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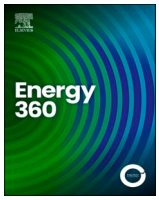

Analysing policy responses to energy poverty in China: A perspective on socio-spatial vulnerability lens

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ABSTRACT

Millions of Chinese households suffer from varying degrees of energy poverty, threatening their access to sufficient energy services. China lacks a national acknowledgement of energy poverty as a problem distinct from initiatives to combat poverty, despite the entrenched environmental and energy injustices that threaten public health. Our Perspective article explores national responses to energy and poverty through a socio-spatial energy vulnerability lens. We analysed The White Paper of China's Practice in Poverty Reduction (2022) as well as the Energy Five-Year Plans (2000–2020), to understand how energy accessibility, social vulnerability, and spatial vulnerability are understood in China. We found that the accessibility of energy services and just pricing of electricity have long been recognised as problems in China, despite the lack of energy poverty policy. From a social perspective, the government has identified some vulnerable groups such as low-income, older people and provided them with financial support. The recognition of spatial vulnerability is reflected in the uneven distribution of energy infrastructure, services, and subsidy policies among regions. Our findings suggest that Chinese policymakers need to consider energy poverty as a distinct problem, and to build effective responses that centre social and spatial vulnerability.

1. Introduction

It is widely recognised that energy is essential for satisfying people's daily needs, maintaining good health, and living comfortably (Middlemiss, 2022a; Ivanova and Middlemiss, 2021; Bouzarovski et al., 2012; Robinson et al., 2018a; Yip et al., 2020). Studies show more than one in five Chinese households (roughly estimated to 280 million of the Chinese population of 1.412 billion people in 2022) face energy poverty (Lin and Wang, 2020; Hong et al., 2022; Zhang et al., 2019). Spatial differences within China have been explored extensively including regional/provincial level comparisons (Zhang et al., 2019; Wang et al., 2015; Liao et al., 2016, 2018; Tang and Liao, 2014; Zhang et al., 2023a; Robinson et al., 2018a) with increasing attention paid to social vulnerabilities (Robinson et al., 2018a; Zhang et al., 2023b) including identification of factors that increase people's likelihood of experiencing Energy Poverty such as rural-Hukou,[1] low housing quality and households with older people. In China most energy poverty studies have been conducted using data aggregated to national and regional scale (Zhang et al., 2019; Wang et al., 2015; Zhu, 2007; Li et al., 2011; Zhu and Ye, 2012; Wu and Zheng, 2016; Xue, 2017). Zhang et al (Zhang et al., 2019). narrowed down the spatial scale to provincial level by using China Family Panel Studies (CFPS) household data, however, CFPS pointed that only 'large provinces' (Shanghai, Liaoning, Henan, Gansu, and Guangdong) have sufficient samples to support comparison and inference at provincial scale (CFPS, 2017). Thus, their analysis limited them to reporting a national level indicator. Wang et al (Wang et al., 2015). investigated both the 30 provinces and 8 economic regions in China to show different characteristics of energy poverty from 2000–2011 using statistic data. Very few energy poverty studies in China have been conducted at a finer spatial resolution or using household data to derive provincial averages. Lin and Wang (Lin and Wang, 2020) measured energy poverty by using a single annual

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[1] Refers to the legal documents produced by the Chinese administrative organs in charge of household administration of the state, which records and retain the basic information of the household population and is also a proof of identity for citizens. There have two divisions: Rural Hukou and Urban Hukou.

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household electricity survey to report energy poverty at regional level. Most existing research has examined empirical case studies or quantitative indicators to assess energy poverty severity and distribution (e.g., based on income, energy burden, or fuel type). To date, only one recent study has conducted a quantitative assessment of China's energy poverty alleviation policies (Chen et al., 2024). The present study offers a qualitative investigation into how energy poverty has been reflected-or overlooked-within national policy discourse, an area that remains largely underexplored.

The socio-spatial variation in energy poverty revealed in the Chinese case support the concept of energy vulnerability presented by Bouzarovski and Petrova (Bouzarovski and Petrova, 2015), which describes vulnerability as a way to highlight the factors that affect the likelihood of becoming energy poor which extend beyond the accessibility-affordability binary, to encompass the nature and structure of the built environment of the home, as well as the articulation of social practices and energy needs. Energy vulnerability thinking has also been deployed in other countries: including the identification of particular groups of people who have specific energy needs (low-incomes, young children, older people, people with a disability or poor health, single parents) (Middlemiss, 2022a; Ivanova and Middlemiss, 2021; Robinson et al., 2018a; Anderson et al., 2012; Sakka et al., 2012; White and Sintov, 2019; Ormandy and Ezratty, 2012; Simcock et al., 2021), as well as recognising the complex and uneven spatial distribution of these potentially vulnerable groups (Robinson et al., 2018a; Simcock et al., 2021; Bouzarovski and Cauvain, 2016; Altan, 2004; Robinson and Mattioli, 2020). Hence, studies of socio-spatial vulnerabilities to energy poverty in both China and other nations highlight the importance of energy vulnerability thinking as a prerequisite to addressing energy poverty and reflecting the effectiveness of relevant policy responses.

Addressing energy poverty by providing access to modern, reliable and affordable energy services is the basis of SDG 7 (Sustainable, 2015). To enhance the understanding and delivery of this goal, a significant body of knowledge has been developed with respect to the causes (Kyprianou and Serghides, 2021; Sareen et al., 2020; Hills, 2011), lived experience (Middlemiss, 2022b; Hesselman et al., 2021; Willand and Horne, 2018; Middlemiss et al., 2018), implications and detection (Sy and Mokaddem, 2022; Salman et al., 2022; Papantonis et al., 2022) of energy poverty which has already led to policy recognition in many countries (v.N. and Bommel, 2021; Bouzarovski, 2018). Public recognition of energy poverty has a longer history in countries such as Ireland (Walker et al., 2014; Healy and Clinch, 2004; Walker et al., 2012, 2015; Kerr et al., 2019) and the UK (Hills, 2011; Kerr et al., 2019; Boardman, 1991, 2010; DBEIS, 2022). The last five years have witnessed a dramatic upsurge in scientific interest and contributions in other European-level studies on the subject (Castaño-Rosa et al., 2019; Recalde et al., 2019; Romero et al., 2018), in turn spawning national legislation (France, the Republic of Cyprus, Slovakia) and responses (Dobbins et al., 2019; Thomson and Bouzarovski, 2018) to energy poverty.

In China, policies and related academic research on energy poverty are somewhat lagging compared to European countries and the growing body of work emerging from other parts of Asia (Sen et al., 2023; Hosan et al., 2024, 2023). China's political economy plays a pivotal role in shaping patterns of energy access and distribution, thereby directly influencing the manifestations of energy poverty. As a state-led economy with strong central planning traditions, China's energy governance is characterized by a hybrid of market reforms and state control, particularly through the dominance of state-owned enterprises (SOEs) in electricity generation and distribution (Andrews-Speed, 2016; Yeh and Lewis, 2004). These institutional arrangements often result in inefficiencies, rigid price structures, and limited responsiveness to local socio-spatial vulnerabilities. Moreover, fiscal decentralization has created disparities in the implementation capacity of local governments, exacerbating regional inequalities in access to clean energy infrastructure and support programs (Shahbaz et al., 2022). Understanding energy poverty in China therefore requires a critical engagement with the underlying political and institutional logics that mediate energy provision beyond simple economic metrics. To date, China lacks a national acknowledgement of energy poverty as a problem distinct from initiatives to combat poverty (Xu and Wang, 2017; NEA, 2018; Démurger and Fournier, 2011). The Chinese government has formulated policies to assist low-income households since the establishment of the Communist Party of China (PRC (2021)), focusing on the eradication of 'poverty defined in absolute terms (absolute poverty)' which was eliminated by 2021.[2] Thereafter, China has made clear its commitment [3] to continue an ambitious poverty alleviation and social protection agenda that will address "relative poverty". This includes commitments to.

> *'Improving social assistance, and to providing high quality employment, life-long learning, health guarantees and comprehensive social security.'*

National policy has begun to embrace a more relative understanding of poverty, especially related to local living standards including aspects on employment, education, water, medical and energy services (PRC, 2021; ILO, 2020). The adjustment of policy emphasis towards addressing relative poverty has also spurred the transition from resolving absolute energy poverty (which has a distinct threshold when measuring energy poverty) to addressing relative energy poverty (capturing other vulnerability factors of energy usage) (Cong et al., 2022). This calls for a thorough understanding of how the energy poverty problem has been recognized in Chinese policies to date, as well as understanding which facets of energy policy are present and absent from policy documents and actions.

Although the lack of formal national acknowledgement of energy poverty restricts the ability to fully comprehend the issue and develop appropriate solutions, there is existing policy in China which shapes energy poverty experiences. Efforts to enhance access to energy services have implicitly alleviated the energy poverty problem in society: ensuring 100 % of households have access to electricity, upgrading electricity grids and increasing clean energy production. In this perspective, we aim to capture energy related policies in China which have shaped energy poverty alleviation and to assess which policy aspects have been overlooked, the authors draw on their previous work, incorporating analytical thinking and existing research on energy poverty in China.

While the concept of energy vulnerability has been widely explored in the Global North, particularly through socio-spatial perspectives (Robinson et al., 2018b; Simcock et al., 2018), the application of this framework in the Chinese context remains underdeveloped. Our study builds on this body of work by operationalizing a "socio-spatial vulnerability" lens specifically attuned to China's unique political, demographic, and infrastructural landscape. In doing so, we extend the existing policies in two critical ways. First, we map how structural social disadvantages-such as aging, rural household registration (Hukou), and gendered care burdens-interact with place-based disparities in energy infrastructure and governance capacity. Second, we situate these intersecting vulnerabilities within China's centralized but spatially fragmented political economy, thereby highlighting how energy access is shaped by both spatial administrative hierarchies and uneven resource distribution. This dual articulation of social and spatial dimensions allows us to move beyond reductive income-based definitions of energy poverty and toward a more context-sensitive framework that captures the lived realities of energy precarity in contemporary China. To this end, we build on energy vulnerability thinking and practices to consider how energy accessibility, social vulnerability and spatial vulnerability elements are reflected in Chinese energy related policies. We review the

[2] Chinese president Jinping Xi announced to the world on 25th February 2021, China has accomplished eradicating absolute poverty.

[3] The Communique of the Fourth Plenary Session of the 19th Central Committee of the Communist Party of China issued in October 2019. https://www.gov.cn/zhengce/2021–04/06/content_5597952.htm

most recent national responses to energy poverty in China through two sets of documents: **1)** The White Paper of China's Practice in Poverty Reduction published by The State Council of the People's Republic of China in 2022; **2)** and the national energy plans during 2000–2020. The main objective of this perspective is to answer three research questions:

1) To what extent do existing policies affect the distribution of access to energy services?

2) Do these policies recognise different energy needs shaped by social circumstances, and if so, how?

3) Do these policies recognise different energy needs shaped by spatial context, and if so, how?

By answering the above questions, threefold contributions are made from this Perspective: 1) Policy-level focus with energy vulnerability framework- we are among the first to apply an energy vulnerability framework (covering accessibility, social, and spatial dimensions) to the analysis of national Chinese policy, rather than household-level or provincial-level outcomes. This approach allows us to uncover structural factors behind energy poverty that are often overlooked; 2) Document-based longitudinal analysis: Our study systematically analyses two important yet underexplored sets of documents - the White Paper on China's Poverty Reduction (2022) and five-year national energy plans from 2000 to 2020 - to trace policy evolution. Prior literature rarely connects such macro policy documents directly with energy poverty alleviation; 3) Critical identification of policy gaps: By linking national policies with known findings from empirical case studies, we identify overlooked aspects of energy poverty, such as the recognition of differentiated energy needs shaped by social and spatial inequalities. This insight offers a critical perspective on what has been done - and more importantly, what has not - in China's energy policy landscape. In the following five sections, Section 2 introduces the strategic energy planning system in China and the analysed documents in this study. The paper then assesses to what extent Chinese policy recognises the three elements identified above: energy accessibility, social and spatial vulnerabilities (Sections 3–5). Having connected the policy responses with the research findings from Chinese energy poverty case studies, we conclude by critically highlighting the essential aspects of energy poverty alleviation that have not yet arisen on the Chinese agenda.

2. Strategic energy planning in china and our analytic approach

Chinese strategic energy planning consists of three main layers of government documents: the energy part of the Five-Year Plan for National Economic and Social Development, Energy Plan for Medium- and Long- Term, and the Energy Five-Year Plan (see Fig. 1). The materials listed on the right-hand side of Fig. 1 are documents published by the Chinese government to coordinate with Five-Year-, Medium- and Long-term energy development goals. The Energy Five-Year Plan is formulated in accordance with the National Economic and Social Development Five-Year Plan[4] outline, which determines the scale and key energy development projects in the five-year period. In the meantime, provincial level energy development has more specific Five-Year Plans for local energy development following the National Energy Five-Year Plan. Because of this, we concentrate on the most current national energy policies, the Energy Five-Year Plans from 2000 to 2020.

This study conducts a qualitative policy analysis of national-level governmental documents to investigate how energy poverty has been reflected-or overlooked-within China's policy discourse over the past two decades. Our analysis focuses on two main sources: 1) National Energy Development Plans from 2000 to 2020, including the 10th, 11th, 12th, and 13th Five-Year Plans and related strategic policy documents; 2) The White Paper on China's Practice in Poverty Reduction (2022). While the primary policy analysis in this paper covers official documents and strategies from 2000 to 2020-including China's Energy Five-Year Plans and national poverty alleviation frameworks-selected post-2020 materials, such as the 2022 White Paper on China's Practice in Poverty Reduction, are included to contextualize more recent developments and policy continuities. These later references are not part of the formal analytic corpus but are incorporated to highlight evolving trends and the potential direction of future policies. Fig. 2 summarises the key milestones in residential energy policy across these documents. In tandem with the realisation of absolute poverty reduction till 2021, the focal points of energy development plans throughout the years have been the enhancement of energy efficiency and the establishment of renewable energy sources. 'Energy poverty' is first mentioned in a national document in 13th Energy Five-Year Plan (2016–2020) that outlines ambitions '*combine energy development with poverty alleviation, promote energy poverty alleviation projects*'. However, this emphasizes the goal of reducing poverty by improving energy planning and distribution in areas (previously Revolutionary Base Areas[5]; areas with a high concentration of ethnic minorities, border areas, and poorer areas than the rest of China), rather than recognizing energy poverty independently and broadly (N.E.A. NEA, 2016). We will delve into these documents to examine the inclusion and omission of responses to energy poverty in the Chinese policy agenda.

We adopted a purposive sampling strategy, selecting national-level documents that are most relevant to shaping discourse around energy access, poverty alleviation, and infrastructure development. This strategy is consistent with qualitative document analysis methods used in energy policy research in other national contexts, such including Netherlands (Athukorala et al., 2019), England, Ireland, France (Kerr et al., 2019) and nations at European-Union level (González-Pijuan et al., 2023). Our analytical framework draws on document analysis as a qualitative method (Bowen, 2009), treating these texts not just as supplementary materials but as primary empirical data. To interpret these documents, we adopt the concept of problematisation (Bacchi, 2014), which allows us to critically explore how 'problems' such as energy poverty are constructed, included, or omitted within official narratives. The analysis of policy documents involves carefully examining and interpreting the collected data to uncover meaning, gain understanding and generate empirical data (Bowen, 2009; Grant, 2008). While documents are often used as secondary or additional sources of data in research projects, there is often much value in focusing solely on analysing the information contained within policy documents. This was made more challenging by the fact that there is no established energy poverty policy in China, and as a result we focused on policy which shapes energy poverty experiences. In the analysis that follows we took a deeper approach to understanding policy documents. Our adoption of a concept of problematisation, which grounds this analysis, to engage the common-sense understanding of problematisation as how something is put forward (or represented) as a 'problem'. It is critically important to interrogate the problematic representations that lodge within public policies in order to see what they include and what they leave out (Bacchi, 2014).

Given the trends in academic interest in this problem elsewhere, we were particularly keen to see how Chinese policy addresses access to energy, and to what extent geographical and social vulnerabilities are

[4] Commencing in 1953, China's first National Economic and Social Development Five-Year Plan is integral to the nation's economic strategy, addressing major construction projects, productivity distribution, and crucial economic proportions. It establishes long-term goals and directions for national economic and social development.

[5] "Revolutionary Base Areas" refer to regions in China that were established and controlled by the Communist Party of China during the revolutionary war, playing a pivotal role as strongholds for revolutionary activities. These areas across the mainland of China and provided crucial support to the revolution, serving as vital rear bases for the Party's growth and development. The included areas can be found at: http://dangshi.people.com.cn/GB/151935/164962/

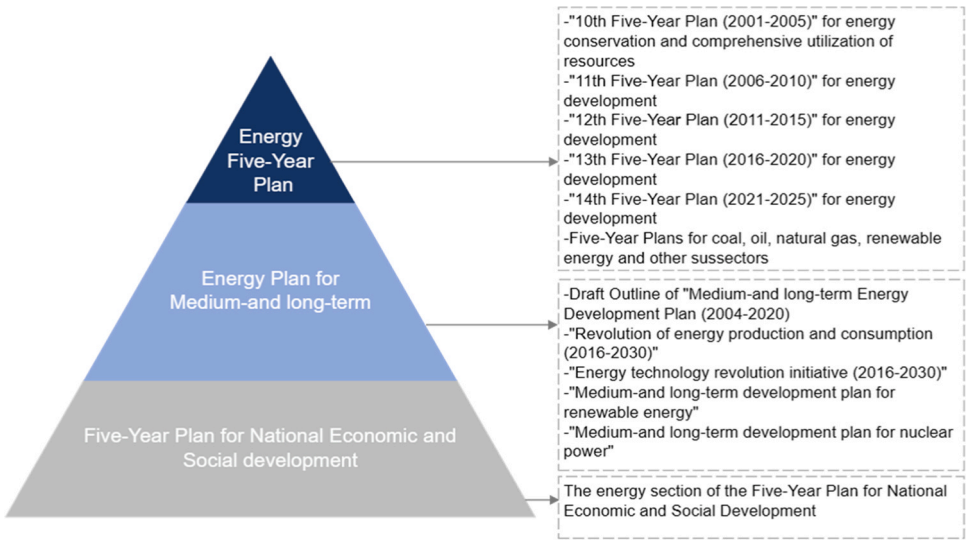

Fig. 1. Energy strategic planning system at national level in China and materials for analysis.

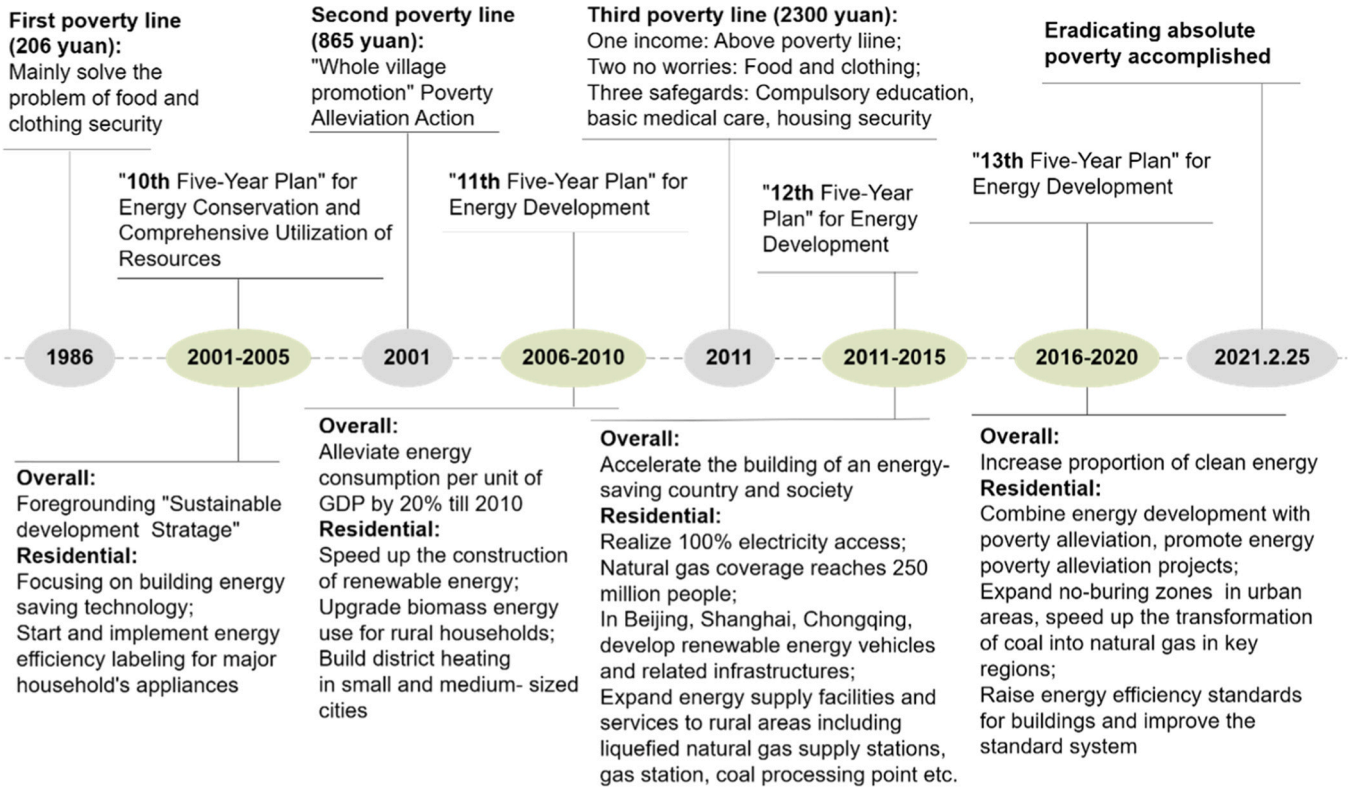

Fig. 2. Historical energy planning and poverty line at national level in China.

taken into account in the policy. In this Perspective, we define 'social vulnerability' as the individual or household-level factors that could potentially increase the risk of experiencing energy poverty, such as income, age, gender, health, education, and family composition. In our analysis, we consistently apply this concept to identify social groups that are more susceptible to energy poverty due to these characteristics (e.g., low-income households, elderly individuals, and households with limited access to education or healthcare), also we define 'spatial vulnerability' as the location-based factors that influence energy access, including the disparities between urban and rural areas, differences in regional infrastructure, and the availability of energy resources in different geographical areas. In the manuscript, we apply this concept by examining how regional disparities in energy access (such as differences in energy infrastructure, energy services, and government subsidies between rural and urban areas) affect energy poverty. In the following Sections (3–5) we address each of these topics in turn.

3. Recognition of energy accessibility

3.1. Energy services

Over the past 20 years, China has struggled with a lack of accessibility to energy services, however, improvements in electricity availability, with a focus on rural areas, have changed this situation (PRC

(2021)). Chinese rural areas have been suffering from energy poverty for a long time with three characteristics: first, the volume of energy consumed is quite modest compared to energy consumption in urban areas (Li et al., 2011). Second, energy consumption is characterised by the lack of availability of clean energy services (e.g., electricity and natural gas) and reliance on solid fuels. Third, it is extremely expensive relative to the average income of rural residents and difficult to obtain clean fuels. In order to increase the distributional accessibility of energy services and to combat poverty, all energy policies for the five-year period from 2000 to 2020 prioritize the building of energy infrastructure in rural areas. Given this, the Chinese Government initiated three grid construction and renovation projects in 1998, 2010 and 2016, addressing the problem of nearly 40 million people having no access to electricity (CEY, 2021). In 2015, the electricity access rate in rural China reached 100 % (PRC (2021)). Since then, the Chinese government has been concentrating on ensuring a steady and continuous supply of electricity (N.E.A. NEA, 2016).

Nevertheless, despite the substantial progress in electricity accessibility among Chinese residents, a deficiency in access to other energy services persists, as noted by scholarly evidence (Lin and Wang, 2020; Wang et al., 2015; Tang and Liao, 2014; Robinson et al., 2018a; Wang et al., 2023). Regarding heating provision, the heating policy in China limits access to district heating – it is generally only available in some urban areas in the provinces North of the Huai-River during the cold winter season. Other urban residents and rural households in the North have to endure the cold winter, rely on solid fuels for gaining thermal comfort, or balance the domestic costs when using electricity to heat homes. Robinson et al. (2018a) found that some homes in northern cities like Beijing, China, are unable to protect themselves from the cold because they do not have access to flexible and effective network infrastructures (e.g. district heating) or high-quality built environments. Furthermore, despite the uneven heating provision within urban areas and between urban and rural China, the overall development of natural gas distribution is still at a low level. For example, China realized its goal of supplying natural gas to 250 million people in the 12th Five-Year Plan period, but this relatively clean energy service only makes up 8.4 % of total energy consumption (PRC (2021)). The coverage of natural gas in remote towns and rural areas is especially low. In the 13th Five-Year Plan for energy development, the government has set up the following goal on natural gas infrastructure to:

> *'Accelerate the construction of natural gas transmission and distribution networks and storage facilities, expanding the coverage of natural gas supply. Gradually streamline natural gas prices, cultivate and expand the natural gas consumer market, and increase the scale of residential gas consumption'.*

In many rural and remote areas of China, solid fuels such as coal, wood, and biomass remain the primary sources of energy for cooking and heating. These fuels are often burned in inefficient stoves or open fires, leading to significant indoor air pollution that poses a severe health risk to the population. According to research, prolonged exposure to indoor air pollution from solid fuels is a leading cause of respiratory diseases, including chronic obstructive pulmonary disease (COPD) and lung cancer, as well as cardiovascular diseases (Chen et al., 1992). Additionally, children and women, who spend more time indoors, are disproportionately affected by the harmful effects of indoor air pollution (Mu et al., 2013).

The Chinese government has made some progress in mitigating these issues through initiatives like the promotion of liquefied petroleum gas (LPG) for cooking in rural areas. However, these programs have faced challenges, particularly in poorer, more remote regions where infrastructure is limited and the cost of transitioning to cleaner fuels remains high (Zhang and Smith, 2007). Furthermore, some rural households continue to rely on traditional biomass sources due to cultural factors and a lack of affordable, clean alternatives. As a result, the negative health impacts associated with solid fuel use continue to be a major concern, exacerbating the broader issue of energy poverty in the country. Tackling indoor air pollution by expanding access to cleaner cooking and heating technologies should therefore be an essential component of China's energy poverty alleviation strategies. Consequently, when considering ways to alleviate energy poverty in China by enhancing the availability of energy services, a crucial step involves constructing and enhancing clean energy-related infrastructure, aligning with goals to reduce greenhouse gas emissions.

3.2. Energy prices

Despite the uneven distribution of energy services, energy prices also shape the varied energy consumption in society and across spaces due to the welfare system[6] in Chinese polices regarding the residential sector. Energy prices (including electricity prices) in China have been regulated by the government for a long time, with two main reformations of electricity price in the residential sector. The first is the phase of cross-subsidy for residential and industrial electricity consumption (Lin and Wang, 2020; Xie and Wu, 2022). The average electricity price in China was 0.56 to 0.62 yuan/Kwh from 1978 to 2012, which was below the average price internationally (0.897 yuan/Kwh, calculated based on the data from International Energy Agency in 2012). However, the general electricity price for the industrial sector is 0.86–1.80 yuan/Kwh. The majority of countries throughout the world have residential electricity prices that are higher than industrial electricity prices because domestic consumers' distributional costs are substantially greater than those of industrial and commercial users (U.N.D. UN, 2023). But in China, consumers in the industrial and commercial sectors pay more for electricity consumption than those in the residential sector, which leads to cross-subsidies for household electricity consumption (CEY, 2021; Xie and Wu, 2022). This results from a comprehensive government initiative to reduce energy poverty involved in 10th Energy Five-Year Plan which indicates:

> '*Ensures people can afford electricity, fosters equity, and supports long-term, robust economic and social growth*'.

Cross-subsidies in the power sector ensure that direct environmental taxes from energy-intensive industries are returned to residential consumers and improves people's livelihoods. However, some studies (Athukorala et al., 2019; Xie and Wu, 2022; Xie et al., 2021; Zheng and Fu, 2015) concerning distortions of energy prices' effects on household consumption indicate that lower energy prices stimulate extra energy consumption in some high-income households. Since energy prices are low, the motivation to take energy-saving measures is also low. Rather than implementing a broad subsidy policy for electricity for all, we should analyse the complex relationship between home energy use and energy poverty in order to provide nuanced subsidies to those households that actually need them. Our analysis of electricity pricing policies, particularly the longstanding use of cross-subsidies from industrial to residential sectors, has been further developed to critically examine the underlying fiscal and distributive trade-offs. While such subsidies have historically ensured energy affordability for low-income households, they have also introduced systemic inefficiencies and revenue distortions within state-owned utilities (Andrews-Speed, 2012). As China moves toward market-oriented electricity reform, including reductions in cross-subsidies, there is growing concern over the fiscal sustainability of maintaining universal affordability without targeted support mechanisms (Yi-Chong, 2021). Moreover, the implicit redistribution embedded in cross-subsidies lacks transparency and may paradoxically favour wealthier urban consumers with higher electricity

[6] Chinese government subsidizes household electricity consumption through two measures: one is a cross-subsidy measure, which reduces residential electricity prices by raising industrial and commercial electricity prices; the other is a direct subsidy to households according to electricity consumption.

usage, while failing to reach rural or marginalized groups with limited access. This highlights the need for a transition toward more equitable and targeted subsidy models—such as means-tested energy assistance-that balance affordability with fiscal responsibility and align with broader goals of energy justice and decarbonization.

Given that cross-subsidy and the electricity consumption inequalities exist in the Chinese energy system (Zheng and Fu, 2015), the Chinese government introduced the second stage of the ladder electricity price scheme (either scaled progressive or stepped incremental prices for electricity) nationwide in 2012[7] built on the 12th Five-Year Plan for Energy Development, and each province is now free to make adjustments in line with its actual circumstances (see Table 1). The majority of provinces have established three tiers of electricity prices for the entire year. Households in the third tier of electricity usage pay their bills based on the most expensive unit price because their consumption is higher than that of households in the first and second tiers. Several provinces even set these three tiers of electricity prices considering the different seasonal periods since the winter or summer time is expected to have larger demand for electricity. For example, the provinces of Hunan, Guangdong, Guangxi, and Hainan set a higher electricity usage amount at the same unit price for the summer or winter time across three tiers for electricity pricing. Thus, the ladder electricity price scheme highlights a more equitable electricity price based on actual use and may shield the population, allowing people to modify their electricity use in the context of a tight budget. This is also a key aim of the 12th Energy Five-Year Plan to lower low-income households' energy costs. In effect, the ladder electricity price transformation noted the energy consumption inequalities not only between the residential and industrial sectors but also among varied income groups of people, offering lower energy prices to the lowest consuming households.

4. Recognition of social vulnerability

4.1. (Income) poverty alleviation

As mentioned in Section 1, China has not recognized energy poverty as a distinct form of (income) poverty (Table 2 shows the differences between 'general poverty' and 'energy poverty' according to established debates), although policies that address domestic energy deprivation exist, and they usually target low-income households. China has increased its poverty threshold in the past 20 years with relation to absolute poverty (Fig. 2). By 2021, China had eradicated absolute poverty[8] (PRC (2021)), and now moved to reducing relative poverty which describes circumstances in which people cannot afford actively to participate in society and benefit from the activities and experiences that most people take for granted. Related strategies include: a comprehensive social protection system inclusive of specific threshold standards; active policies to assist people out of poverty; and supportive, redistributive fiscal policies (T.S.C.I.O.o.t.P.s.R.o.C. PRC, 2021; I.L.O. ILO, 2020). Strategies to deal with relative poverty bring an opportunity for policy makers to think of ways to continuously enrich people's life, that should include how to meet domestic energy needs in daily life. Scholars (Middlemiss and Simcock, 2019) also claim the benefits of having a separate concept of energy poverty to poverty is that it helps reveal structural and systemic factors producing inadequate domestic energy services that go beyond low-incomes. Given that Chinese policy has now turned its attention to relative poverty, it could be an opportune moment to establish a clear definition of energy poverty and implement relevant measures for its alleviation, as part of the broader goal to eliminate relative poverty.

4.2. Other vulnerable groups

Chinese policy has already identified and supported specific socio-demographic groups that are particularly vulnerable to energy poverty: for instance, households with low incomes, with older people, disabled people, or children (age<16), or living in rural areas and heating their homes only with electricity, or that solely rely on electricity for heating due to the clean energy regulations. As we mentioned above, many initiatives for the general welfare of the populace focus on low-income groups with some further consideration of households with older people, people with a disability, or children (age<16), especially when those groups of people live in rural areas. Consequently, financial subsidies including electricity and housing, are currently the primary method for solving energy inequity regarding low-income groups.

Two types of low-income household in China have been recognized as needing the relevant subsidies: **1)** Five-guarantee households[9] (also called "wubao (五保)" in Chinese) which refers to:

> '*Ensuring that the households with older people, disabled people, or children (age < 16) living in rural areas have guarantees to access food, clothing, hospital, housing, burial*'.

5. The minimal assurance households (also called "dibao (低保)" in Chinese) refers to

> '*Households with members of the family who are unable to work owing to a serious sickness or disability, and households whose income falls below the local minimum-security level*" (PRC, 2021)'.

These households can benefit from the minimum living allowance, which applies to both urban and rural areas. To meet the electrical needs of the Five-guarantee households and the Minimal Assurance households, the government distributes 120 Kwh of free electricity to each household annually in addition to the ladder electricity scheme. Provinces in China have different subsidy programs in place for people who heat their houses exclusively with electricity. The National Energy Administration (NEA)[10] recommends:

> '*Providing subsidies for electric heating in order to lower the expense of ensuring thermal comfort in the winter and to prevent air pollution from burning fossil fuels in households without district heating facilities* (N.E.A. NEA, 2016)'.

Liaoning province, for instance, lowers electricity costs by 50 % from 22 p.m. to 5 a.m. the next day, for residents who rely solely on electricity to heat their homes during cold seasons (from November to

[7] China's National Development and Reform Commission promoted the 'Ladder Electricity Prices' system for residents which would cover most provinces in China except for Xinjiang and Tibet, specifically, the first grade of electricity amount has been raised, but the price has basically remained the same as the previous electricity price. the second and third tiers in most provinces raised prices by 0.05 yuan and 0.3 yuan respectively. As of late July in 2012, 25 provinces have begun to fully implement this system except for Anhui, Guizhou, Hunan, and Shaanxi provinces, which are still under preparation. https://www.ndrc.gov.cn/fggz/tzgg/ggkx/201207/t20120709_1064623.html?code= &state= 123

[8] 'Absolute poverty' means that an individual or family cannot maintain a minimum standard of living. Simply put, it means living below the subsistence line, lacking food, and clothing, and having to solve the problem of survival. And with that comes the concept of "relative poverty" which refers to the income and living standard of individuals or families' average income and living standard is still relatively low, although they have basically solved the problem of food and clothing and be out of absolute poverty.

[9] China's rural Five-Guarantee system started from the "Rural Five Guarantees Work Regulations" issued by The State Council on January 23, 1994.

[10] A national bureau managed by the State Council Ministries and Commissions in charge of energy development and industry supervision affairs of the People's Republic of China. It is currently managed by the National Development and Reform Commission.

Table 1
The residential ladder electricity price scheme in provinces and municipalities of China (2024).

Province	Evaluation period	First tier Electricity consumption (Kw*h/household/month)	Electricity price (yuan/Kwh)	Second tier Electricity consumption (Kw*h/household/month)	Electricity price (yuan/Kwh)	Third tier Electricity consumption (Kw*h/household/month)	Electricity price (yuan/Kwh)
Beijing	Year	0–240	0.4883	241–400	0.5383	> 400	0.7883
Tianjin	Year	0–220	0.49	221–400	0.54	> 400	0.79
Hebei	Year	0–180	0.52	181–280	0.57	> 280	0.82
Shanxi	Month	0–170	0.477	171–260	0.527	> 260	0.777
Inner Mongolia	Month	0–170	0.43	171–260	0.48	> 260	0.73
Liaoning	Year	0–180	0.5	181–280	0.55	> 260	0.8
Jilin	Year	0–170	0.525	171–260	0.575	> 260	0.825
Heilongjiang	Year	0–170	0.51	171–260	0.56	> 260	0.81
Shanghai	Year	0–260	0.617	261–400	0.667	> 400	0.917
Jiangsu	Year	0–230	0.5283	231–400	0.5783	> 400	0.8283
Zhejiang	Year	0–230	0.538	231–400	0.588	> 400	0.838
Anhui	Year	0–180	0.5653	181–350	0.6153	> 350	0.8653
Fujian	Month	0–200	0.4983	201–400	0.5483	> 400	0.7983
Jiangxi	Year	0–180	0.6	181–350	0.65	> 350	0.9
Shandong	Year	0–210	0.5469	211–400	0.5969	> 400	0.8469
Henan	Year	0–180	0.56	181–260	0.61	> 260	0.86
Hubei	Month	0–180	0.57	181–400	0.62	> 400	0.87
Hunan	Winter and summer	0–180	0.588	181–450	0.618	> 450	0.91
	Spring and autumn	0–180	0.588	181–350	0.618	> 350	0.91
Guangdong	Summer	0–260	0.61	261–600	0.66	> 600	0.91
	Off-summer	0–200	0.61	201–400	0.66	> 400	0.91
Guangxi	Peak	0–190	0.5283	191–290	0.5783	> 290	0.8283
	Off-peak	0–150	0.5283	151–250	0.5783	> 250	0.8283
Hainan	Summer	0–220	0.6083	221–360	0.6583	> 360	0.9083
	Off-summer	0–160	0.6083	161–290	0.6583	> 290	0.9083
Chongqing	Month	0–200	0.52	201–400	0.57	> 400	0.82
Sichuan	Month	0–180	0.5224	181–280	0.6224	> 280	0.8224
Guizhou	Year	0–180	0.4556	184–333	0.5056	> 333	0.7556
Yunnan	Month	0–170	0.45	171–260	0.5	> 260	0.8
Shaanxi	Year	0–180	0.4983	181–280	0.5483	> 350	0.7983
Gansu	Month	0–160	0.51	161–240	0.56	> 240	0.81
Qinghai	Month	0–150	0.3771	150–230	0.4271	> 230	0.6771
Ningxia	Year	0–170	0.4486	171–260	0.4986	> 260	0.7486

Source: Authors elaborated based on the release from provinces and municipalities till June 2024.

Table 2
A summary of the differences between 'general poverty' and 'energy poverty'.

Aspect	Energy poverty	General poverty
Definition	Inability to afford adequate energy services (heating, cooling, lighting) to maintain a healthy living environment (Bouzarovski and Petrova, 2015).	Inability to meet basic living standards, such as food, shelter, healthcare, and education (Smith, 1776).
Focus	Energy access and costs, particularly for heating and cooling (Middlemiss, 2022b; Thomson et al., 2019).	Broad economic hardship affecting all aspects of life.
Key factors	High energy costs, poor housing insulation, low income, inefficient energy systems (Robinson et al., 2019).	Low income, unemployment, lack of access to basic services.
Indicators	**10 %:** Spending more than 10 % of household income on energy, inadequate home insulation (Boardman, 1991; DLUHC, 2020). **Low Income High Cost (LIHC)**: Energy poverty under LIHC occurs when a household has a lower income and spends a high proportion of it on energy, leaving them with inadequate resources for other essentials (DLUHC, 2020). **Low Income Low Energy Efficiency (LILEE)**: Energy poverty under LILEE happens when a household has a low income and lives in a home with poor energy efficiency, leading to high energy bills despite low energy usage (DESNZ, 2023).	Income level below the poverty line, lack of access to essential services.
Targeted interventions	Improving energy efficiency of homes, reducing energy costs, providing financial assistance for heating/cooling.	General welfare programs (e.g., food assistance, unemployment benefits), housing subsidies.
Vulnerable groups	Elderly, children, low-income households, rural communities, renters (Robinson et al., 2018a).	Individuals with low or no income, homeless people, unemployed individuals (Middlemiss and Simcock, 2019).
Health implications	Increased risk of respiratory and cardiovascular diseases due to cold, heat stress from inadequate cooling.	Poor nutrition, poor mental and physical health, lack of access to healthcare.
Impact on well-being	Difficulty in maintaining a comfortable indoor temperature, higher energy bills leading to financial strain.	Inability to meet basic needs such as food, clothing, and shelter.
Geographic relevance	More prominent in colder or hotter climates where heating and cooling are essential.	Global issue affecting all regions, particularly in low-income countries or areas with high unemployment.
Long-term effects	Chronic health problems due to extreme indoor temperatures, financial strain from high energy costs.	Long-term poverty cycle, poor educational outcomes, and lack of social mobility.

March). Meanwhile, other provinces have varied policies on clean heating subsidies based on the actual electricity demand with a specific maximum limit, which covers the clean heating types not only the 'coal to electricity' households, but also the 'coal to natural gas' households. These initiatives all take into account the dual objectives of reducing households' heating costs and reducing air pollution.

6. Recognition of spatial vulnerability

6.1. Rural and remote areas

Chinese energy policy has addressed spatial inequalities resulting from the uneven distribution of energy infrastructure by enhancing basic energy services and improving energy efficiency, particularly in rural areas and remote regions. Firstly, the 12th and 13th Five-Year Plans both call for:

'*The expansion of urban energy supply infrastructure and services to rural areas, with a particular focus on strengthening the building of rural infrastructure like liquefied gas supply stations, gas stations, briquette processing points, biomass gas stations, and pipe networks.*'

They also call for:

'*The establishment of maintenance and technical service stations for a variety of energy facilities, the development of professional service businesses and personnel for rural energy, and an improvement in the capacity of these facilities.*'

In terms of remote border areas including Tibet, Xinjiang, Qinghai, Sichuan, Yunnan and Inner Mongolia, 12th and 13th Five-Year Plans for Energy Development both emphasize:

'*Making use of local renewable energy resources to speed up the construction of small power sources such as micro hydropower, small wind power, household photovoltaic systems, and wind-solar complementary power stations to solve the shortage of electricity in affected areas*.'

Enhancing energy efficiency of domestic energy use by providing subsidies for energy-efficient appliances is the second strategy to assist rural households in eliminating energy poverty (Andrews-Speed, 2009). The Home Appliance to Rural Households Policy, introduced by the Chinese Ministry of Finance in December 2008 as a specific measure outlined in the 11th Five-Year Energy Plan to enhance residential energy efficiency, is a crucial step in putting these measures into effect for households. The 11th Energy Five-Year Plan indicates that:

'*Rural households can receive a 13 % market-price subsidy when purchasing any of the following 10 home appliances: electric bicycles, TVs, washing machines, refrigerators, mobile phones, computers, water heaters, microwaves, and induction cookers.*'

Meanwhile, these home appliances have a higher energy standard than previous products, for example, refrigerators are classified as level 2 of China's new standard, equivalent to level A and A+ in the European Union in 2008. While these initiatives have elevated the usage of electrical goods in rural areas and promoted energy conservation and emission reduction, there has been insufficient feedback on the subsequent consumption patterns of households. This includes the frequency and affordability of utilizing specific energy-saving equipment, which is crucial for addressing energy efficiency disparities in rural areas. Even among rural regions in China, considerable heterogeneity exists in terms of energy poverty conditions, shaped by diverse geographic, socio-cultural, and infrastructural contexts. For instance, studies have shown that ethnic minority regions such as Xinjiang and Yunnan face distinct energy poverty challenges due to geographic isolation, infrastructural limitations, and cultural practices (Collan et al., 2022; SUN et al., 2014). Recognizing and addressing these intra-rural disparities is essential for designing equitable and spatially sensitive energy poverty interventions in China.

6.2. Urban areas

Urban areas, in contrast to rural and remote regions, have witnessed more advanced development in domestic energy provisions and services, particularly focusing on heating, housing, and shared electric cars, aligning with policy agendas for both social development and climate mitigation. "*Building district heating facilities in small and medium-sized cities*" was designated as a welfare and energy-saving project for the 11th Five-Year term (2006–2010) in the northern urban districts which typically have a cooler climate than the southern areas, while the North and the South have been divided by the Qin-Huai Boundary Line a very important geographical line in China.[11] However, not all households in Northern urban areas can benefit from district heating, and many still heat homes using solid fuels, such as firewood and coal which impose severe undesirable impacts on public health and environment associated with indoor and outdoor air pollution. In order to increase environmental sustainability, the Chinese government has implemented the Winter Clean Heating Plan for Northern Regions (2017–2021)[12] and "*invested 35.12 billion yuan in the Clean Heating Program, which has been implemented in 43 cities across Northern China*". This initiative switches household heating fuel from coal to natural gas, electricity, or clean coal through mandates and incentives. Despite the fact that this program has assisted in achieving environmental goals, one potential drawback is that low-income households may experience energy poverty as a result of the transition's higher heating expenses (Xie et al., 2022; Barrington-Leigh et al., 2019). Characterizing these homes could be beneficial to understand how to enhance household welfare through better program design and execution, such as the Clean Heating Program.

In the meantime, energy-efficiency measures focused mostly on the built environment in order to save energy and protect the environment have been implemented in urban areas. Since the 10th Five-Year Plan for Energy Development, which places a strong '*emphasis on energy-saving housing technologies and appliance labelling for key household appliances*' the concept of energy conservation has been written into government documents. '*The development of an energy-saving nation and the advancement of an energy-efficiency standard system*' are also highlighted in the 12th and 13th Five-Year Plans. However, urban residents have not consistently been the focal point of policy discussions on energy poverty alleviation related measures, despite the fact as illustrated in Section 3.1 that urban areas also encounter energy poverty issues akin to those in rural and remote regions (Lin and Wang, 2020; Zhang et al., 2023a; Robinson et al., 2018a; Zhang et al., 2023b). For instance, an investigation in Beijing revealed that due to the privatization of the housing market spanning several decades, disparities in energy access have emerged for individuals without access to well-constructed and energy-efficient living spaces, resulting in inequalities in the ability to purchase or rent high-quality, energy-efficient residences (Robinson et al., 2018a). As a result, it is crucial to acknowledge and address energy poverty challenges in urban areas, especially when they exhibit variations from rural areas due to economic and social disparities. Considering a broader range of geographical differences will enable a more comprehensive approach to mitigating regional inequalities in energy services and consumption.

Given that vulnerability is not a discrete, additive category but rather a dynamic, intersecting set of factors that vary across individuals and communities (Robinson et al., 2018a). for example, how elderly individuals with limited mobility, living in rural western provinces with underdeveloped infrastructure, face compounded barriers to accessing

[11] The Qinling Mountains-Huaihe River Line (simplified as 'Qin-Huai Boundary Line') is the geographical dividing line between the northern and southern regions of China, also the line of 0-degree Celsius division, 800 mm precipitation division etc., which has very important geographical implications in China.

[12] Refer to: https://www.gov.cn/xinwen/2017–12/20/content_5248855.htm

affordable and clean energy. These intersecting disadvantages reflect a deeper structural issue, wherein demographic characteristics (e.g., age, gender, health status) and spatial conditions (e.g., housing quality, access to networks) interact to exacerbate energy-related deprivation (Middlemiss et al., 2019; Robinson et al., 2018c). Recognizing these compounded risks moves the analysis beyond a binary urban–rural framework and supports a more granular understanding of energy poverty's multidimensionality in the Chinese context.

7. Conclusion and policy implications

7.1. What is included?

The evidence reviewed in this paper indicates that energy poverty related responses have been partially embedded in Chinese policy agendas on energy planning and poverty alleviation. By analysing the Energy Five-Year Plans from 2000 to 2020 as well as The White Paper of China's Practice in Poverty Reduction, we were able to answer the research questions set out in Section 1. Although the Chinese government does not define energy poverty as a unique type of (income) poverty, national energy plans and poverty policies have recognized the accessibility of energy services and just energy pricing (electricity). These policies attempt to distribute benefits of energy services and burdens of energy price more equally. In current Chinese policy, some sociodemographic groups vulnerable to energy poverty, such as households with low incomes, older people, disabled people, children below 16 years, living in rural areas, or heating their homes only through electricity, have already been recognized and provided with related support. In terms of recognition of spatial vulnerability, the spatial sensitivity of energy poverty is reflected in the differences between urban and rural energy infrastructure, services, and subsidy policies.

7.2. What is missing?

Based on the analysis of energy poverty related recognitions in existing Chinese policies, we situated these findings in relation to existing studies regarding Chinese energy poverty and identified responses that need to be considered in future. The Venn diagram (Fig. 3) shows the overview of the presence and absence of energy poverty responses in China. Regarding energy accessibility, China has recognised the need to consider the distribution of energy services in society, and to generate fairer electricity pricing, as well as to provide heating infrastructure in some urban areas in the North. Nonetheless, there is ample room for further development of clean energy infrastructure, particularly for the delivery of renewable energy and natural gas. Policies should be vigilant about possible burdens on energy poor households' domestic consumption, if reformation of the energy market results in further reduction of cross-subsidy to residential energy prices in future. In addition, it's important to be aware of other interconnected factors that are related to energy accessibility, such as housing conditions and retrofit initiatives that may have an impact on natural gas pipeline entries, which may restrict access to clean energy services or the ability of a

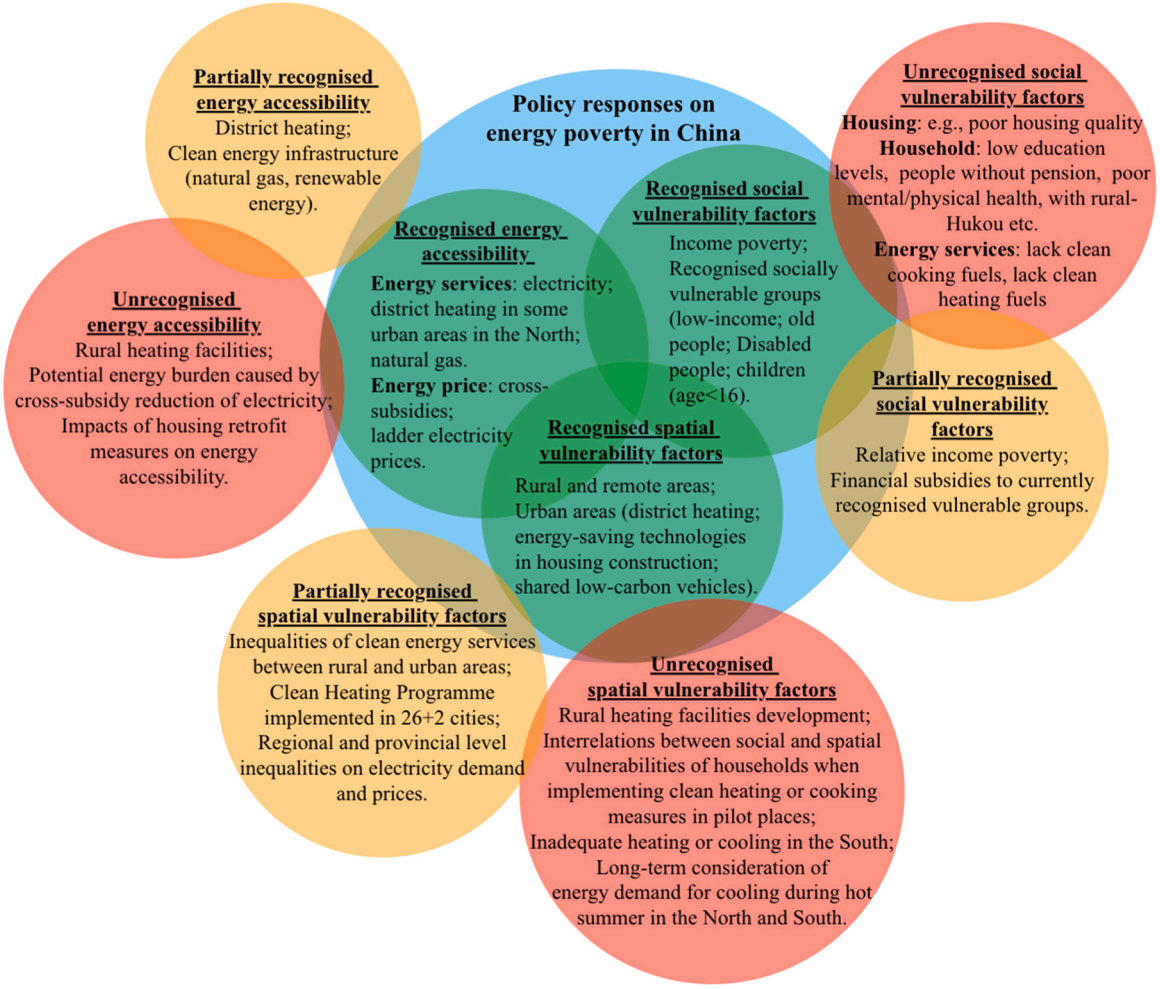

Fig. 3. The presence and absence of energy poverty responses in Chinese policies using a red-amber-green indicator Note: the red, amber, green circles show the unrecognised, partially recognised, and recognised aspects relate to energy poverty in Chinese policies separately.

household to obtain adequate heating services.

When providing energy support, China has recognized a number of vulnerable groups, however, the support has primarily focused on direct financial need without taking other social vulnerability factors related to domestic energy consumption into account. For example, households with specific vulnerabilities have been evidenced to have a strongly risk of falling into energy poverty, such as poor housing quality and low energy efficiency which can cause insufficient thermal comfort during cold winter season (Robinson et al., 2018a; Zhang et al., 2023b); households with lower education levels (Zhang et al., 2023b; Xie et al., 2022); smaller household sizes; households with larger housing areas (Xie et al., 2022); households lacking clean cooking fuels; households with rural-Hukou; households with poor physical/mental health; mainly female households; households with old people; households without pensions (Zhang et al., 2023b). For example, in rural China, gendered energy burdens are often shaped by deeply rooted patrilocal traditions, wherein women marry into and reside with their husband's families, frequently in extended households located in underdeveloped villages. This social structure can exacerbate energy poverty risks for female-headed households or elderly women, who may have limited decision-making power over household energy use, reduced access to financial resources for energy-related investments, and heightened exposure to indoor air pollution from traditional fuels (Zhang et al., 2022). For instance, Liu et al (2024). found that older rural women in western provinces bear a disproportionate burden of fuel collection and household heating, especially in households lacking clean cooking infrastructure. These intersecting vulnerabilities illustrate that gender is not an isolated factor but is tightly interwoven with household structure, cultural norms, and spatial inequality in shaping energy access and deprivation. Most of these social characteristics related to energy vulnerability have been neglected in current energy related policy agendas. Current initiatives in China primarily focus on subsidizing clean heating, which benefits public health and air quality but may not fully address the long-term alleviation of energy poverty. Policies need to integrate housing quality improvements, including better insulation and access to natural gas pipelines, which are critical to addressing energy poverty in a comprehensive way. Furthermore, while the government acknowledges the issue of low-quality housing, more action is needed to enhance housing efficiency and ensure that vulnerable populations can access necessary energy services.

In terms of recognition of spatial vulnerability to energy poverty, the current spatial sensitivity of energy poverty responses is reflected in the differences between urban and rural energy infrastructure, services, and subsidy policies. Recent research also suggests a need for spatial vulnerability recognition in energy policy agendas, especially rural-urban division and among provinces (Lin and Wang, 2020; Zhang et al., 2023a; Robinson et al., 2018a; Zhang et al., 2023b), as well as the west-east division (Lin and Wang, 2020; Tang and Liao, 2014). Some research suggests that energy poverty levels are fairly equal in both rural and urban areas across provinces in China (Zhang et al., 2023a), noting that urban energy poverty has received less attention and discussion until now. Actions on housing, heating, and sharing low emission vehicles in pilot cities have been implemented among urban residents as part of policy agendas with the dual goals of social development and climate mitigation, however, future policies should take into account these concrete and comprehensive measures due to the complexity of particular households in places due to the socio-spatial interrelations (Robinson et al., 2018b). Thus, whether it is a rural-urban division or a regional division, these types of spatial vulnerability to energy poverty are all determined by the spatial differences in household income, expenditures and sociodemographic characteristics related to energy consumption. These differences are not currently thoroughly recognised in energy policy, because it does not directly address energy poverty.

7.3. Institutional barriers

Despite increasing policy recognition of energy inequality, structural constraints embedded in China's political economy continue to hinder effective implementation. The dominance of state-owned utility enterprises in electricity and gas provision can limit responsiveness to local energy needs, as their centralized operations often prioritize infrastructural expansion and economic efficiency over equitable access (Andrews-Speed, 2016; Lo, 2015). Moreover, China's fiscal decentralization framework poses challenges for vertical coordination: while national directives set ambitious targets, subnational governments shoulder disproportionate fiscal and administrative responsibilities. Variations in local government capacity have been linked to uneven outcomes in the rollout of clean energy infrastructure, subsidy allocation, and enforcement of building energy codes (Shen, 2017; Sun et al., 2023). Without institutional reforms that address these governance frictions, energy poverty policies risk fragmentation or dilution during implementation.

7.4. Towards a just transition in China

Recent advancements in China's decarbonization agenda-particularly the national dual-carbon goals (carbon peaking by 2030 and neutrality by 2060)[13]-have introduced both opportunities and challenges for addressing energy poverty. While the expansion of renewable energy, electrification, and clean heating initiatives holds promise for improving environmental and health outcomes, these transitions may inadvertently deepen spatial and socioeconomic inequities, especially in rural and underserved areas. In this Perspective, we examined the interlinkages between low-carbon energy policies and energy poverty, highlighting how current interventions such as the Clean Heating Program can impose disproportionate burdens on low-income households due to high upfront costs, lack of infrastructure, or limited affordability of clean technologies. These insights underscore the importance of designing synergistic policies—such as targeted retrofitting, equitable subsidies, and inclusive pricing mechanisms—that bridge decarbonization goals with social equity, paving the way for a just energy transition in China.

CRediT authorship contribution statement

Caitlin Robinson: Writing – review & editing. **Ian Philips:** Writing – review & editing, Supervision. **Lucie Middlemiss:** Writing – review & editing, Supervision. **Lin Zhang:** Writing – review & editing, Writing – original draft, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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[13] China's '3060' decarbonization target: China's government is committed to hit emissions' peak by 2030 and carbon neutrality by 2060 which was announced in September in 2020 by the President Jinping Xi. China's

Data availability

Data will be made available on request.

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