this study, we examine the relationship between energy poverty and marketization from a broader macro-perspective. On one hand, we further validate the role of marketization development in alleviating energy poverty at the macro-level. On the other hand, our study delves into the mechanisms through which the development of marketization alleviates energy poverty. First, marketization alleviates energy poverty by expanding energy supply but does not achieve this effect through improvements in energy efficiency. This finding is consistent with previous studies. For instance, Wang and Wang (2022), using Chinese provincial panel data, demonstrate that marketization does not significantly impact the improvement of energy efficiency. Second, the development of marketization reduces the incidence of energy poverty by increasing human capital and, consequently, the use of clean energy. A similar conclusion is found in the study by Yi and Liu (2015) and others, who assert that the development of marketization and human capital promotes green businesses and green jobs, ultimately driving the adoption of clean energy. Finally, the rise in disposable incomes also constitutes an important pathway through which marketization influences energy poverty. This finding aligns to some extent with Lu and Jiang (2008), who discuss the positive effects of marketization on economic development and incomes.

6 Conclusion

6.1 Research conclusion

While marketization is occurring worldwide, and economic development is on the rise alongside marketization, the existence of energy poverty runs counter to the goal of economic development. This study bridges the concepts of marketization and energy poverty to elucidate the inherent connection between them and to explore the underlying mechanisms using a two-way fixed effects model and an instrumental variables approach.

Specifically, the key findings of this paper are as follows: First, we find that overall, marketization development is effective in reducing the incidence of energy poverty. Second,

we find that marketization can mitigate energy poverty by enhancing the quantitative supply of energy. However, it does not significantly impact energy poverty by improving the efficiency of energy supply. Finally, our empirical results suggest that marketization can decrease the prevalence of energy poverty by increasing per capita disposable income and promoting the use of clean energy.

6.2 Theoretical implications

First, this study represents an extension of marketization discourse into the realm of welfare, closely associated with the capacity approach theory. Previous examinations of marketization have predominantly centered on socioeconomic aspects like education (Lundahl et al., 2013) and employment (Freeman & Schettkat, 2002), seldom delving into the welfare domain. Within the field of welfare, Amartya Sen's capability approach theory holds significant importance. Sen posits that when an individual possesses adequate capabilities to tackle issues, the root causes of poverty can be effectively addressed (Srinivasan & Sen, 1983). Energy poverty, defined as the lack of access to sufficient and clean energy for environmental or personal reasons, can be viewed as a form of capability deprivation. This paper systematically investigates how marketization can mitigate energy poverty by addressing this deprivation of capabilities, thus contributing to a deeper comprehension of the practical implications of the capability approach theory.

Second, this research contributes to the expansion of sustainable development theory. Sustainable development theory advocates for development that meets the current generation's needs without compromising the well-being of future generations, guided by principles of fairness, continuity, and shared responsibility. Energy poverty is intricately linked to environmental challenges and the prospects for future generations. Presently, there is a growing emphasis on sustainable communities as a new societal model during the ecological transition process (D'Adamo et al., 2023). Effectively enhancing energy access and improving social well-being to facilitate the establishment of sustainable communities is an ongoing concern within sustainable theory. This paper's exploration of the relationship between energy poverty and marketization delves deeper into how sustainable development in the energy sector can provide sustainable development theory with insights from a marketization perspective.

Finally, the article's discussion of marketization, human capital, and clean energy contributes to the enhancement of Green Development theory. Green Development theory pertains to an approach to economic growth and social development that prioritizes efficiency, harmony, and sustainability. The concept of the green premium, central to Green Development theory, suggests that people's embrace of the underlying principles of green development can effectively drive the sustainable growth of the social economy (Wei et al., 2023). This paper delves into the interplay between marketization, human capital, and clean energy, offering valuable support for this concept and outlining specific pathways to realize the principles of Green Development theory.

6.3 Managerial contributions and policy implications

Furthermore, this study delves into the relationship between marketization and energy poverty, emphasizing its significance in establishing favorable environmental, social, and

governance conditions. Such conditions can, in turn, foster a robust business environment, as highlighted by Habib and Mourad (2023), ultimately promoting the advancement of marketization. This underscores the managerial implication of our exploration of the marketization-energy poverty connection. Moreover, our analysis suggests a managerial implication regarding mechanisms. Enhancing individual-level human capital necessitates proactive efforts from citizens, while improving the societal environment calls for increased government focus on facilitating citizens' growth.

In light of our findings regarding the relationship between energy poverty and marketization, we propose several recommendations. Firstly, the pivotal role of marketization in mitigating energy poverty underscores the importance of deepening marketization development and integrating with the global economy for countries and regions. Simultaneously, the accumulation of human capital and the transformation of industrial structures play significant roles in facilitating market-driven energy poverty alleviation. Therefore, regions with lower levels of marketization development should prioritize enhancing regional human capital and promoting the transformation of their industrial structures to encourage the use of clean energy. Additionally, the adoption of clean energy can be encouraged through financial penalties and by reinforcing individual and societal norms. However, research suggests that as societies progress, normative influences tend to be more effective than monetary incentives (Lee, 2017). Hence, it is crucial to focus on guiding social opinions and fostering a socially driven ethos. Lastly, one of the roles of marketization is to enhance resource allocation efficiency. However, owing to the monopolistic nature of the energy sector, achieving such improvements can be challenging. Therefore, governments should expedite market-oriented reforms within the energy sector to effectively enhance resource allocation efficiency.

6.4 Limitations and future research perspectives

However, it is important to acknowledge some limitations in our study. Firstly, our analysis is based on a dataset spanning only 15 years. Future research could benefit from a more extended time frame and a more comprehensive perspective. Moreover, to delve deeper into the relationship between individual energy poverty and marketization development, a micro-level perspective would be valuable, but data constraints prevented us from exploring this aspect further. Therefore, future studies could investigate this connection from a micro-level standpoint.

Appendix

See Figs. 4 and 5, Tables 11 and 12.

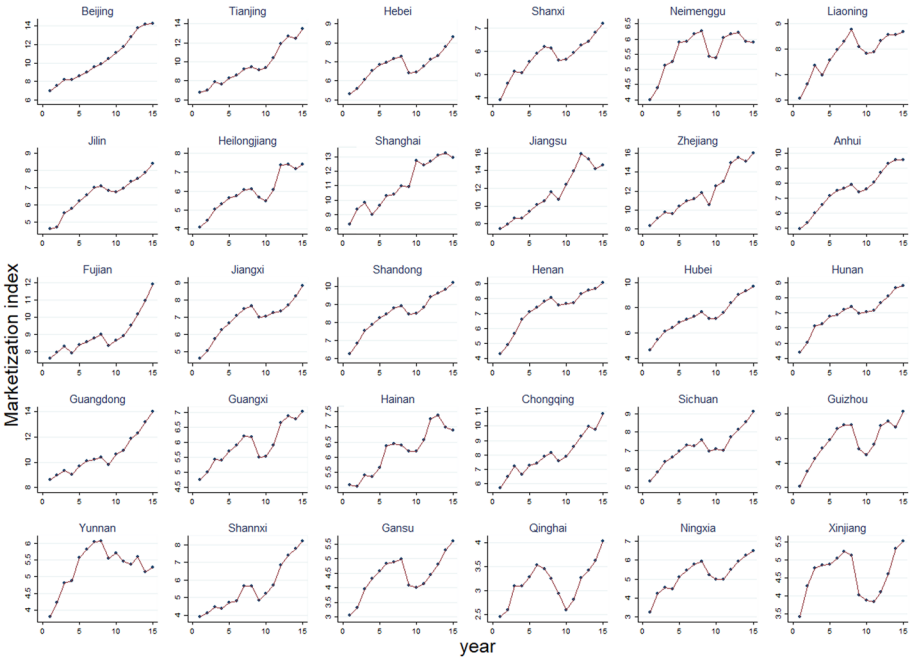

Fig. 4 Evolution of the marketization index of each province

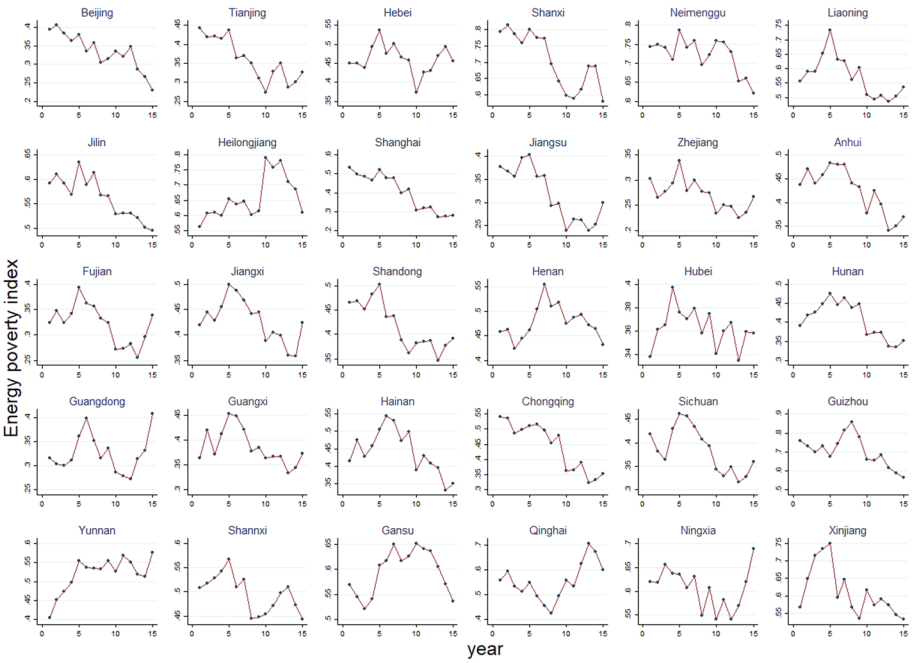

Fig. 5 Evolution of the energy poverty index of each province

Table 11 First-stage regression results of the baseline

	(1)	(2)	(3)
Regression methods	FE	FE	FE
Variables	MI	MI	MI
OY	0.244***	0.261***	0.323***
	(0.0262)	(0.0355)	(0.0574)
Constant	−24.34***	−26.65***	−33.63***
	(3.391)	(4.528)	(6.834)
Control	NO	YES	YES
Province fixed effect	YES	YES	YES
Time fixed effect	NO	NO	YES
Observations	450	450	450
F-value	86.8	59.74	140.22
R-squared	0.654	0.811	0.877
Number of provinces	30	30	30

Table 11 displays the results of the first-stage regression employing the instrumental variable. Column (1) presents the outcomes without the incorporation of control variables and time fixed effects. Column (2) reveals the results with the inclusion of control variables but without controlling for time fixed effects. Column (3) exhibits the outcomes after adding control variables and controlling for time fixed effects. Notably, all columns indicate that the coefficients of the marketization gene are significant at the 1% level. ***, **, and * denote statistical significance at the 1, 5, and 10% levels, respectively

Table 12 Control variables including GDP and population

	(1)	(2)
Regression methods	IV-FE	IV-FE
Variables	EPI	EPI
MI	−0.0248**	−0.0287**
	(0.0104)	(0.0115)
GDP	−1.77e–06	−9.75e–07
	(1.67e–06)	(1.87e–06)
Population	−2.04e–06	−2.43e–06
	(3.16e–05)	(3.10e–05)
Constant	0.559***	0.562***
	(0.161)	(0.153)
Other controls	YES	YES
Province fixed effect	YES	YES
Time fixed effect	NO	YES
Observations	450	450
Number of provinces	30	30

Table 12 displays the regression results after incorporating controls for GDP and provincial population in each province. Column (1) showcases the outcomes with control variables but without controlling for time fixed effects, while Column (2) reveals the results with control variables and the inclusion of time fixed effects. In all columns, the coefficients for marketization are statistically significant at the 10% level. ***, **, and * indicate statistical significance at the 1, 5, and 10% levels, respectively

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