The spatio-temporal evolution of energy poverty in China: Assessment, drivers, and policies

Lin Zhang

Submitted in accordance with the requirements for the degree of

Doctor of Philosophy

University of Leeds

Sustainability Research Institute

Institute for Transport Studies

School of Earth and Environment

May 2023

The candidate confirms that the work submitted is her own and that appropriate credit has been given where reference has been made to the work of others.

The Candidate's original intention was to submit in an alternative paper format, and that in the end COVID-19 got in the way. Thus, the candidate still will present 2 of the papers in format, because they work better that way.

Acknowledgements

First of all, I would like to thank my amazing Ph.D. supervisors: Lucie Middlemiss, Ian Philips, who have been with me from day one of this Ph.D. journey and have brought their massive unique perspectives and feedback. Many thanks to Lucie for believing me since I first wrote her email from China. Thank you for being a patient, critical, constructive, supportive, energetic, and practical supervisor - it helped me grow to be a more rigorous academic. Also, thank you for being an amazing mentor and unique friend throughout happy and difficult times, especially during COVID time, your care made me believe in myself and be kinder to myself. Most of all, thank you for being a moral compass together with other scholars in "energy poverty research family" and showing me that being academic is also an activism responsibility - especially regarding the realistic energy poverty issue which is related to the possible access of justice and well-being of a lot of families. I am as much thankful to Ian, for his outstanding ability to explain difficult concepts, methods, as well as the narrative techniques on academic writing and make them seem to be the easiest thing; thank you for showing me your magic for R. Thank you in particular for our numerous chats on how to deal with the technique issues I encountered. I absolutely appreciate your great patience and constructive suggestions to me when I lacked some motivation for the project during a time in quarantine. Also, your always calm mind (with a dash of humour now and then) inspired me for so many times. I could gain positive energy every time after the supervision meetings and feedback emails with you and Lucie, I feel so lucky to have both of you as my supervisors!

This Ph.D. would not have been possible without the funding support from China Scholarship Council, as well as the data support from China Social Science Survey Centre in Peking University. Special thanks to John Barret, Milena Buchs, for providing insightful thoughts on my Transfer Report, and to Alice Owen, Anne Owen, Yim Ling Siu for their constructive ideas and efforts on my paper. Thank Julia Martin-Ortega, and Natalie Kopytko for giving me the opportunities to assist teaching in two modules for semesters, great experiences in Statistical Ocean while having a great time collaborating with you. Also, had a great time working with Eberechukwu Ihemezie, Thirze Hermans, Khatun Zannat, thank

you all! Especially thank you to Michelle Lesnianski and other staffs in SEE, for creating a supportive environment to work in.

Thank you to the several incarnations of the 9.157 office (before COVID), 9.127 office (in and post-COVID), and colleagues in SRI: Ben Robra, Max Nawrath, Linas Svolkinas, Emmanuel Ricco Likoya, Jose Barbero, Ruth Smith, Anuszka Maton, Hanna Pettersson, Joe Lawley, Zubaida Umar; you made me laugh, pushed me to be kinder to myself and not to give up. A further thank you to the SRI PhD group on WhatsApp, the virtual Friday Quiz Nights at the start of the COVID times was my lifeline to feel connected and motivated throughout uncertain times. Massive thanks to Huiting Lu and Zhuoqian Yang, for sharing lunches, dinners, coffees, drinks, and walks and being amazingly supportive friends, thank you for all your kindness. Thank you to Nan Cui, Peng Gao, Ruifan Tang, Rui Zhou, Xinmeng Zhang, Kaimeng He, Shasha Cai, Qingyang Zhao, Xiang Li, Hui Chang, Yang Ren, I will always remember the wonderful trips, the countless weekends and chats, and festival celebrations with endless laughter we spent together. Moreover, thanks to my rented house located in BV in Leeds which has loaded plenty of laughter.

Huge thanks to my lovely parents for their endless and unconditional love and support. To my mom for her open-mindedness and optimism, in whatever I have ever set out to do, and to my dad for being my role model of extraordinary personalities. I would also want to thank my dear younger brother who accompanied and brought me a lot of fun through video chats. Further thanks to the rest of my family (my uncle and cousin) for being such an unquestionable source of support. Special thanks to my dear grandpa and aunt whose spirits, and positive attitude towards lives will influence me forever. Last but not least, I want to thank my “Dino”, for his great companionship and spiritual encouragement every single day, who also let me know myself better by acting as a “mirror”. Finally, I would appreciate myself, for cherishing the quality of bravery all the time and letting me realize that I am stronger as I thought!

Abstract

Building an understanding of energy poverty in China is crucial to deliver the dual goal of Sustainable Development Goal 7 (Ensure access to affordable, reliable, sustainable and modern energy for all) and China's '3060' [1] decarbonisation strategy. Energy is essential for satisfying human needs, at the same time, energy consumption is the main contributor of the greenhouse gas emissions driving the climate crisis. There is thus a need to understand what kind of and who is vulnerable to energy poverty in China, and how to formulate effective responses.

Because there is no officially adopted measure of Energy Poverty in China, I constructed the classic "10% indicator" and "LIHC indicator" and developed a novel comparison of the two indicators after calculating energy poverty at the household level. Also, I addressed an important gap in energy poverty and energy vulnerability research in China: the role that sociodemographic characteristics play in shaping and potentially ameliorating situations of energy poverty, to investigate who is most vulnerable to energy poverty in China. Finally, I reviewed and reflected the energy poverty responses in national policies. The principal dataset used for this analysis required me to repurpose five waves of the China Family Panel Studies (a nationwide representative panel survey) which has not been used before for measuring energy poverty spatially and temporally. A contribution of this thesis is demonstrating the ability to leverage the value of routinely collected social data in order to develop these useful indicators of social wellbeing.

I found energy poverty levels are common in both rural and urban areas across case-study provinces (Gansu, Liaoning, Henan, Shanghai, Guangdong) during study period (2010-2018), noting that urban energy poverty has received less attention and discussion until now. The "10% indicator" reveals the rural-urban gap of energy poverty rates as more substantial than under the "LIHC indicator". Households with specific sociodemographic characteristics under vulnerability domains of housing and transport, education and employment, health, household structure, and social security, are more likely to suffer from energy poverty. I consider that both of energy poverty's assessment and vulnerability factors imply the need to recognise domestic energy poverty in China, taking into account social and spatial heterogeneity of vulnerabilities is an essential starting point.

1 China's '3060' decarbonization strategy: 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 carbon emissions should start declining in 2030. And by 2060, carbon emissions should reach net zero.

Table of Contents

List of Tables

List of Figures

Abbreviations

CFPS	China Family Panel Studies
CO_2	Carbon Dioxide
EP	Energy Poor
IEA	International Energy Agency
NEA	National Energy Administration of China
SDGs	Sustainable Development Goals
UN	United Nations

Chapter 1 Introduction

1.1 Empirical context

1.1.1 Why "energy povrty" is a issue in China?

Energy products and services are unequally distrubuted among households in China which can lead to deprivations in domestic energy use. Modern energy products such as electricity and natural gas account for 92.8% of total energy use in 2020 in the residential sector (see Figure 1.1). China achieved 100% coverage of electricity in 2009 (IEA, 2010), however, there are huge disparities in household energy consumption between and within regions including a rural-urban division.

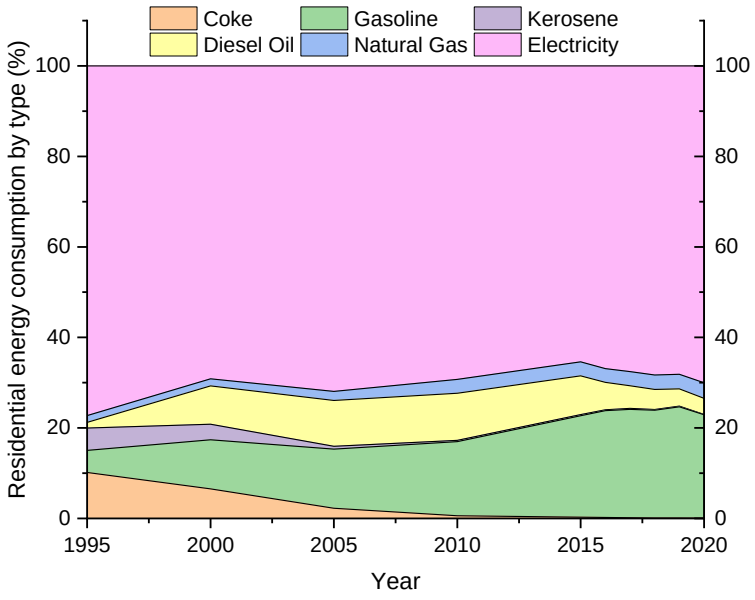

Figure 1. 1. Proportion of residential energy consumption by types from 1995 to 2020
Source: Data from China Energy Yearbook 2021

For example, Figure 1.2 shows the distribution of residential energy consumption between urban and rural areas in China in 2020. It can be seen that rural areas have a substantial portion of coal use which is 9.2 times than that in

urban areas. Residential use of coal can present serious human health problems because the coals are generally mined locally with little regard to their chemical composition and the coals are commonly burned in poorly vented or unvented stoves directly exposing residents to the indoor or outdoor emissions (Finkelman et al., 2002). Also, district heating facilities are only available in certain cities in northern China, there are no district heating facilities in rural areas or southern cities. District heating in Northern cities has been implemented via the District Heating Policy[2] due to the relatively cold climate in winter complared to southern China. Even under the present District Heating Policy, there are parts of some metropolitan areas of northern China that lack sufficient heating supplies in the winter (Robinson et al., 2018c). There are huge differences in Natural gas consumption between urban and rural areas as well. Moreover, even within urban areas, inequalities around enegy services and housing quality exist in different areas. Figure 1.3 depicts contrasting properties in urban Gansu, where one lacks gas pipe access, relying on polluting stoves with a chimney, while the other enjoys clean energy services through a connected gas pipe. This disparity highlights significant inequalities within nearby Chinese communities. Uneven distribution of energy products and services may result in household limitely consuming essential energy as a survival mechanism to cope with vulnerabilities, which has impacts on health, learning environment, family relationships, and dignity (Yip et al., 2020). Thus, the inequalities of energy products and services in China coheres around a generic understanding of "energy poverty"- as a condition whereby people are unable to secure adequate levels of energy services in the home (Bouzarovski et al., 2012).

2 National standard "Code for Thermal Engineering Design of Civil Buildings" (GB50176-93), the average temperature of the coldest month and the hottest month over the years is used as the main index to divide the country into five regions: severe cold, cold, hot in summer and cold in winter, hot in summer and warm in winter, and mild. In severe cold and cold regions (northern regions), district heating is implemented from mid-November to next mid-March (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2013). https://www.mohurd.gov.cn/xinwen/gzdt/201301/20130124_212672.html

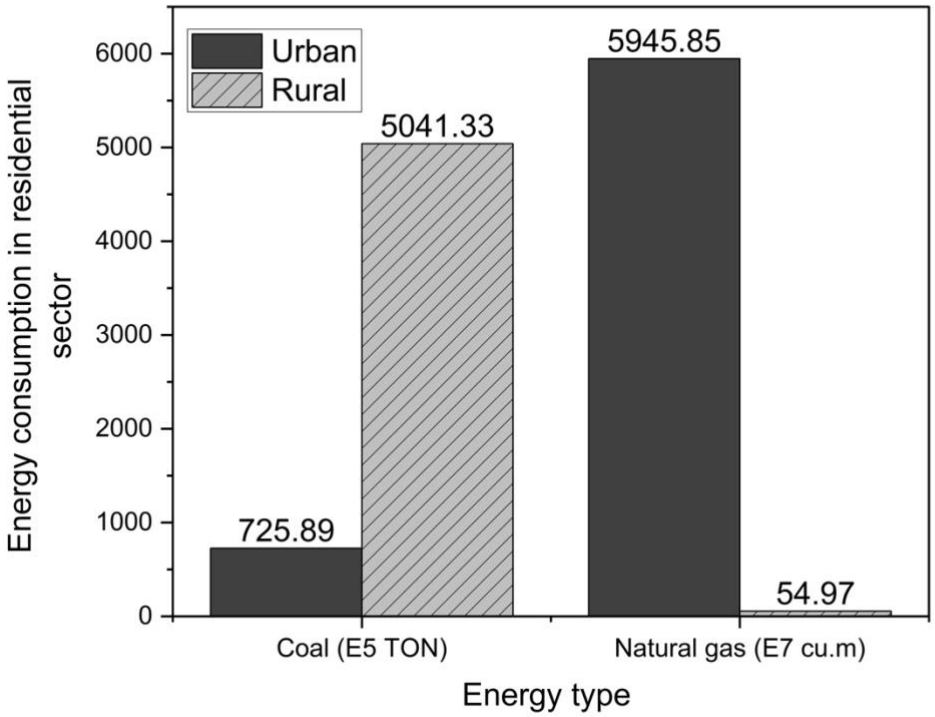

Figure 1.2. Residential energy consumption of coal and natural gas in urban and rural China in 2018

Source: Data from China Energy Statistical Yearbook 2019

Figure 1. 3. Examples of properties within two Gansu communities situated within a 10-minute walking distance.

Source: Authors

1.1.2 Energy poverty identified in western world

Globally, energy poverty has been acknowledged for decades. **1)** A dedicated and stand-alone goal on energy poverty already exists, SDG 7, to "ensure access to affordable, reliable, sustainable and modern energy for all" is included in Sustainable Development Goals (SDGs) of the UN's 2030 Sustainable Development Agenda. Which highlights the disproportionate impact that injustice in the provision of, or access to, energy services is having upon marginalized groups of people (UN, 2015). Energy access is not universal, and SDG 7 raises questions of poverty and vulnerability caused by poor distribution, unaffordable supply, and unstable provision. These challenges lead to people failing to meet their daily needs, maintain good health, and live comfortably. **2)** Energy poverty has also been recognized as policy and academic research agendas within many western countries and institutions: United Kingdom (Boardman, 1991, Middlemiss, 2017, Middlemiss et al., 2018, Baker et al., 2018, Robinson, 2019), Poland (Buzar, 2007), International Energy Agency (Birol, 2007, IEA, 2010), European Union (Thomson et al., 2017b, Dobbins et al., 2019, Saheb et al., 2019, Bouzarovski et al., 2021), United Nations (Bouzarovski et al., 2012, UNDP, 2019), France (Isolde, 2015), Spain (Romero et al., 2018), United States (Bednar and Reames, 2020), Slovakia (Strakova, 2014, Koďouskov´a and Bo˘ruta, 2022).

Moreover, scholars from the above countries have highlighted the spatial and social components of energy poverty when seeking a practical solution to reduce it (Robinson et al., 2019, Robinson et al., 2018b, Bouzarovski, 2018) since both socio- and spatial- vulnerability can result in the likelihood of a loss of wellbeing in the household (Robinson et al., 2018a). **1)** Firstly, energy is integral to socio-spatial relations (Calvert, 2015) which is discursively wrapped up into socio-spatial identities such as 'community' (Bailey et al., 2010, Dorow and O'Shaughnessy, 2013), 'nation' (Perreault and Valdivia, 2010, Bouzarovski and

Bassin, 2013), 'home' (Spinney et al., 2012), 'local' (Devine-Wright and Wiersma, 2013), and 'region' (Vogel, 2016). Furthermore, increasing evidence implies that the development of energy infrastructures is not experienced evenly across space which (re)produce the situations of energy poverty at local and household scales (Jenkins, 2018, Salman et al., 2022, Nguyen and Su, 2022, Abbas et al., 2022, Sovacool, 2015, Robinson and Mattioli, 2020, Bouzarovski et al., 2012, Harrison, 2013). Uneven social-spatial relations create a need for contextualized energy poverty research which seeks to investigate situations in which "individuals or households are unable to access adequate heating, cooling, or other required energy services in their homes at an affordable cost" (Thomson and Bouzarovski, 2018). **2)** Secondly, social determinants of energy poverty along with related political determinants can cause people's domestic energy deprivation (Middlemiss, 2022b). Scholars articulate that the nature of the labour market and welfare state affect people's opportunities to earn a living wage, also the regulation of housing and energy markets shapes people's cost of living (Middlemiss, 2022b). Other Sociodemographic characteristics (physical and mental health, disability, old people, young children, single parent, female, pensioner, private renter, non-gas heating) (Robinson et al., 2018a, Snell and Bevan, Ivanova and Middlemiss, 2021, Robinson, 2019) and social relations (relationships with family, friends, agencies and other distant others) (Middlemiss et al., 2019, Anderson et al., 2012) of the household also have some effects on how likely energy poverty is to occur and how well individuals are able to deal with it. **3)** Thirdly, Thomson et al. recognise the challenges of measuring energy poverty as 'it is a culturally sensitive and private condition, which is temporally and spatially dynamic' (Thomson et al., 2017a), which echoes the effects of spatial components and emphasized the temporal dynamic of energy poverty research. The effects of spatial components of energy poverty have been evidenced to varying degrees (Kyprianou and Serghides, 2021, Sovacool, 2012, Pachauri and Spreng, 2011), at different scales (Middlemiss, 2022b, Zhou and Shi, 2019) and using a variety of framings and indicators in European and Asian

nations (Robinson and Mattioli, 2020, Siksnelyte-Butkiene et al., 2021, Day et al., 2016). Given the intrinsically geographical nature of socioeconomic status, demographic characteristics, travel patterns, and transportation options, a spatial patterns perspective has been also considered in social energy vulnerability (Robinson et al., 2018a) and transport energy vulnerabilities respectively (the latter also conceptualized as part of "double energy vulnerability" together with "domestic energy poverty")[3] (Robinson and Mattioli, 2020, Simcock et al., 2021, Sovacool et al., 2023). Thus, the evolving research agenda on vulnerability to energy poverty not only acknowledges the most disadvantaged groups but also highlights the potential for a new research direction pursuing related studies and policies on energy poverty in China, which may provide a deeper understanding and allow more effective intervention design in the face of this multifaceted issue.

1.1.3 Motivation of this project

To date, China does not recognize energy poverty and lacks a strategy that encompasses definitions, reduction objectives and periodic evaluation in policy agenda. Despite this, a limited amount of research into energy poverty in China has been ongoing since 2000 (Robinson et al., 2018c, Wang et al., 2015, Yang et al., 2017, Wu and Zheng, 2016, Tang and Liao, 2014, Wang et al., 2014b, Jiang et al., 2020, Xie et al., 2022, Wei et al., 2014, Xia et al., 2022, Li et al., 2011, Zhao et al., 2018). Besides acknowledging China has energy poverty problem, existing energy poverty research focusing on China tends to pay attention to either urban or rural areas (Lin and Wang, 2020, Wang et al., 2015, Dong et al., 2021, Zhang et al., 2019), highlighting the different effects of energy poverty in one or the other.

3 Robinson and Mattioli (2020) firstly described the notion of "double energy vulnerability (DEV)" - is "the increased likelihood of negative impacts upon well-being, owing to the intersection of domestic energy poverty (DEP) and transport energy poverty (TEP)".

It would be useful to consider other geographic differences as well as rural and urban. From the latitude perspective, Northern China has colder winters than southern China due to the geographical location[4]. District heating is available in some northern urban areas, as was previously mentioned, but because southern residents experience hotter summers and residents close to the boundary likely experience colder indoor temperatures without district heating than northerners do, they frequently look for alternative methods of maintaining comfortable indoor temperatures. While the energy poverty rates are greater in central and western China from a longitude perspective, this is consistent with the economic growth map of China (Western, Central, and Eastern regions make up China's economic gradient from poor to prosperous) (Zhang et al., 2019, Liao et al., 2016). Additionally, due to the benefits of accessibility and affordability for fossil fuels in the locations, northern and western rural residents use the most coal, whereas eastern rural residents use the most electricity and natural gas for cooking and heating (He et al., 2018). Natural gas consumption in rural areas is remarkably low compared to urban areas, while per capita coal consumption in rural areas is noticeably greater (see Figure 1.4). We can see that people are consuming very different amounts and types of energy, which suggests that some will be under-consuming or not accessing adequate energy services. Yet, for the Chinese Government, energy poverty is a nebulous term that does not exist in any statutory capacity. In other words, the national government has not formally recognized energy poverty as a distinct problem.

4 North and south in China is divided by Qinling Mountains-Huai River Line - an important geographical concept in China, which was first described by geographer Xiangwen Zhang. The line is not only a division of the north and south, but also divisions of 0°C isotherm in January, annual precipitation of 800mm.

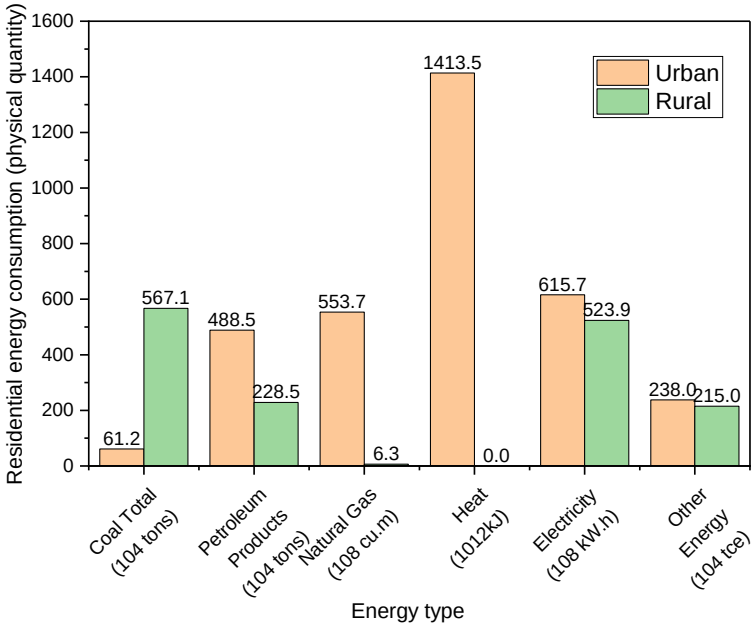

Figure 1. 4. Distribution of total residential energy consumption between urban and rural areas in China in 2020.
Source: Data from China Energy Yearbook 2021

Consequently, the following knowledge gaps exist:

- Not much is known about the energy poverty situation spatially and temporally considering socio-spatial vulnerabilities at household level in both urban and rural areas across China.
- Not much is known about the effectiveness of polices concerning energy poverty issue in China.

This thesis delves into the subject of energy poverty research in the context of China by concerning these overlooked aspects through a national-wide social survey.

1.2 Summary of research gaps and original contributions

1.2.1 **Research gap 1:** no official energy poverty statistics or indicators, nor are there survey specifically designed to measure household energy poverty;

Contribution 1: in this thesis I repurpose an existing administrative dataset and developed a method to derive energy poverty indicators.

Developing methods to allow the construction of energy poverty indicators and measures is a prerequisite to understand and formulate suitable policies for alleviating energy poverty. There are no statistical yearbooks or specific surveys in China which comprehensively investigate or monitor household energy poverty. Using a multidimensional approach with macro scale data, or a combination of macro and micro data (which is a common approach used to date in the literature as above) may hide some information of the specific spatial scale (e.g., the district heating division between northern and southern, or urban and rural in China may cause various lived experiences). Household level data currently used in academics (Lin and Wang, 2020, Zhang et al., 2019, Wang et al., 2023) usually tends to report cross-sectional and the overall aggregate national energy poverty with a lack of understanding of the dynamics behind domestic energy poverty at the household scale over time.

What are not known are:

- How is energy poverty distributed on a household level in China?

- What spatial differences in energy poverty exist between different climate regions and between rural and urban areas?
- How energy poverty changes over time?
- What places, and groups of people have the most severe energy poverty problem?
- What is the variation of different approaches for capturing energy poor households?

This range of exploratory questions is addressed in chapter 4 of the thesis, with a thorough exploration of currently available dataset by focusing on five waves of household social surveys from 2010 to 2018.

1.2.2 **Research gap 2:** no research has explored vulnerability drivers of Chinese energy poverty;

Contribution 2: in this thesis I use the vulnerability framework to fill this gap.

Vulnerabilities in households can result in the household falling into energy poverty, preventing them from accessing and affording the level of energy services needed for a decent life (Bouzarovski et al., 2012). Ongoing academic research on energy poverty has already defined some of the spatial and social vulnerabilities e.g., (Robinson et al., 2018b, Ivanova and Middlemiss, 2021, White and Sintov, 2019, Middlemiss and Simcock, 2019, Middlemiss, 2022a), which allow me to identify overlooked social and spatial aspects of energy vulnerability in the Chinese context. There are currently no studies which explain the drivers of China's energy poverty through a vulnerability lens, especially through a range of sociodemographic characteristics which has been identified by other nations.

It is unknown:

- Who is vulnerable to energy poverty?
- What are the differences of these vulnerability across space?

These questions are answered in chapter 5 of the thesis by focusing on the five potential vulnerability domains of housing and transport, education and employment, health, household structure, and social security, providing a comprehensive exploration of the links between household sociodemographic characteristics and energy poverty. I have so far evidenced that belonging to specific socio-demographic types (e.g., household with rural-Hukou, old people, mainly female, disabled people etc.) would increase the risk of a household falling into energy poverty in China which also has spatial variations. This study is the first of its kind relating to the Chinese case.

1.2.3 **Research gap 3:** no policy review on energy poverty responses in China;

Contribution 3: in this thesis I combined the research results and the reflections of current policy agendas to provide insights to fill this gap.

The lack of knowledge of energy poverty at a micro level and of the socio-demographic groups vulnerable to energy poverty makes it challenging to develop nuanced insights of energy consumption for just development and well-being. This has implications for policy that aims to realize sustainability and alleviate inequality of energy use among society. Unlike European nations, China lacks national energy poverty strategy and responses that encompass definitions, reduction targets/objectives, indicators and periodic evaluation. Chinese energy policy up to now has shown a lack of understanding of energy poverty. The response related to energy poverty in previous energy policy agendas is not well understood or considered. This gap is addressed in chapter 6 with reviewing and

reflecting on the most recent governmental policies on Poverty Alleviation and Energy Five-Year Plan, as well as discussing the possible solutions to frame energy poverty policy drawn from analysis in previous parts of this thesis. All these above knowledge gaps collectively inform the research presented in this thesis.

1.3 Research framing: aims and questions

The aims of this thesis intend to fill the above identified research gaps which have been illustrated as follows:

- To assess the energy poverty situation spatially and temporally in China at the household level.
- To explore vulnerability drivers associated with household energy poverty in the Chinese context.
- To review and reflect energy poverty responses in national policies and to offer policy-related insights.

I linked these three research aims to specific research questions (research question 1-5 been shown in Figure 1.5), theoretical, empirical, and methodological contributions are produced across chapters in this thesis by answering these five research questions.

Figure 1. 5. "Tree" diagram of research questions and contributions in this thesis

Because there is no officially adopted measure of Energy Poverty in China, I constructed the "10% indicator" and "LIHC indicator" and developed a novel comparison of the two indicators after calculating energy poverty at the household level. Also, I addressed an important gap in energy poverty and energy vulnerability research in China: the role that sociodemographic characteristics play in shaping and potentially ameliorating situations of energy poverty, to investigate who is most vulnerable to energy poverty in China. Finally, I reviewed and reflected on the energy poverty responses in national policies. The principal dataset used in this thesis required me to repurpose five waves of the China Family Panel Studies' surveys (a national-wide representative panel survey)

which has not been used before for measuring energy poverty spatially and temporally in terms of pure household level analysis. As such a contribution of this thesis is demonstrating the ability to leverage the value of routinely collected social data in order to develop these useful indicators of social wellbeing.

1.4 Structure of the thesis

This thesis draws from the research aims and questions outlined above: the repurposed use of routinely collected administrative data; the household level energy poverty investigation over time and across spaces; the adaptable measurement evaluation of energy poverty in China; sociodemographic characteristics of energy vulnerability drivers in the Chinese context; and the evidenced and potential policy responses concerning a sustainable and just society. Below I outline the thesis structure in more detail (see Figure 1.6).

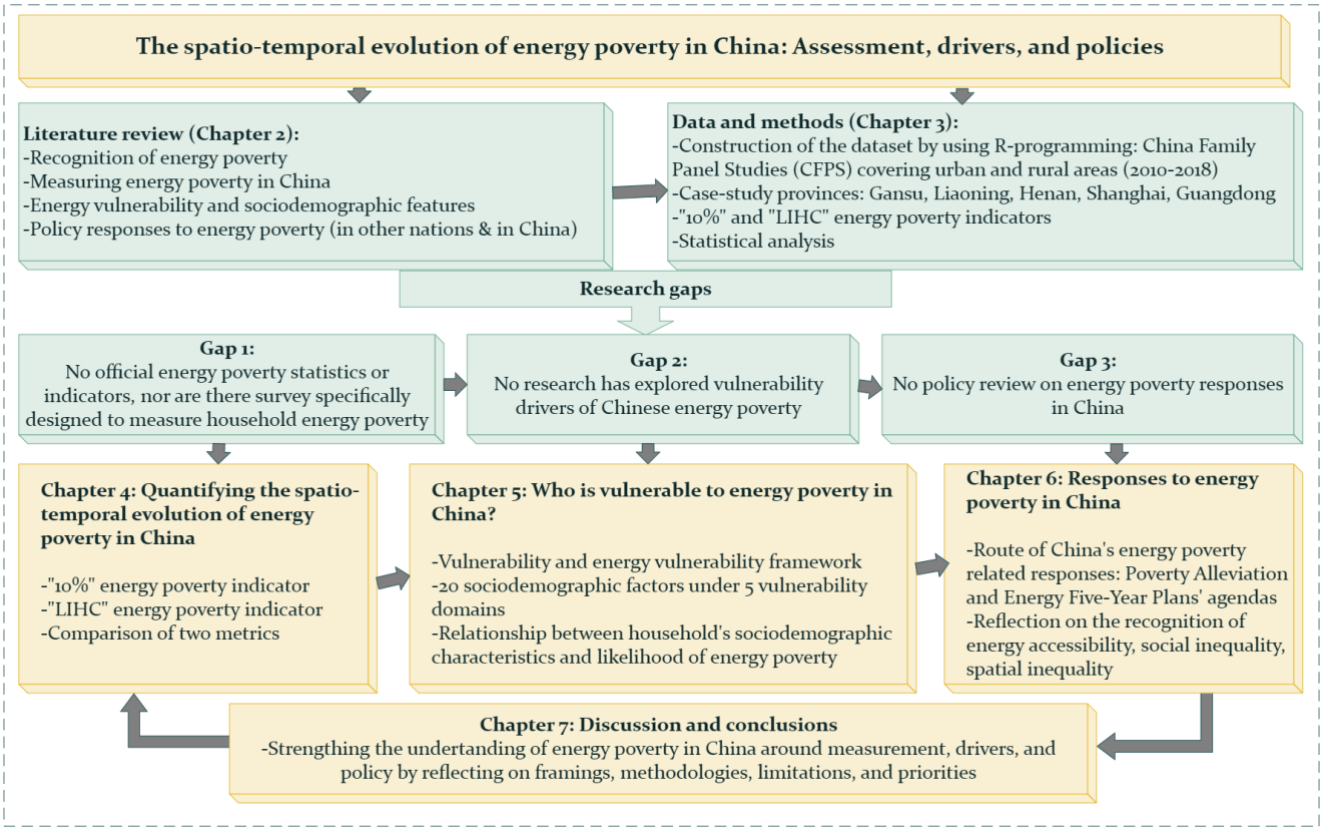

Figure 1. 6. Research framing and structure of the thesis

Chapter 2 Literature review

2.1 Recognition of energy poverty

Various energy poverty metrics have been configured, defined and experienced in different ways around world but there is no unanimously adopted definition of energy poverty (Pachauri et al., 2004, Boardman, 1991, Bouzarovski and Petrova, 2015, Bednar and Reames, 2020, Middlemiss et al., 2019, Day et al., 2016, Nussbaumer et al., 2012, Thomson and Bouzarovski, 2018, Bouzarovski et al., 2021, Sareen et al., 2020, Thomson et al., 2017b, Robinson and Mattioli, 2020). Table 2.1 gives a summary of the various ways of defining energy poverty. The contemporary academic understanding of energy poverty is that it is a multi-faceted and complex problem that has different characteristics in different places and for different people (Bouzarovski et al., 2012, Bouzarovski, 2018, Karpinska and Śmiech, 2020, Middlemiss and Gillard, 2015, Sokołowski et al., 2020, Pachauri et al., 2004, Wang et al., 2015). Many nations and scholars have opted to have multiple indicators in order to reflect this complexity (Hills, 2011, Energy Poverty Action, 2019, Baker et al., 2018).

The UK is widely perceived to be a pioneer of the energy poverty (also termed 'fuel poverty' in UK agenda) (Boardman, 2010, Hills, 2012) which is the first country includes energy poverty in policy agenda and carries on periodically examinations. There are three indicators developed: the '10%' threshold adopted before 2011, for recognizing households that suffer energy poverty issues which refers to the required expenditure on energy as a percentage of disposable income exceeding 10% (Boardman, 1991); the 'Low Income High Cost (LIHC)' indicator adopted during 2011-2020, which defines a household as energy poor if it has a lower income and higher energy costs than median level (Hills, 2012); and the most recent 'Low Income Low Energy Efficiency (LILEE)' metric, which is based on the new measurement of the Fuel Poverty Energy Efficiency Rating

(FPEER) combined with disposable income data after housing costs and energy needs which is below the poverty line (National Statistics, 2022).

Energy poverty knowledge in the rest of Europe is less developed, although a wider range of approaches has been used. Single country studies have been conducted in Ireland (Healy and Clinch, 2002), France (Dubois, 2012, Legendre and Ricci, 2015), Greece (Katsoulakos, 2011, Santamouris et al., 2013), Germany (Heindl, 2015), Hungary (Bouzarovski et al., 2016), Austria (Brunner et al., 2012), Spain (Phimister et al., 2015), Italy (Miniaci et al., 2014), and Denmark (Nierop, 2014). There is also an established body of comparative research, focusing on the EU specifically (Bouzarovski and Tirado Herrero, 2017a, Consortium, 2009, Healy, 2017, Dubois and Meier, 2016, Bouzarovski and Tirado Herrero, 2017b, Thomson et al., 2017b), and on Central and Eastern Europe and Central Asia (EBRD, 2005) Three main methods of measurement can be identified through these studies: **1)** expenditure approach, where comparing household energy costs to absolute or relative thresholds can be used as a proxy to gauge the degree of domestic energy deprivation; **2)** consensual approach, based on self-reported evaluations of indoor living conditions and the household's access to some fundamental needs in relation to the society it lives in; **3)** direct measurement, when a comparison is made between the level of energy services (like heating) provided in the residence and a set standard (Thomson et al., 2017b). We can be aware from these various energy poverty metrics across countries, that energy poverty is sensitive to regional contexts, as well as to individual behaviour, climatic, and sociodemographic characteristics.

Globally, a growing body of literature addresses geographical differences in energy poverty to varying degrees, at different scales. Research has produced national comparisons between Asian countries (India and China) and among European countries (Pachauri and Jiang, 2008, Thomson and Bouzarovski, 2018); regional comparisons within one nation (UK) (Robinson and Mattioli, 2020,

Gillard et al., 2017); disaggregation of national policy to small areas within Portugal, and area-based targeting to supplement national indicators, such as in Northern Ireland (Simoes et al., 2016, Walker et al., 2012); bottom-up indicators that explore a wider range of spatial inequalities in cities of US (Reames, 2016, Reames et al., 2018); and spatially-orientated indicators that account for the spatial variability in the importance of energy poverty drivers in UK (Robinson et al., 2019).

Table 2. 1. Typical explanations of energy poverty from previous work

Dimension	Source	Description	Deprivation issues	Research area
Accessibility	(Pachauri & Spreng, 2004; Bazilian et al., 2014)	Poor availability of energy carriers appropriate to meet household needs.	Access to modern energy infrastructure, Sufficient appliances to meet household energy needs	Developing countries
Affordability	(Boardman, 1991)	High cost of fuel compared to household earnings, taking into account the impact of tax or aid programs. Being unable to invest in building new energy infrastructure.	High or rising energy prices, Low household incomes;	Developed countries
Efficiency	(Rudge, 2012)	Useful energy is lost disproportionately during energy conversions in the home.	Inefficient building environment, Inefficient heating or cooling system, Outdated appliance stocks	Developing and developed world
Flexibility	(Bates et al., 2012)	Unable to switch to an energy service delivery model suitable for household requirements.	Limitation for adequate facilities for cooking, lighting, electricity, heating etc.	Developing and developed world
Practices	(Bates et al., 2012; Bouzarovski & Petrova, 2015)	Lack of understanding regarding assistance options or household energy-saving techniques.	Unfavorable education level, energy cognition and related government agendas	Developed world
Relationships	(Middlemiss et al., 2019)	Energy poverty and social relations are inextricably linked since excellent social relations can both facilitate and result from access to energy services.	The ability of people to deal with energy poverty is influenced by their relationships with family, friends, organizations, and distant others, as well as by their access to a variety of resources, membership in particular collectivities, the requirement to fulfill social obligations, and the typical explanations for poverty and energy use.	Developed world
Governance	(Bednar & Reames, 2020)	The national understanding and use of energy poverty aid are shaped by governmental program eligibility conditions and congressional financial expenditures.	Instead of enhancing household wellbeing and lowering overall energy poverty, measurement and evaluation measures are dependent on the distribution of government funds and the number of vulnerable households who receive assistance.	At the federal level in the United States

Energy poverty is increasingly becoming an issue of concern in the policy and research agendas of the UK, Ireland, European Union (EU) and its Member

States. The number of available methods for the measurement of energy poverty is steadily growing both in quantity and complexity. The choice of indicator of energy poverty depends on the research question, the accessibility of the data and the spatial scale of data. As a result, a large body of literature aimed at quantitatively assessing the extent and evolution of domestic energy deprivation at various scales appeared over the last decade. The three more commonly used measurement approaches are - household income/expenditure-based indicators, consensual indicators based on household responses to material deprivation survey questions, direct measurement based on comparison between the level of energy services (like heating) provided in the residence and a set standard. Parallel to this, research based on indicators and conducted across the EU has proposed "regions" of European energy poverty with unique household energy deprivation levels and underlying causes.

2.2 Measuring energy poverty in China

The limited existing studies of energy poverty in China predominantly used either an expenditure approach (Zhang et al., 2019, Hong et al., 2022, Xie et al., 2022), a rate of solid fuels use (Hong et al., 2022, Zhang et al., 2019, Tang and Liao, 2014), or multidimensional measurement (Wang et al., 2015, Dong et al., 2021) by quantitatively analysing a combination of national statistical data and surveys.

2.2.1 Expenditure and solid fuel use measurements

This following paragraph provides a review of studies of energy poverty in China based on expenditure and solid fuels indicators. The expenditure approach is one of the most commonly used methods of analysing energy affordability. The energy costs faced by households are assessed against absolute or relative thresholds providing a proxy for estimating energy poverty. Among the most

enduring energy poverty thresholds approach is the "10% indicator" which is shaped by early work in the UK (Boardman, 1991). Using the rate of solid fuel use to examine energy poverty foregrounds the accessibility aspects of modern energy services. The studies from Zhang et al. and Hong et al. (Hong et al., 2022, Zhang et al., 2019) identified energy poor households by adopting a combination of the expenditure threshold method (set at 10% of energy expenditure process total income to maintain consistency, and energy expenditures include spending on a wide range of forms of energy: electricity, water, fuel, and heating) and the proportion of solid fuel used for cooking, analysing China Family Panel Studies (CFPS) survey data. Zhang et al. generated a multidimensional proxy by combing the two dimensions of expenditure threshold and proportion of solid fuel using an equal weighting method. They estimated the energy poverty rate in China as being 57.78% of households in 2012 which then fell to 48.98% in 2016. Hong et al. used the above two dimensions as substituted variables for energy poverty and adopted the proportion of firewood use for cooking (at the proportion of 30.53%) rather than coal use for cooking (at the proportion of 5.41%). Zhang et al. and Hong et al. (Zhang et al., 2019, Hong et al., 2022) both linked energy poverty with solid fuel use in order to consider clean energy and health impacts. Zhang et al. (Zhang et al., 2019) also pointed out that energy poverty remains a critical issue in urban areas. This revealed the deep inequalities in domestic energy provision that exist in more affluent city regions in China. Work from Lin and Wang (Lin and Wang, 2020) estimated energy poverty in China by using electricity consumption data from the Chinese General Social Survey of 2014 at household level. They estimated that energy poverty exists in China at the proportion of 18.9% by adopting both the "10% indicator" and "LIHC indicator" from the UK.

2.2.2 Multidimensional measurement

This following paragraph provides example of studies of energy poverty in China based on multidimensional approaches. Wang et al. (Wang et al., 2015) comprehensively evaluated energy poverty in China from 2000 to 2011 by constructing an index consisting of energy service availability, energy consumption cleanliness, energy management completeness, household energy affordability, energy efficiency including indices of electricity consumption, and ownership of air-conditioners. They found Anhui, Henan, Hebei, Shanxi, and Jiangxi were the provinces with severe energy poverty in China from 2000 to 2011. Anhui province ranked as the most energy poor of China's 30 provinces The primary causes are Anhui's weaker local government energy management performance and higher reliance on solid fuels to meet daily needs, especially in rural regions.

2.2.3 Spatio-temporal scale identifications

There has been some research observed longitudinal trends of energy poverty in China. The downward trend over time of energy poverty in China has been observed during 2000-2011 at provincial level by Wang et al. (Wang et al., 2015), the evaluation results in their study show that China's energy poverty showed a trend toward reduction from 2000 to 2011, China's energy service availability improved slightly; energy consumption cleanliness showed no significant change; energy management completeness decreased with fluctuations; and household energy affordability and energy efficiency improved continually. Same downward trend during 2012-2016 at national level has also been evidenced (Zhang et al., 2019). There is room for further evaluation of energy poverty from the spatial and temporal perspectives.

Scholars looking at energy poverty in China are continually highlighting the spatial scale of the data. In 2020, Yip et al. (Yip et al., 2020) criticized the applicability of the "10% indicator" based on the expenditure approach when looking at Hong Kong. It was the first and only study to qualitatively capture energy poverty in Hong Kong by using data from five in-depth household case studies and 14 semi-structured interviews taking the lived experience of households as their central lens. They point out the significant needs for space cooling, and health dangers of hot summer nights in Hong Kong due to the unusual legal-political factors arising from subdivided rental apartments, in combination with extreme hot weather conditions. Yet, to date, relatively few studies tried different approaches to capture energy poverty emerging from different regions in China. This suggests a research need to develop approaches to compare and contextualize the evaluation of Chinese energy poverty more precisely at household level in different regions to formulate targeted polices for energy poverty alleviation.

2.2.4 Macro and micro levels of data

In China most energy poverty studies have been conducted using data aggregated to national and regional scale (Zhu, 2007, Zhu and Ye, 2012, Li et al., 2011, Wu and Zheng, 2016, Xue, 2017, Zhang et al., 2019, Wang et al., 2015). Zhang et al. (Zhang et al., 2019) narrowed down the spatial scale to provincial level by using CFPS household data, however, a published limitation of the CFPS is 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 governmental 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 household electricity survey to report energy poverty at regional level.

Compared to the macro scales studies above, Xie et al. (Xie et al., 2022) explored heating energy poverty in northern rural areas of Beijing and Hebe provinces regarding the implementation of a 'Clean Heating Program' in 2019. They found the overall energy poverty's extent has increased due to the clean heating program [5], specifically, energy poverty is significantly increased by replacing coal with electricity and gas, while it is decreased by replacement with clean coal. In addition, those with lower income and no insulation for their houses are negatively affected to a larger degree. Robinson et al. (Robinson et al., 2018c) paid attention to energy poverty research from a thermal comfort perspective based on household surveys including 800 respondents across 12 districts in Beijing. They highlighted vulnerabilities such as inefficient networked infrastructures and low quality of the built environment, that increase the likelihood of households being unable to access adequate heating in the home across urban areas.

I thoroughly evaluated existing studies' assessments of energy poverty in China in this section. The methods utilized primarily focused on quantitative analysis, and they may be summed up in the following bullet points:

- Consensual approach and direct measurement as done in European context (section 2.1) have not been found in use in Chinese energy poverty research due to the lack of access to periodic evaluation or related data.

5 The main goal of the program in the studied areas is to transition household heating energy from coal to cleaner energy. This is because the studied areas are in Northern China, where heating by coal is one of the major sources of air pollutants and carbon emissions.

- The expenditure approach and a rate of solid fuels use are two of the most commonly used methods of measuring energy poverty in China, although they place greater emphasis on reporting the rate of energy poverty at the national level.
- The multidimensional approach often evaluates energy poverty in China using governmental statistical data from yearbooks, which obstructs knowledge of actual energy use at household level.
- Longitudinal studies on energy poverty in China are necessary to understand how it changes over time, but there aren't any of these analyses done at the household level.
- The majority of the literature focuses on rural energy poverty in China rather than urban areas.

Evaluating energy poverty is a prerequisite of understanding and formulating suitable policies for alleviating energy poverty as I demonstrated in section 1.1. This thesis aims to develop the applicable spatial and temporal assessment of energy poverty in the context of China at household level based on a thorough review of current literature.

2.3 Energy vulnerability and sociodemographic features

Specific vulnerabilities are often associated with people who have particular sociodemographic characteristics which are associated with a particular need for energy (Middlemiss, 2022b). This includes households with low-incomes (Anderson et al., 2012, Sakka et al., 2012, Yip et al., 2020, Xie et al., 2022), young children (Hernández, 2016, Robinson et al., 2018a), older people (Ormandy and Ezratty, 2012, Vandentorren et al., 2006, Robinson et al., 2018a), disabled people (Day et al., 2016, Ivanova and Middlemiss, 2021, Middlemiss and Gillard, 2015, Snell and Bevan), or single parents (White and Sintov, 2019, Robinson et al., 2018a).

Some examples of the additional needs of households have include the following. During winter months with high heating bills, low-income households -reduce energy use to thermally uncomfortable levels (Anderson et al., 2012). Old people require a narrower band of temperatures for health and are more likely to suffer exacerbated mortality during extreme heat or cold weather if unable to maintain the appropriate temperature (Ormandy and Ezratty, 2012, Vandentorren et al., 2006). Households with children bear additional costs associated with ensuring that children are well fed and healthy (Hernández, 2016). Also, under-occupancy of homes with older residents whose children have left as another reason for energy poverty, parents and children, however, have different priorities, with the former often willing to endure challenging conditions but responding leniently to their children's requests (Yip et al., 2020). Compared to the general population, people with disabilities may need more energy to realize a range of essential capabilities (Day et al., 2016). Illness or disability can limit freedom of movement and employment, which raises energy costs due to people being at home more (Middlemiss and Gillard, 2015, Ivanova and Middlemiss, 2021, Snell et al., 2015). There is a strong connection between people with multiple vulnerabilities and energy poverty, these vulnerable groups reach beyond a need for greater levels of energy services, to accessibility and affordability.

The diversity of socio-demographic characteristics associated with vulnerability and subsequent losses of wellbeing to energy poverty also have a complex and uneven spatial distribution (Bouzarovski et al., 2012, Robinson et al., 2018a). In England, for example, a higher percentage of pensioners reside in rural areas, whereas families with young children are more concentrated in city suburbs, people with disabilities or illnesses are more likely to reside in urban areas or coastal communities, and lone parent families tend to concentrate in urban areas (ONS, 2011a, Robinson et al., 2018a). Additionally, households in the

private rented sector tend to concentrate in inner-city regions, where properties are disproportionately inefficient and renters frequently lack housing rights (Altan and Hasim, 2004, Bouzarovski and Cauvain, 2016). Acknowledgement of these complex social-spatial vulnerabilities is a useful step in developing understanding and policy responses to energy poverty.

Given these experiences in other nations, it can be expected that belonging to specific socio-demographic types will also increase the risk of a household falling into energy poverty in China. Studies on the variation of energy poverty in China have been conducted, although they typically compare between regions and through time. None of these have addressed the associations between household socio-demographic characteristics and risk of energy poverty. Energy is not purchased for its own sake, but for the energy services that it delivers; some energy services are essential for wellbeing and survival as in the case of cooking, heating and access to clean water, and, as such, knowing who can and cannot access adequate energy is important (Ivanova and Middlemiss, 2021, White and Sintov, 2019).

2.4 Policy responses to energy poverty in other nations

From the policy perspective, the UK government is recognized as the first country leading the policy recognition and responses to energy poverty as I noted in section 2.1 (Boardman, 1991, Boardman, 2010, Bouzarovski et al., 2021, Pelz et al., 2018, Tardy and Lee, 2019, Wei et al., 2014, Yip et al., 2020, Baker et al., 2018). The devolved energy poverty strategy to support reductions in energy poverty (DBEIS, 2022) in the UK formally recognizes households as energy poor according to most recent Low Income Low Energy Efficiency (LILEE) metric, if: **1)** it is living in a property with an energy efficiency rating of band D, E, F or G as determined by the most up-to-date Fuel Poverty Energy Efficiency Rating (FPEER) Methodology; **2)** its disposable income (income after housing costs

(AHC) and energy costs) would be below the poverty line (DESNZ, 2023). The UK has data from nationwide investigations to support a periodic evaluation and response to fuel poverty exacerbated by the climate crisis (Dobbins et al., 2019). The government targets to systematically advance household energy efficiency by particular dates signal a national commitment for overall household wellness and access achieved through the multiple benefits of energy efficiency (Thomson and Bouzarovski, 2018, Thomson et al., 2017b). The priorities of energy efficiency measures were signalled by the LIHC indicator in UK, which has been criticised for not covering all energy poverty alleviation and underplaying the role of changing energy costs (Middlemiss, 2017). UK based energy poverty research has supported policy design and responses, scholars emphasized the vital role of multidisciplinary approaches based on lived experience when facilitating policy design regarding energy poverty, which is absent in current policy agendas in UK (Middlemiss et al., 2018, Gillard et al., 2017). Moreover, disadvantaged groups such as disabled people, low-income families, and old people are officially regarded as the most vulnerable to energy poverty in the UK though the former two groups tend to be under-represented in policy decisions (Gillard et al., 2017).

Energy poverty and the concept of vulnerable consumers has been also explicitly considered in European legislation and a group of member states for more than a decade (Kyprianou and Serghides, 2021, Pye and Dobbins, 2015, Koďouskov´a and Bo˘ruta, 2022, Dobbins et al., 2019, Castaño-Rosa et al., 2019). The momentum behind the energy chapter in the Lisbon Treaty provided a driving force in the drafting of the Third Energy Package (TEP) and subsequent adoption in 2009, which brought energy poverty and vulnerability into mainstream EU energy policy, and established it as a European issue (Thomson and Bouzarovski, 2018, Bouzarovski, 2018). In particular, the TEP established the following legal requirement to protect vulnerable consumers in energy markets:

"Member States shall take appropriate measures to protect final customers, and shall, in particular, ensure that there are adequate safeguards to protect vulnerable customers. In this context, each Member State shall define the concept of vulnerable customers which may refer to energy poverty and, inter alia, to the prohibition of disconnection of electricity (gas) to such customers in critical times" Electricity and Gas Directives (Directive 2009/72/EC; Directive 2009/73/EC)

Several members, including France, the Republic of Cyprus, Slovakia, and the Republic of Ireland, described national initiatives that help to reduce energy poverty in their national policies in succession (see Table 2.2).

Table 2. 2. Summary of legislated energy poverty recognitions from some European states

Country	Start	Definition	Fuels aspects	Household aspects	Dwelling	Evaluation	Department
UK	2001	"A household is living in a property with an energy efficiency rating of band D, E, F or G as determined by the most up-to-date Fuel Poverty Energy Efficiency Rating (FPEER) Methodology; and its disposable income (after housing costs and energy needs) would be below the poverty line"	Space heating; Water heating; Lights and appliances; Cooking; The mix of different fuels used by each household.	The number of people who live in the dwelling and their occupancy patterns;	The size of the property; The energy efficiency of the dwelling;	English Housing Survey (EHS)	Department for Levelling up, Housing & Communities (DLUHC)
France	2009	"if he/she encounters particular difficulties in his/her accommodation in terms of energy supply related to the satisfaction of elementary needs, this being due to the inadequacy of financial resources or housing conditions"	Fuels cost	Subjective measure (people reported to be feeling the cold)	Heating facility	Housing survey	Observatoire National de la Précarité Energétique , or ONPE funded jointly by government (Observatoire for poverty and social exclusion, and the environment agency) and by the three large energy companies
The Republic of Cyprus	2012	"The situation of customers who may be in a difficult position because of their low income as indicated by their tax statements in conjunction with their professional status, marital status and specific health conditions and therefore, are unable to respond to the costs for the reasonable needs of the supply of electricity, as these costs represent a significant proportion of their disposable income."	Electricity cost; Replacement of old and energy inefficient home appliances	Low income; Professional status; Marital status; Specific health conditions		European Statistics on Income and Living Conditions (EU-SILC) survey; Household Budget Survey (HBS)	Cyprus Recovery and Resilience plan
Slovakia	2015	"Energy poverty under the law No. 250/2012 Coll. Of Laws is a status when average monthly expenditures of household on consumption of electricity, gas, heating and hot water production represent a substantial share of average monthly income of the household"	Electricity cost; Gas cost; Heating cost; Water heating;	Low-income; Pensioners	housing allowances; Energy efficient and affordable (social) housing		Slovak national energy regulator Regulatory Office for Network Industries (RONI)
Republic of Ireland	2016	"…a household that spends more than 10% of their income on energy is considered to be in energy poverty"	Fuels cost	Low income	Ensuring the energy efficiency performance of the housing stock	"Appropriate methodology for measuring and tracking energy poverty in Ireland"-An Energy Poverty Advisory Group	An inter departmental/agency group chaired by the Office of Social Inclusion; An Energy Poverty Advisory group; Sustainable Energy Authority of Ireland (SEAI)

Source: Based on the work from (Pye and Dobbins, 2015, Thomson and Bouzarovski, 2018)

2.4.1 Subsidy of household bills for vulnerable users

Protecting household access to fuels and providing them with financial assistance to pay their energy bills directly help them obtain necessary energy services and reduce their energy burdens. Home energy services that protect against disconnection for households during the colder winter months are available throughout Europe (Bouzarovski, 2018, Bouzarovski et al., 2021, Simcock et al., 2018, Thomson and Bouzarovski, 2018). The direct financial support measures as well as the disconnection measures are always targeted to specific vulnerable groups, such as low-income households, pensioners, or disabled people (Thomson, 2020, Ivanova and Middlemiss, 2021, Middlemiss, 2022b, Middlemiss et al., 2020). However, there is still a need to focus on a long-term solution for energy poverty through enhancing household energy situations (for example, enhanced energy efficiency) and safety measures for any potential energy crises (Guan et al.).

When it comes to the household level, initiatives that are more specifically aimed at a temporal winter fuel allowance (Bridgen and Robinson, 2023) and particular vulnerable category of households, such as low-income, senior citizens, residents of social housing, single parents, or those who use heating oil, will typically be more successful at combating energy poverty than non-targeted policies (Thomson and Bouzarovski, 2018, Pye and Dobbins, 2015, Koďouskov´a and Bo˘ruta, 2022). Regressions has been used to recognize the correlations between vulnerable groups and likelihood of falling into energy poverty, including binary logistic regression (Snell et al., 2015, Thomson and Snell, 2013), ordinary least squares (OLS) model (Zhang et al., 2019, Robinson et al., 2018a) etc. In order to combat energy poverty, many Eastern and Central European nations also offer social to low-income households (e.g., in Bulgaria, Croatia, Latvia, Slovakia or Slovenia). Targeted policies towards to socially excluded

minorities (e.g., the Roma population in Slovakia) can help to mitigate their exposure to prevalent extreme forms of energy poverty (Koďouskov´a and Bo˘ruta, 2022). Scholars have evidenced the efficiency of these targeted measures are a very powerful way to address energy poverty in the long term (Thomson and Bouzarovski, 2018, Baker et al., 2018, Robinson et al., 2018a). To be sure, there are similar policies in other parts of Europe, but certain advantaged groups still lack attentions in both policy and academic research at local context.

2.4.2 Energy efficiency of housing stock

Policies to improve household energy efficiency concentrate on renovating housing stock, (e.g., improving the building insulation of housing or replacing heating systems), and constructing new energy efficient social housing. The housing stock might not be of sufficient quality to avoid energy poverty, countries therefore implement large programs to renovate and improve the existing building stock, for example in Eastern Europe the large apartment buildings from the communist era (Koďouskov´a and Bo˘ruta, 2022, Sika et al., 2020). These renovation programs are often partly funded through European support, such as structural funds. Examples include programmes in Bulgaria, Czech Republic, Latvia or Romania) (Pye and Dobbins, 2015, Thomson and Bouzarovski, 2018). Some parts of Europe have relatively low levels of energy poverty largely due to the well-developed social housing systems in some countries, particularly in Northern and Western Europe, which provide low-income households with energy-efficient housing. National Building Fund Loans in Denmark, the STEP program in the Netherlands, or the climate premium in Bielefeld, Germany are a few examples of energy poverty policies applied to social housing (Thomson and Bouzarovski, 2018, Castaño-Rosa et al., 2019). Targeted energy efficiency for buildings is implemented in half of all European Union member states while tackling the underlying structural reasons of energy

poverty, with the majority aiming to finance retrofits through grants or loans (Thomson and Bouzarovski, 2018). Each nation's experience with energy poverty will differ in scope and severity, necessitating a unique approach that focuses on finding solutions that address the particulars of the issue.

In this section, I evaluated energy poverty recognitions and responses from the official policy perspective combining critical analysis from academia in other nations, especially some of the European states which recognized energy poverty on a national level. Results reveal that increasing energy policy priority - has the potential to address energy poverty in some cases, but its benefits and drawbacks for energy-poor families need to be carefully weighed.

2.5 Policy responses to energy poverty in China

Although existing policies to address the issue differ significantly between nations, they can be divided into two general categories: subsidy of household bills for vulnerable users, energy efficiency of housing stock, whether they are socially-led policies or energy-led policies to alleviate energy poverty (Pye and Dobbins, 2015, Koďouskov´a and Bo˘ruta, 2022, Kerr et al., 2019, Thomson and Bouzarovski, 2018, Kyprianou and Serghides, 2021).

In Chinese case, relatively limited studies related to Chinese energy poverty policy research have investigated the correlation between energy poverty and climate actions (Zhu and Ye, 2012, Zhu and Zhao, 2012, Wang et al., 2014b, Luo and Liu, 2013, Li, 2009, Zou et al., 2010, Yang et al., 2017, Luo and Huo, 2007, Huang, 2011, Zhang and Wang, 2005, Wei, 2013, Wang et al., 2023). This may be partly due to the lack of national energy poverty recognition and strategy in China. The lack of definitions, reduction targets/objectives and periodic evaluation is a barrier to researchers engaging with this issue. The Chinese government has developed several important regulations in recent years that

take into account how energy development and climate change are developing synergistically. This includes steps to increase domestic energy efficiency, particularly for cooking and heating, for example: financial subsidies for Minimal Assurance Households [6] to increase their ability to pay for clean energy; distributed heating replaced by district heating in some urban areas; houses renovated for heat preservation and energy saving (Wei, 2013). Studies show that these initiatives do not primarily address energy poverty, nevertheless they benefit the clean energy implementation (Wang et al., 2014a, Liao et al., 2016, Sawhney, 2013). For instance, there are two key implemented phases in the adoption of renewable energy policy: **1)** To solve the problem of rural renewable energy supply; **2)** To address growing environmental problems. The main action of the former is to develop and promote clean energy such as solar, wind, geothermal, tidal and biomass energy in light of local circumstances. The main goal of the latter is to replace fossil energy with renewable energy and optimize the energy mix emphasizing wind, solar and biomass energy. As in other nations, there is a risk that those households that are most vulnerable will fall behind if policy does not take energy poverty into account while implementing climate mitigation measures.

In the Global North, plans to transition to a low-carbon economy usually lead to concerns being raised about how environmental legislation would affect more vulnerable individuals, such as those who are facing energy poverty (Middlemiss, 2022b). Several studies have explored how China's residential energy consumption is impacted by climate mitigation efforts (Xie et al., 2022, Barrington-Leigh et al., 2019, Liu and Mauzerall, 2020, Wang et al., 2023). For example, Wang et al. (2023) discovered that urban households typically pay a

6 In 1997, The State Council of China issued "the Notice on Establishing a National System of Minimum Living Security for Urban Residents (State No. [1997]29)". For urban-Hukou households whose per capita household income is lower than the local minimum living security standard, they shall get financial support from local government. After 2003, the system was gradually extended to rural areas.

smaller and decreasing percentage of their income on energy, while the energy burden on rural households grew as a result of the initiated rapid energy transition. Xie et al. (2022) examined the impact of Clean Heating Programs on household energy transition in rural Beijing and Hebei provinces and found it was possible to assess the policy-induced rise in energy poverty. They made note of the higher likelihood of energy poverty among homes with lower incomes, lower levels of education, and smaller household sizes. More energy poverty is present into those with lower incomes and homes that are not insulated. Liu and Mauzerall (2020) estimated the annualized capital and operational expenses for rural households in the Beijing-Tianjin-Hebei region to employ clean heating technology (Liu and Mauzerall, 2020). They emphasized the most energy-efficient solutions by contrasting the prices of various technologies. Barrington-Leigh et al. (2019) estimated the impact of the clean heating program in Beijing on household energy use and expenditure, well-being, and indoor environmental quality, by comparing treated and untreated villages that vary in socioeconomic conditions. They found that, in some low-income districts, the program had negative impacts on well-being, measured as overall satisfaction with life, because of the increase in expenditures after the transition from coal to electricity (Barrington-Leigh et al., 2019). These studies indicate that vulnerable households with lower income, less education, and smaller household size may experience worsening energy poverty after implementing clean heating programs or taking other steps to combat climate change (Xie et al., 2022). The focus of current energy poverty studies in China is primarily on low-income groups rather than a thorough understanding of other sociodemographic groups that may be more susceptible to energy poverty. It is unclear whether such groups are taken into account in policies.

Additionally, the majority of the studies now being conducted on the relationship between energy poverty and climate action focus on rural areas (Wu

and Zheng, 2016, Zhu and Ye, 2012, Zhu and Zhao, 2012, Xie, 2010, Zhao et al., 2018, Wang and Feng, 2002, Tang et al., 2016, Luo and Liu, 2013, Wang and Dong, 2005), as well as some specific areas under exploration of specific programs listed above (Xie et al., 2022, Barrington-Leigh et al., 2019, Liu and Mauzerall, 2020, Wang et al., 2023). A few studies have already recognized the neglected urban energy poverty in China (Lin and Wang, 2020, Robinson et al., 2018c, Wang et al., 2023). Although Wang et al. demonstrated that urban households tend to spend a lower and decreasing proportion of their income on energy under the transition from traditional solid fuels to modern clean energy (Wang et al., 2023), this expenditure perspective may not capture the vulnerability factors to energy poverty of housing and the related accessibility of clean energy infrastructure in urban China. In parallel with the less attention to urban energy poverty in China, less attention has been paid to policy responses on urban energy poverty in China. Thus, it is essential to systematically understand the spatial differences of Chinese energy poverty responses, especially the aspects, levels, and the kind of people involved, to improve the recognition and effectiveness of policy actions.

In this section, I provide a comprehensive review of studies on the Chinese energy poverty responses through policies. I found relatively limited studies exist in this field partly due to the lack of national energy poverty recognition and strategy in China, which causes a barrier to researchers engaging with this issue. Studies that have already been conducted have focused on the relationship between energy poverty and environmental initiatives, as well as how climate mitigation efforts affect China's home energy consumption. They both have a strong emphasis on rural areas. Thus, there is no research comprehensively reviewed energy poverty response embedded in previous or current policy agendas at national level encompassing both urban and rural areas, as well as take into account of the most recent findings from Chinese energy poverty research.

Chapter 3 Data and methods

The analysis presented in the next three chapters (4,5 & 6) is based on methods I developed to repurpose the "China Family Panel Studies (CFPS)" in order to answer the five research questions identified in Figure 1.4. This allowed me to calculate energy poverty metrics and to investigate energy poverty in China at household scale. Section 3.2 introduces why I chose CFPS surveys and how I constructed the dataset from the original surveys used in this thesis, which I talk about the more substantial challenges I faced in doing this, the ways in which I solved them. The rationale for the selection of the case-study provinces including consideration of spatio-temporal scopes can be found in section 3.3. Section 3.4 explains the energy poverty metrics used in this thesis. A description of the statistical analysis undertaken is included in section 3.5. Section 3.6 is the reflections on data and methodologies in this work consisting of strengths and limitations. Please note that more comprehensive methodologies and data descriptions will also be introduced in each of the respective results chapters (chapter 4, 5 & 6) for the chapters' integrity and coherence.

3.1 Research theory

3.1.1 'New energy paradigm'

Thomas Kuhn famously described a paradigm as a coherent patter of research organized around commonly shared theoretical propositions and models, and a paradigm shift or 'revolution' as the emergency of an alternative framework of common and shared analysis (Kuhn, 1961). Kuhn's approach to the history and philosophy of science has been subject to fierce debate and criticism (Popper, 2005, Nagel, 1962, Kuhn, 1970). In 2005, Helm (Helm, 2005) critically argued Kuhn's statement of incommensurate paradigm shifts with the old paradigm by focusing on energy system and introducing 'new energy paradigm'

from an institutional and policy perspectives. He proposed that the new energy paradigm is to build upon the strengths of the 1980s and 1990s approaches, rather than reject it wholesale, which central question is how to design a new energy policy with security of supply and climate change at the core. Two inspirations can be obtained from these philosophies: One is paradigm shifts should be regarded systematically and historically, which typically requires a change in the context and a change in ideas in response. The other one is the theme of security and sustainability of energy should be enhanced in energy research across multiple disciplines.

Throughout this thesis, I argue that an energy lens is beneficial for understanding fundamental changes and challenges to societies, economies, and the environment. Ensuring the availability and accessibility of energy services in a carbon-constrained world will require developing new ways-and new geographies - of producing, living, and working with energy. In this thesis, I have borrowed Helm 's statement of 'new energy paradigm' (Helm, 2005) to portray the relationships I have analyzed using an energy lens which is structured by the new energy paradigm of digging into its geographical and social aspects.

3.1.2 Geographical perspective: space, places, and spatial disparity

Energy systems are constituted spatially: the components of the system are embedded in particular settings and the networked nature of system itself produces geographies of connection, dependency, and control (Ren et al., 2022, Wu et al., 2021). Clark, Feldman and Gertler (Clark et al., 2018) described economic geography as 'a field of academic enquiry preoccupied with the geographical scope and scale of economies in the context of economic change, the driving forces behind those changes, and the role of localities in global

economic transformation. Bridge et al.,(Bridge et al., 2013) defined 'geographies of energy transition' mostly under this economic geography scope which concentrates on two main aspects: 'first, the distribution of different energy-related activities across a particular space; and second, the geographical connections and interactions between that space and other spaces'. They also argued that the latter one is more important because of inter-reginal energy trade and mitigation scheme which both emphasize the importance of new energy paradigm.

The various locations, landscapes, territoriality, institutions, cultures, and society can all generate spatial variations in associated energy activities and interactions among places, understanding this variation and difference is important since 'spatial differentiation is understood not as a static mosaic of inherent difference, but as a process of simultaneous equalization and differentiation—the "ongoing production of differences between places"' (Crang, 1997). In most cases, the energy transition has a stronger effect on enhancing the differences between places rather than promoting spatial convergence. For example, the develop extent of building regulations and residential energy facilities may uneven across places which are highly related to local climatic conditions and policies. The process of spatial differentiation – or the 'production of geographical difference' – is not limited to energy systems themselves, but extends to their implications for patterns of economic growth and social development (Bridge et al., 2013).

3.1.3 Social perspective: decoupling discourses of energy and inequality

Households' energy consumption plays a vital role along with social and economic development since the livelihood conditions, a transition towards

cleaner and more forms of energy is highly associated with people's well-being and other activities. Most famous assumption related to household energy transition is 'Energy Ladder' which assumes households to mimic the behaviour of utility maximizing neoclassical consumer, which implies that they will move to more sophisticated energy carriers as their income increases. The energy ladder was designed as a hierarchical relationship between households' rise in economic status and the fuel types they use for cooking and heating (see the left hand side in Figure 3-1) (Hosier and Dowd, 1987). Higher ranked fuels are usually more efficient and costly but require less input of labour and produce less pollution per unit of fuel. "*The energy ladder also assumes that more expensive technologies are locally and internationally perceived to signify higher status. Families desire to move up the energy ladder not just to achieve greater fuel efficiency or less direct pollution exposure, but to demonstrate an increase in socioeconomic status*"(Masera et al., 2000). Rather than perfect substitutes for more traditional fuels, a growing body of empirical studies on household energy use show that the energy transition does not occur as a series of simple, discrete steps; instead, multiple fuel use is more common which depicts as 'Energy Stack' (see the right hand side Figure 1-1) (Campbell et al., 2003, Heltberg, 2004, Karekezi and Majoro, 2002, Leach, 1992, Martins, 2005). The co-existence of 'Energy Ladder' and 'Energy Stack' illustrates that a kind of disparities and inequalities present among society's energy consumption, and the multiple fuel use patterns in households are the result of complex interaction between income status, fuel supply, commercial energy prices, culture, and traditions etc.. Contextualized analysis of disparities and inequalities of household's energy consumption as well as the interact mechanism of various factors related to it, is essential to deliver the realization of accessible, affordable, and cleaning 'new energy paradigm' in household energy transition.

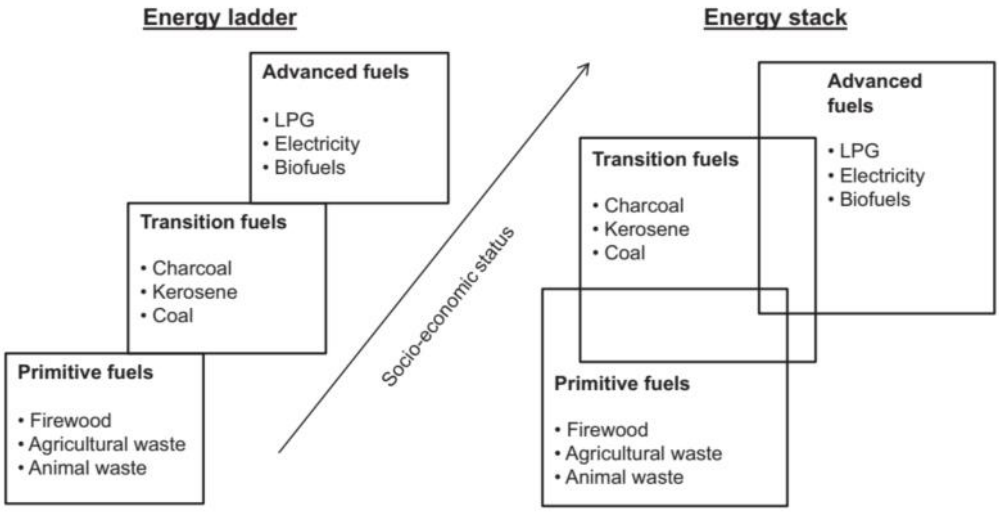

Figure 3. 1. The energy transition process
Source: (van der Kroon et al., 2013)

3.2 Cleaning and constructing the dataset

I designed my research in China, a nation that lacks energy poverty recognition and a strategy that encompass definitions, reduction targets/objectives and periodic evaluation. However, I repurposed and constructed a dataset for Chinese energy poverty research through an administrative social survey data - China Family Panel Studies (CFPS).

3.2.1 Household level data

In China most energy poverty studies have been conducted using data aggregated to national and regional scale (Zhu, 2007, Zhu and Ye, 2012, Li et al., 2011, Wu and Zheng, 2016, Xue, 2017, Zhang et al., 2019, Wang et al., 2015) due to the lack of household level data. I navigated my research data by reviewing current governmental statistics, energy related surveys and case studies in Chinese energy poverty research. Government statistics including energy related indicators (residential energy consumption per capita by types and urban-rural division, basic stations on heating supply in some cities by parts of regions,

investment in electricity, steam, hot water production and supply by regions) (Lu et al., 2022) in statistic yearbooks are mostly collected at a macro scale (national or provincial). Some of the indicators are good measures to evaluate energy access and the level of infrastructure by energy types and regions, but this kind of macro scale and limited time-series data cannot capture the real energy consumption of households.

Recent studies emphasised the importance of micro data, thus studies based on survey dataset came to fore (Zhang et al., 2019, Hou et al., 2017, Lin and Wang, 2020). However, recognition of energy poverty is not present politically so the current micro datasets, including large scale published surveys and project-based surveys, are not designed to gather information on household energy consumption. Project-based surveys include the China Family Panel Studies (CFPS) dataset which is a nationwide, large-scale, and multidisciplinary social tracking survey project launched in 2010, and the Chinese General Social Survey (CGSS) which has a section on residential energy consumption 2014 (CRECS 2014) focusing on household energy issues and is executed by the Department of Energy Economics of Renmin University of China (Lin and Wang, 2020). In order to investigate Chinese energy poverty at a broader spatial and temporal scale, and at a household level, I chose CFPS dataset in this study range from 2010 to 2018 contains lots of household information in families and individual interviews within the nation.

3.2.2 Processing of the CFPS surveys

The China Family Panel Study (CFPS) is a routinely collected longitudinal administrative dataset that contains a series of household questionnaire surveys spanning four themes of data - “Adult theme, Child theme, Family economic theme, Family common theme”. The survey also records any drop out or replenishment of the households in the panel over the course of each survey wave

(current waves cover the period from 2010 to 2018, which is also the focus of this thesis). 25 provinces, municipalities, and autonomous regions in China are included in the CFPS baseline sample (2010 wave), which accounts for 95% of China's population. In addition to interviewing 14,960 households and 42,590 people, the 2010 baseline survey also carried out a long-term follow-up study (2012, 2014, 2016, 2018) on selected samples. This survey is the first of its kind in China. It constitutes a project to conduct a large-scale, comprehensive social follow-up survey for academic purposes with an objective of becoming the most reliable study on Chinese families and society.

While this administrative and reliable dataset does not set out to measure energy poverty, it contains specific information about domestic energy use, household income and expenditure that allow me to construct indicators of energy poverty in China. Also, the sociodemographic information contained in this dataset allow me to identify characteristics that seem to drive vulnerability to energy poverty. The structure of the CFPS dataset used in this thesis is shown in Figure 3.2, and detailed processing steps were taken as follows:

- Identified key investigated indicators on household energy expenditure, income, and sociodemographic factors.
- Focused on indicators that may have a relationship with energy poverty.
- Unified indicators on "Family economic theme" across five waves of the survey. For example, when I was gathering the indicator on “household annual expenditure on electricity” across all five waves (2010, 2012, 2014, 2016 and 2018), I noted that in the 2012 wave, household annual expenditure on electricity was collected together with water expenses. According to the statistics included in Ministry of Water Resources of the People’s Republic of China (http://www.mwr.gov.cn/), the residential water price implements a non-tiered pricing system before 2015 in China and is varied across provinces with an average of 2.50 yuan per cubic meter in 2012; plus, the

proportion of residential water expenditure in 36 key Chinese cities in 2012 are between 0.21% and 0.67% of disposable income (http://www.mwr.gov.cn/sj/#tjgb). As a result, in order to make the consistency with other waves' data, I kept the statistics on "household annual expenditure on electricity and water" as electricity cost from the 2012 wave since the water expenses are a relatively small amount. Please find thorough discussion on detailed limitations, solutions and prospect towards the data and methodology in section 3.6.

- Processed the sociodemographic data from "Adult theme" and "Children theme" surveys which contain interviews and record data at the individual level within a family.
- Discussed, calculated, categorized, and aggregated the selected sociodemographic data at the individual level into the household level according to the recorded "family code".
- Combined the processed sociodemographic data from "Adult theme" and "Children theme" surveys with the "Family common theme" to create a comprehensive sociodemographic dataset for this project. Detailed variables used are explained in specific chapters.

Based on the constructed dataset, this thesis provides a means determine the measurement and driving factors of China's energy poverty problem at household level based on micro-data which has not been done in previous research.

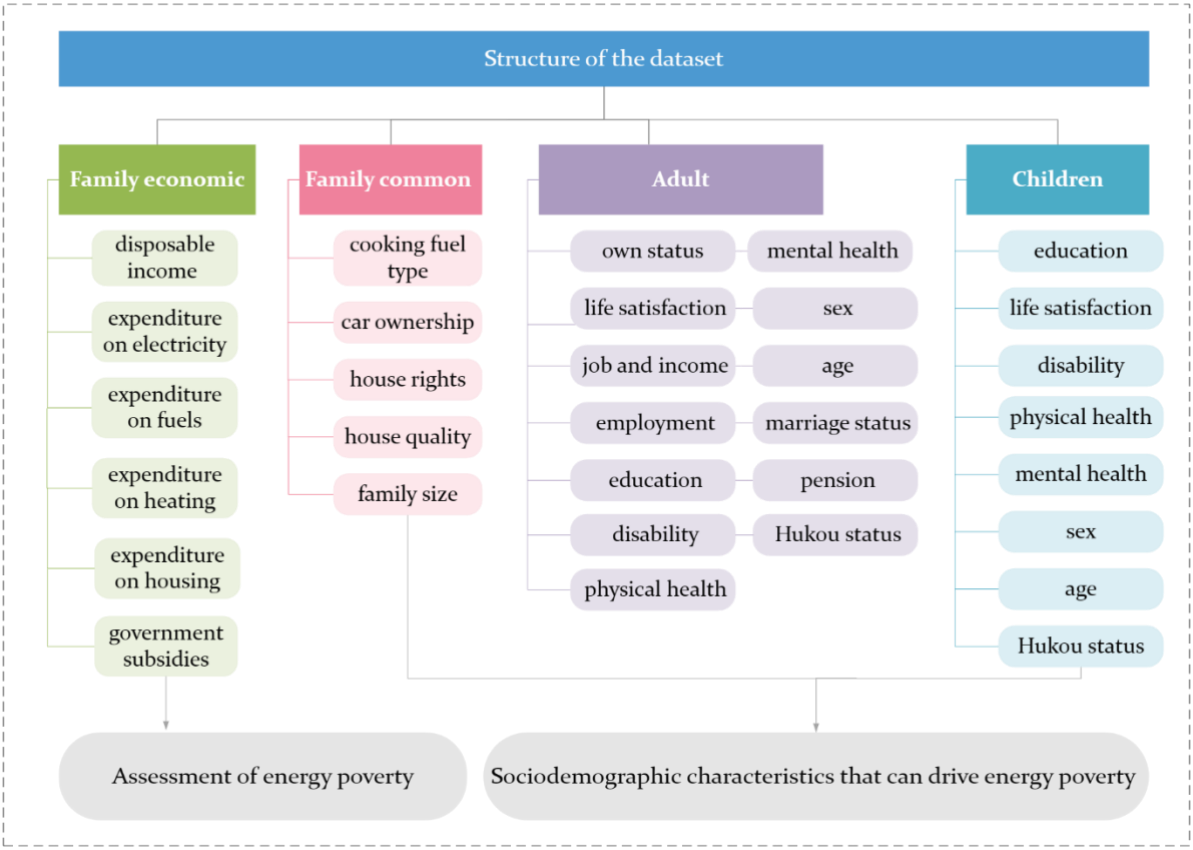

Figure 3. 2. Structure of the dataset in this thesis

Note: *Hukou statues* 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 UrbHukou.

3.3 Spatio-temporal scope of this study

3.3.1 Survey information

The CFPS has the largest spatio-temporal scope and comprehensive household information amongst existing surveys in China. In terms of temporal scope, the survey has tracked baseline survey respondents (2010) and their families (n = 14,960 households and 42,590 individuals per survey round) and four subsequent survey waves (2012, 2014, 2016, 2018). There are three useful features of the CFPS dataset in terms of spatial scope: **1)** Both rural and urban households are included in the CFPS dataset. this means that this thesis can

compare energy poverty in rural and urban areas (Note as discussed in section 2.2.3 urban energy poverty research has received less attention and discussion until now). **2)** national-wide survey, the CFPS contains data from almost all Chinese provinces in all regions of China. The CFPS dataset contains household level data from 25 provincial level areas[7] including 4 municipalities (Tianjin, Beijing, Chongqing, Shanghai), and 1 autonomous region (Guangxi Zhuang Autonomous Region), and 20 provinces [8]. **3)** The CFPS dataset has two sample frames, one is called "large provinces" (Shanghai, Liaoning, Henan, Gansu, and Guangdong) that aims to recruit 8,000 households to provide provincial level analysis. The other investigated provinces are called "small provinces" surveying 8,000 households in total across the other 20 provinces to provide national level analysis when combined with data from "large provinces". Only five "large provinces" (Shanghai, Liaoning, Henan, Gansu, and Guangdong) have sufficient sample sizes to support provincial level analysis and comparison (CFPS, 2017).

3.3.2 Geography of research area

In this thesis, I selected the data from the five "large provinces" across four survey themes mentioned above. The reasons for only focusing on the "large provinces" sample frame are: **1)** these provinces have sufficient sample size to facilitate analysis of household energy consumption and comparison at provincial scale, which can also bridge the gap of reporting a finer scale energy poverty rather than just national energy poverty by using this dataset through the work from Zhang et al. and Hong et al. (Zhang et al., 2019, Hong et al., 2022). **2)** the geographical dispersion of these five provinces (shown in Figure 3-3) provides a representative understanding of China's energy poverty problem by

7 China's 34 provincial-level administrative regions including 23 provinces, 5 autonomous regions, 4 municipalities, 2 special administrative regions (Constitution of the People's Republic of China).

8 All investigated 20 provinces are Jiangsu, Zhejiang, Fujian, Jiangxi, Anhui, Shandong, Hebei, Shanxi, Jilin, Heilongjiang, Hunan, Sichuan, Guizhou, Yunnan, Shaanxi, Shanghai, Liaoning, Henan, Gansu, and Guangdong.

different climate zones. **3)** the various geographical and socio-economic features of these five provinces are conducive to the study of spatial differences of energy poverty (shown in Table 3-1).

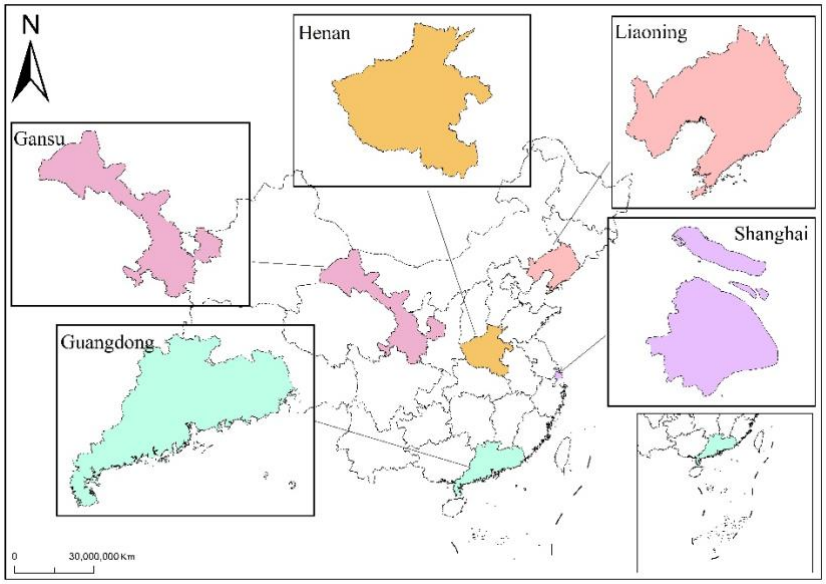

Figure 3. 3. Location maps of the five study provinces

Table 3. 1. Geography and economic information of the five study provinces

Province	**Location**	**Region division**	**Population** Million	**Economy**	
				GDP (billion RMB) 2018	National GDP rank
Guangdong	N 20°13'-25°31' E 109°39'-117°19'	South	11521	107671.7	1
Gansu	N 32°11'-42°57' E 92°13'-108°46'	North	2647.43	8718.3	27
Henan	N 31°23'-36°22' E 110°21'-116°39'	North (except Xinyang city)	9640	54259.2	5
Liaoning	N 38°43'-43°26' E 118°53'-125°46'	North	4351.7	24909.5	15
Shanghai	N 30°40'-31°53' E 120°52'-122°12'	South	2428.14	38155.32	10

Source: China Statistical Yearbook (2019)

3.4 Construction of energy poverty indicators

3.4.1 "10% energy poverty indicator"

I calculated the two classic energy poverty metrics to measure Chinese energy poverty: "10% indicator" and "LIHC indicator" based on the construction of the dataset introduced in section 3.2 & 3.3 above. The dataset included information on domestic energy use, household income and actual expenditure (not including household's expenditure on cooling due to the dataset limitation) that allow me to quantify energy poverty rate by using "10% indicator" and "LIHC indicator" rather than other metrics (e.g., multidimensional approach and Low-Income Low Energy Efficiency (LILEE) which has been discussed in section 2.1 & 2.2.

The "10% indicator" of energy poverty counts households who spend over 10% of their income on energy as energy poor (Boardman, 1991). This indicator is an absolute measurement focusing on affordable warmth, and domestic energy needs including lighting, heating water, appliance usage and cooking. A Before Housing Cost (BHC) definition of income is used to generate a ratio between modelled fuel expenses and income. Modelled fuel costs are produced from the price of energy and a modelled estimate of "necessary" consumption that accounts for the size of the property, the number of occupants, energy efficiency, and the mix of fuels utilized (Simcock et al., 2018). I applied this concept to the calculation of whether each household in the dataset was in energy poverty based on the availability of related energy data (see section 3.2.2). For the calculation of equivalised income, we consider the real household size rather than weighted household size regarding the number of children, adults, or old people to be consistent with the fuel costs' calculation. In our energy poverty calculation

based on the CFPS surveys, the '10% indicator' should satisfy the two conditions as follows (Lin and Wang, 2020):

$$condition\ 1:\ \frac{Domestic\ fuel\ costs/Family\ size}{Equivalized\ income\ (before\ housing\ costs)} \geq 0.1 \quad (3.1)$$

$$condition\ 2: Equivalized\ income < Median\ equivalized\ income \quad (3.2)$$

Where the Equivalized income is calculated as:

$$Equivalized\ income = Disposable\ \ Income/Family\ size \quad (3.3)$$

3.4.2 "LIHC energy poverty indicator"

The UK government adopted a "Low Income High Cost (LIHC) indicator" instead of "10% indicator" during 2011 to 2021, to provide a relative measure of energy poverty (Hills, 2012). The fuel cost threshold is an equivalized, weighted median of the fuel costs of all households. The income threshold is calculated as 60% of the weighted median income After Housing Costs (AHC). The income figure for each household is equivalized and combined with the equivalized fuel costs of the household. Therefore, the income threshold is higher for those households that require a greater level of income to meet larger fuel bills to avoid a situation of high income and high costs. Energy poverty under the "LIHC indicator" should satisfy the two conditions as follows (Lin and Wang, 2020):

$$Equivalized\ income \leq 60\%\ Equivalized\ median\ income \quad (3.4)$$

$$Equivalized\ fuel\ costs \geq Median\ fuel\ costs \quad (3.5)$$

Where the Equivalized income is calculated as:

$$Equivalized\ income = \frac{Disposable\ income - Housing\ cost - Domestic\ fuel\ costs}{Family\ size} \quad (3.6)$$

The "10% indicator" has drawn criticism for being overly susceptible to changes in the price of energy. (Hills, 2012, Moore, 2012). Considerable examination and critique of both indicators exists (Boardman, 2012, Middlemiss,

2017, Moore, 2012), not least because the introduction of the 'LIHC indicator' significantly decreased the number of energy-poor families in the UK as a whole. While practitioners often refer to the "10% indication" as the more understandable of the two metrics, the UK government employed the "LIHC indicator" in practice between 2011 and 2021 to meet its statutory targets. (Robinson and Mattioli, 2020). However, there is no existing energy poverty research to comprehensively apply these two indicators in China at household level whilst simultaneously considering spatial and temporal context. I analysed the results and applicability of these two indicators in the following chapter 4 & 5.

3.5 Statistical analysis

In order to assess the difference between "10% and LIHC indicators", as well as the associations between likelihood of experiencing energy poverty and household's sociodemographic characteristics, I performed T-tests (chapter 4) and logistic regressions (chapter 5) in this thesis. Detailed information can be found in the relevant chapters.

In chapter 4, I applied a T-test to identify the statistical differences between two indicators' ("10% and LIHC indicators") results after normality tests, I compared the results of the "10% indicator" by three quintile groups (lowest 20%, 40%, and 60% income quintiles) with the results of "LIHC" indicator.

In chapter 5, I have run logistic regressions and added new spatial insights by looking at the full sample, urban, rural, and each single province separately. I include whether a household is energy poor as the dependent variable in the regression model. Other sociodemographic variables under vulnerability domains are set as independent variables. This is the first such analysis on Chinese data.

3.6 Strengths and limitations

3.6.1 Significant advantages

A few existing studies (published during the course of my Ph.D.) also have used data from CFPS to try to capture energy poverty in China (Zhang et al., 2019, Hong et al., 2022, Lu et al., 2022) Most of these examined energy poor households and reported the energy poverty rate at national level by adopting a combination of expenditure threshold method and the proportion of solid fuels use for cooking.

This thesis narrows down the spatial scale and identifies five case-study provinces (which is called "large provinces in CFPS due to the large sample size compared to other provinces included in CFPS): Gansu, Henan, Liaoning, Shanghai, Guangdong, to report a finer scale rate of energy poverty and carry on a comparison of energy poverty across provinces which locate in different parts of China. In section 3.3, I demonstrated the detailed reasons of sufficient samples, various climate conditions, and representative geography in choosing these five case-study provinces by mapping them. As a result, the research presented in chapters 4 and 5 are the first studies in comparison of assessment and factors of energy poverty in these five case-study provinces covering both the North and South of China. In addition, the dataset of these five case-study provinces also supports comparison between rural and urban areas in this thesis.

Overall, the construction of the dataset and case-study choice have been produced by processing five waves of 6,163 household social surveys (including 14,546 individual surveys of each wave), the analysis presented in this work has implications for Chinese energy poverty research, future related research and policies. Previous studies were more concerned with Chinese energy poverty in rural (Yuan et al., 2018, He et al., 2018, Wu and Zheng, 2016, Tang and Liao, 2014,

Peng et al., 2010, Hou et al., 2017) and remote areas (Xie, 2010) using macro level data, or a specific area using micro level data, and this study adds to them by evidencing a finer scale comparison and real domestic energy poverty situation using representative household surveys. The use of these administrative social surveys to investigate the issue of energy poverty in China and the socio-spatial vulnerability analysis is advantageous to the creation of targeted policies that are tailored to the needs of the most vulnerable households, according to comprehensive estimation of the rate of energy poverty and the household vulnerable factors linked to it.

3.6.2 Practical challenges

This section describes specific limitations of the data and methodologies conducted in this Ph.D. This thesis relies on longitudinal secondary data source, methods, and assumptions that are not immune to limitations. I summarize here the limitations of the data and methodologies reflected through analysis in chapter 4, 5 & 6 in this thesis.

In chapter 4, one of the limitations is the expenditure-based energy poverty measurement. Measuring energy poverty in China is subject to data limitation, as there are no official definitions or evaluations regarding household energy consumption. It was not possible to find a set of indicators available for comprehensively evaluating domestic energy conditions of all kinds of household's energy deprivations, especially lacking data, such as energy efficiency of housing, people's feeling about indoor thermal comfort. Since specific policy implementation at local-level household identification would require detailed microdata at the lowest geographical level. Thomson et al. (2017) critically reviewed current energy poverty metrics at EU level which indicates that there are three main methods (see section 2.1): **1)** expenditure approach - where examinations of the energy costs faced by households against absolute or

relative thresholds provide a proxy for estimating the extent of domestic energy deprivation; **2)** consensual approach - based on self-reported assessments of indoor housing conditions, and the ability to attain certain basic necessities relative to the society in which a household resides; **3)** direct approach - where the level of energy services (such as heating) achieved in the home is compared to a set standard (Thomson et al., 2017b). The lack of supportive data relating to the latter two approaches limits the understanding of domestic energy deprivations in China. Nevertheless, this study fully extended the data use based on expenditure approach including household levels' expenditure on domestic electricity, heating, fuels, and hosing, existing studies using the same dataset only calculated the rate of solid fuel use as energy poverty indicator. The other point this study tried to balance this approach limitation is further involving the vulnerability factor analysis which contribute to capturing energy poverty households by categorizing various sociodemographic features that breaking the limits of existing methods and data, such as consideration of household with low housing quality, be mainly female, have old people, have disabled people etc.

The other methodological challenge relevant to chapter 4 is the only large sample frames of five case-study provinces. CFPS pointed that only "large provinces" (our five study cases of Shanghai, Liaoning, Henan, Gansu, and Guangdong) have sufficient samples to support comparison and inference at provincial scale (CFPS, 2017). These five provinces provide a representative understanding of China's energy poverty problem by different climate zones and allow a provincial level comparison on household data. However, the limitation of insufficient data of other 20 "small provinces" make this study could not report the spatial differences at a wider national scale.

In chapter 5, although this study overcame energy poverty measurement limitation by doing further energy vulnerability investigation demonstrated in the first limitation of chapter 4, there is another challenge with more nuanced

exploration of each sociodemographic features. The findings point towards an important new research agenda to develop understanding of the socio-spatial vulnerability of energy poverty in China, and potentially a broader range of nations which lack political will to address this problem, or research on energy poverty. However, the research did not capture how detailed categories of each sociodemographic feature (e.g., people with different number/kind of disabilities; household receiving different kind of government subsidies; if have access to gas network; vulnerability indicators by gender) (Snell et al., 2015, Robinson, 2019, Ivanova and Middlemiss, 2021) and other sociodemographic categories on domains of ethnicity and social exclusion, mobility to key services (employment centre, primary school, secondary school, further education establishment, general practitioner's surgery, hospital, food shop, and town centre) by public transport or walking (Robinson and Mattioli, 2020) due to the data limitations, which can serve as potential avenues for future investigation.

In chapter 6, the methodological challenge lies in reflecting local energy plans (at provincial level) or energy projects. This thesis reviewed national poverty alleviation and energy policies during 2000-2020 combining the research results from chapter 4 & 5, especially policy agendas on National Five-Year Plans over rounds. Scholars elaborated the importance of spatial sensitivity when doing energy justice research: focusing on different local context of across nations (Jenkins et al., 2016, Hall et al., 2013), and household and community level (Gillard et al., 2017, Walker, 2011) issues import an spatial sensitivity to energy justice framework (Koďouskov´a and Bo˘ruta, 2022). In China, provincial level energy development is following National Energy Five-Year Plan due to the top-down system. However, lacking investigation at local scale may limit the understanding of policy effectiveness at the local, community and household scales.

Finally, despite the limitations and uncertainties described above, the research presented in this thesis provides important considerations for Chinese energy poverty analysis. With the use of the concepts and methods presented in this thesis and being transparent about limitations and uncertainties that come with the data, there is still the potential for valuable research on a household level in another local context.

3.6.3 Covid-19 impact

1) Impact

As a doctoral student, my research project has been significantly impacted by the Covid-19 pandemic. The original research project was focused on investigating energy poverty in China, including assessment of the situation, identification of vulnerability drivers and analysis on related policies to this issue. However, due to the isolation and regulation policies in both UK and China, it was no longer feasible to conduct the research as originally planned, especially on the methodology, plans for data collection and progress of research.

- Before the pandemic, I had planned to conduct mixed-method research, including both qualitative interviews and quantitative surveys in the field in China in order to construct a comprehensive and novel energy poverty research framework based on Chinese case. However, due to the pandemic, I was unable to visit China and, for confidentiality reasons, was unable to obtain some forms of household data from the Institute at Peking University, which calls for a site visit. This caused a significant disruption to my original methodological plan.
- The inability to travel to China also impacted my research for specific data collection. I had originally planned to conduct interviews with households in case-study provinces, key stakeholders in the energy

sector, including government officials, NGOs, and academics, to gain a deeper understanding of the issue of energy poverty in China. However, the pandemic prevented me from doing in-person interviews, so I had to come up with alternative methods of data collection.

2) Measures taken to mitigate disruptions

To mitigate against the disruption caused by the pandemic, I made several changes to my research methodology and data collection plans upon careful discussion with my supervisors.

- To mitigate the disruption caused by the inability to conduct mixed-method research in China, several steps were taken to adapt the methodology and address the challenges.

  • Firstly, I focused on leveraging existing secondary data sources that were publicly available to gather quantitative data on energy poverty in China. These sources included national surveys, statistical databases, and research reports that provided valuable insights into the prevalence and characteristics of energy poverty in different regions of China.

  • Additionally, to compensate for the lack of qualitative interviews, I conducted an extensive review of existing literature and qualitative studies on energy poverty in China. This allowed me to gain a deeper understanding of the experiences, challenges, and perspectives of individuals and communities affected by energy poverty in the Chinese context.

  • Furthermore, to ensure the development of a comprehensive and novel energy poverty research framework, I engaged in virtual discussions and consultations with experts and my supervisors in the field who had previously conducted qualitative research on energy poverty or related

fields in China or a broaden European context. These discussions provided valuable insights and helped validate the findings and conclusions derived from the quantitative analysis.

- To mitigate the disruption caused by the inability to conduct face-to-face interviews with households and key stakeholders, alternative methods of data collection were explored.

  • Firstly, I turned to online survey source to gather quantitative data at household scale. By adopted and processed a series of administrative social surveys, I was able to reach a diverse range of household information and construct data on their energy costs, income levels, and other sociodemographic variables.

  • To enhance the reliability and validity of the data collected through alternative methods, rigorous quality control measures were implemented. This involved ensuring survey questions were well-selected, conducting pilot analysis to calculate energy poverty rates in China, comparing my results with previous studies, and employing validation techniques to verify the accuracy of the collected data and related results around chapters.

Chapter 4 Quantifying the spatio-temporal evolution of energy poverty in China from 2010 to 2018

4.1 Introduction

Given that China lack of national energy poverty recognition and strategy which is a barrier to researchers engaging with this issue (see section 2.5). Due to the limited nature of research on Chinese energy poverty, the evidence base is rather uneven, and skewed towards particular places and concerns. For instance, **1)** more attention of Chinese energy poverty research is paid to rural energy poverty (Pachauri and Jiang, 2008; Xie, 2010; Démurger and Fournier, 2011; Li et al., 2011; Hao et al., 2014; Tang and Liao, 2014; Liao et al., 2016; Tang et al., 2016; Xie et al., 2022). There are very few studies focusing on energy poverty in single urban areas in China (Robinson et al., 2018b), or comparing research between urban and rural areas, relative to the larger number of explorations of energy poverty in rural areas. **2)** due to a lack of household energy investigations at the micro level in China, present Chinese research on energy poverty mostly intended to report the energy poverty rate at the national level (Zhang et al., 2019, Wang et al., 2023). There is one study which reports energy poverty rates at a provincial level, but given that it is based on governmental statistics, it may fail to capture the real conditions of household energy consumption (Wang et al., 2015). Further studies have used surveys on a household level, comparing energy poverty situations among provinces by using single index, for example, Liao et al. compared the solid fuel use in rural areas of 10 Chinese provinces by using a social health survey (Liao et al., 2016). There is no research comprehensively comparing energy poverty among Chinese provinces at a micro scale covering both urban and rural areas, as well as considering various energy costs at a household level. **3)** temporal trends of energy poverty have been evidenced in several studies (Liao et al., 2016, Wang et al., 2015), however these are outdated and cannot reflect the

most recent situation of energy poverty in China. Liao et al. revealed the temporal changes of rural household solid fuel use based on China Health and Nutrition Survey (CHNS) from 1989 to 2011 (Liao et al., 2016). Wang et al. also evaluated energy poverty in China by using governmental statistics before 2011 (2000-2011). These gaps formed the inspiration for measuring energy poverty spatially and temporally in this chapter. In this chapter, I offer a detailed analysis of the energy poverty measurement in China, articulating its specific nature and geographical diversity. I draw on data collected at the household level, which after considerable processing can be used to calculate two commonly used indicators: "10% indicator" - in which a households spend over 10% of their disposable household income (Boardman 1991), and "Low Income High Cost (LIHC) indicator" - in which energy poor households have both below average income and above average energy costs (Hills 2012.). I firstly described the development of household disposable income and domestic energy costs in China geographically and temporally. I then compare five regions of China by applying two metrics to these data to examine how energy poverty has changed over time and how it is distributed geographically, both in urban and rural areas. I discuss the variations between the two approaches to calculating energy poverty and outline the rates of energy poverty in the provinces over time. By doing this, I demonstrate that energy poverty indicators can be created even if China does not specifically collect data for this purpose. This offers a greater understanding of the problem of energy poverty and provides new insights on effective energy poverty measurement in China for researchers and policy makers.

4.2 Selected data and methods

In this section I explained the detailed selection of the data from the processed CFPS dataset used in this chapter, including a series of household

questionnaire surveys containing domestic energy consumption data, and the energy poverty metrics of the "10% and LIHC indicators" has been introduced in section 3.3.

4.2.1 Selected data

Table 4.1 summarizes the data used. Valid survey returns are slightly lower than the target (1,600 households of each large province, see chapter 3) (CFPS, 2017), but still sufficient for the analysis I conduct. Even while CFPS was not specifically created to gather data on residential energy use, it nonetheless gives us valuable information, such as the data of type of fuel used for cooking, family expenditures on energy use etc.

Table 4.2 lists the variables utilized in this chapter to measure energy poverty at household level in five case-study provinces. In each wave, the precise collection of residential energy costs was modified. Household's expenditure on electricity, fuel, and heating are all included in the five surveys from 2010 to 2018 which are key energy activities in household daily life despite the slight adjustment of statistical items (Yip et al., 2020, Day et al., 2016). For the purpose of data consistency, I estimated the yearly energy expenditures per capita for each family. As a result, the expenses for fuel and electricity have been converted to annual costs. Household income and housing cost data were also included since they play a vital role in affecting household energy choice and cost, and also in the calculation of "LIHC indicator" (Robinson et al., 2018b). These surveys looked at two different sorts of income; in the 2012 survey, variable "Fincome1" represents net family income from 2011 to 2012, while variable "Fincome2" represents net family income from 2011 to 2012 adjusted to a comparable price based on 2010. Empirically, using revenue at comparable prices can lessen the effects of long-term price fluctuations. However, since other households' energy

expenditures do not take into account for the comparable pricing calculations in this study, I choose to utilize variable "Fincome1" as the household income in calculation of energy poverty rate. This ensures the consistency of data for each survey year.

Table 4. 1. Description of sample size in five provinces

Province / Year	Sample area	Guangdong	Gansu	Henan	Liaoning	Shanghai
	Total	1394	1537	1506	1478	1405
2010	Urban	784	297	612	856	1166
	Rural	610	1240	894	622	239
	Total	1187	1494	1466	1378	1039
2012	Urban	644	285	627	715	814
	Rural	534	1192	831	635	205
	Total	1293	1490	1544	1381	1011
2014	Urban	715	357	679	744	824
	Rural	574	1132	853	630	185
	Total	1332	1527	1518	1361	919
2016	Urban	780	408	634	692	766
	Rural	503	1105	868	613	125
	Total	1462	1599	1511	1296	851
2018	Urban	874	496	676	699	755
	Rural	539	1089	819	585	80

Table 4. 2. Variables used in this chapter

Year	Variables
2010	Household disposable income (yuan)
	Expenditure on electricity last year (yuan)
	Expenditure on housing last year (community management, heating, etc.) (yuan)
	House costs (yuan)
2012	Household disposable income (yuan)
	Expenditure on electricity last month(yuan)
	Expenditures of heating
	Housing costs (yuan)[9]
	Expenditure on fuel last month(yuan)[10]
2014-2018	Household disposable income (yuan)
	Monthly expenditure on electricity (yuan)
	Payment for heating system (yuan)
	House costs (yuan)
	Monthly expenditure on fuels (yuan)

4.2.2 Methods

The introduction of methods used in this chapter was introduced in section 3.3, I scrutinize the spatio-temporal distribution of energy poverty yielded by the "10% and LIHC indicators" based the dataset. I seek to understand whether the "10% and LIHC indicators" are applicable in representing energy poverty in the Chinese case.

Specifically, in the calculation of "10% indicator", I referred to the income grouping method of the China Statistical Yearbook to avoid high-income high-

9 Household' expenditure on 'housing' refers to any type of housing expenses in the year of the survey, including rent, loans, repairs, and maintenance, etc..

10 Household' expenditure on 'fuels' refers to self-heating and cooking fuel costs, including natural gas, liquefied gas, coal, firewood, charcoal, etc. Household' expenditure on electricity, heating, fuels, and housing all unified as annual expenditure per capita of household.

consuming households being marked as energy poor under "10% indicator" and defined those learning less than 60% median income as low income. And further identified three lower quintile income groups (bounded by the 20%, 40% and 60% percentiles based on real income data of households in our dataset) which we use in the energy poverty calculations under "10% indicator". I used the descriptions of '1st quintile', '2nd quintile', '3rd quintile' below throughout the thesis to depict these three income groups.

In the calculation of "LIHC indictor", I defined the low-income threshold is calculated as 60% of the weighted median for income After Housing Costs (AHC) as I introduced in section 3.3.2. Thus, the follow-up spatial-temporal energy poverty analysis under "LIHC indictor" does not have the income divisions as "10% indictor" does.

4.3 Results

4.3.1 Household income level

Energy poverty is closely tied to households' income levels and daily energy costs, thus before calculating the rate, I first try to understand how these factors are distributed throughout our household samples.

Figure 4.1 compares the income of three lower quintile income groups (1st quintile', '2nd quintile', '3rd quintile) based on real income data of households in our dataset. The figure shows a generally rising trend of households' income from 2010 to 2018 in both rural and urban areas. In addition, differences in income can be seen between provinces; considerably higher income in eastern provinces (Shanghai, Guangdong, and Liaoning), less in central (Henan), and even less in western (Gansu). This is in line with the current pattern of economic development in China. Shanghai's per capita income is much higher than the

other four provinces regardless of income quintile and the division of rural and urban. In the 1st quintile, rural households' income per capita in Shanghai is approximately four times than that in Gansu province, and 3.5 times higher in urban households. Despite the improvement in the economy throughout the study years, there are geographical differences in household income between rural and urban areas as well as among the five provinces.

Figure 4.2 and Figure 4.3 show income disparities among different groups. I compared the 1st and 3rd quintiles. Income disparity is greater in urban than rural areas.,. Figure 4-2 shows the income gap between 3rd and 1st quintiles in rural households increased between 2010 and 2018. Figure 4-3 shows an increasing income disparity trend from 2010 to 2018 also exists between the 1st and 3rd quintiles in urban households. Shanghai has the largest income gaps between the 1st and 3rd quintiles in both rural and urban areas. Household disposable income will be impacted by geography disparities (including rural-urban areas, different provinces, and income quintile groups), and these variances will probably also determine differences in household energy use.

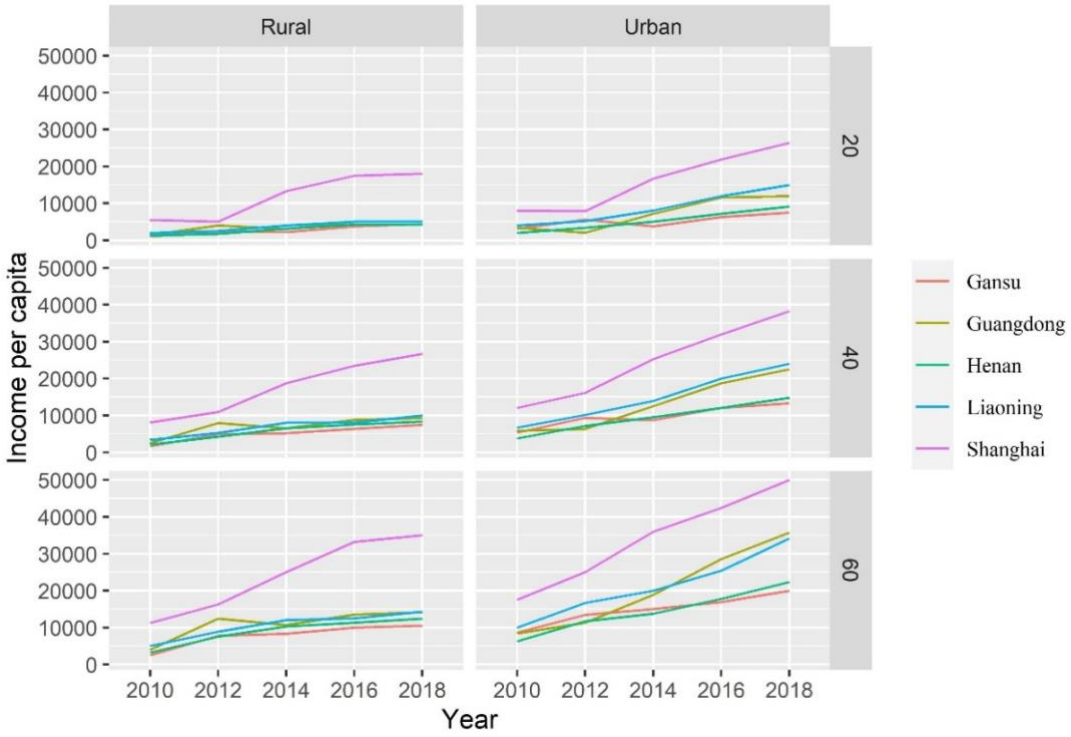

Figure 4. 1. Mean income per capita of the 1st, 2nd, and 3rd income quintiles of household in five provinces from 2010 to 2018

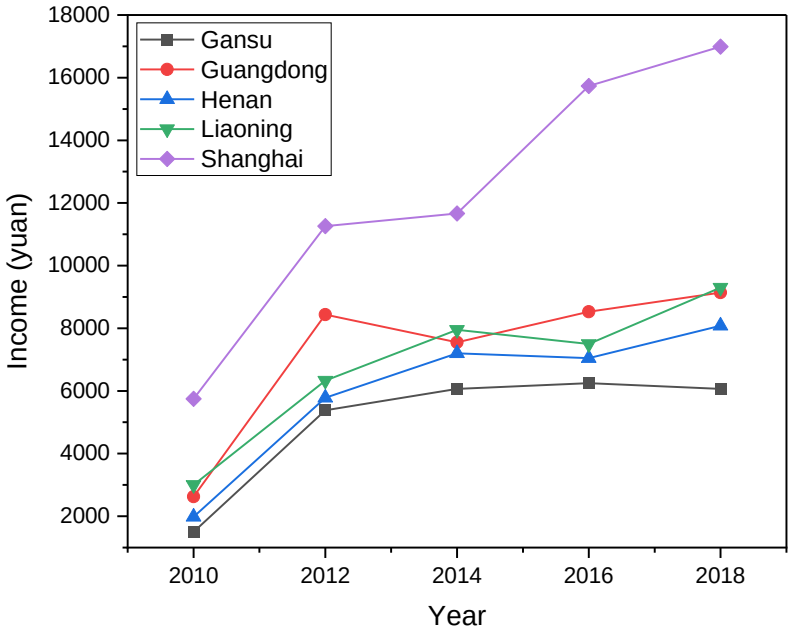

Figure 4. 2. Income gaps between the 3rd and 1st quintiles in rural area from 2010 to 2018

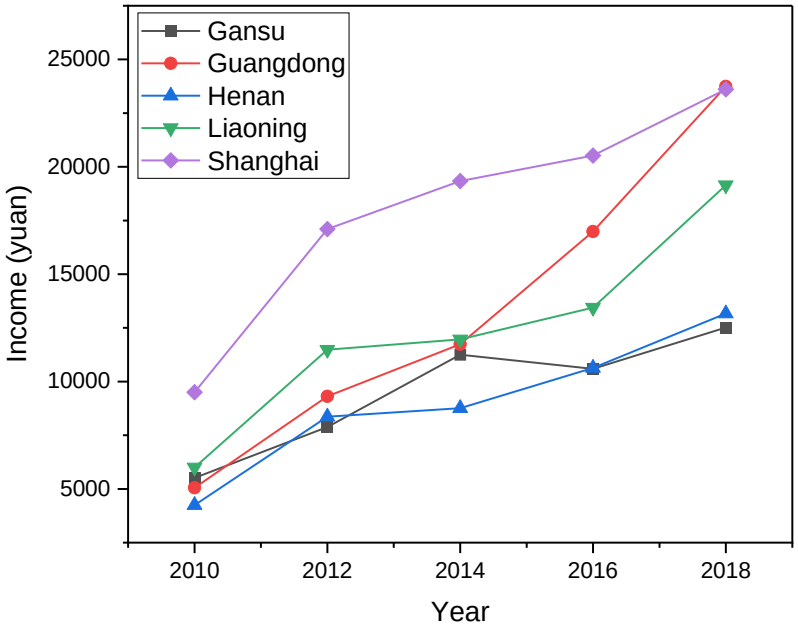

Figure 4. 3. Income gaps between the 3rd and 1st percentiles in urban area from 2010 to 2018

4.3.2 Household energy expenses

Energy costs and other home expenses are influenced by disposable income per capita. As described in section 4.2.1, I concentrate on four components of domestic energy consumption: electricity, heating, fuels, and housing. Here, I disaggregate these aspects into urban-rural and provincial categories. This is to give us a sense of the actual energy consumption of households in our sample before calculating the rate of energy poverty.

1) Electricity

Figure 4.4 shows the evolution of households' electricity cost per capita from 2010 to 2018 in each province. Firstly, the median value of the boxes in the plots reflects the average level of household electricity expenditure. In rural areas, households' electricity expenditure has been rising gradually during the eight-

year study period except for in Shanghai where costs spiked in 2012. The length of the box (inter quartile range) in the plots reflects the range of electricity consumption costs for a specific sample group. We can observe an increase in disparity of electricity cost per capita through the length of the boxes during the study period. Also, the degree of disparity varies between the five provinces. The disparity of household electricity cost per capita is most obvious in rural Liaoning, in 2018. However, in rural Shanghai, the disparities of household electricity cost per capita changed only slightly between 2010 and 2018.

In urban Henan and Liaoning there is a gradual trend of increasing expenditure somewhat similar to the rural pattern in those provinces. In urban Gansu, the median expenditure decreases between 2010 and 2018. In the other urban areas, there has been more fluctuation. The possible reason of this fluctuation in 2012 may be due to the implementation of 'Ladder Electricity Prices' [11] in 2012 to promote social justice and conservation of resources, and some improved adjustments towards to this policy such as off-peak electricity price and rental housing electricity bill settlement in 2013 and 2014 [12]. In urban areas, the disparity in electricity expenditure remained similar in each province over the study period. This suggests the overall electricity consumption in urban areas have developed equally, though unequal electricity consumption still

11 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 the 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

12 China's National Development and Reform Commission informed to fully implement off-peak electricity price for residential sector and encourage residential users to participate in this policy making. Standardize the settlement of electricity bills for rental houses, and owners are not allowed to increase the price of electricity for tenants.https://www.ndrc.gov.cn/xwdt/xwfb/201312/t20131225_956260.html?code=&state=123 https://www.ndrc.gov.cn/fggz/tzgg/ggkx/201401/t20140106_1072397.html?code=&state=123

exists, including ownership of electrical equipment, efficiency of appliances, and people's practice (Lin and Wang, 2020).

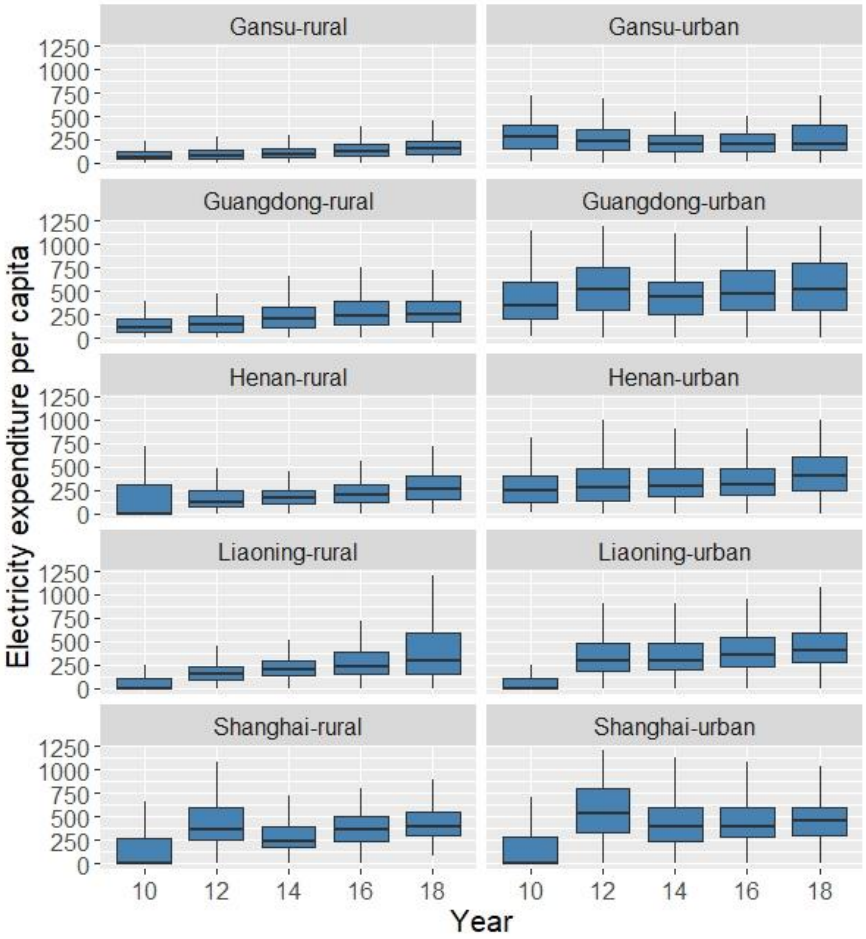

Figure 4. 4. Households' expenditure on electricity among five provinces from 2010 to 2018

2) Housing

Figure 4.5. shows the evolution of households' housing cost per capita from 2010 to 2018 in each province, here the housing cost refers to any type of expenditure households paid on their housing including rent, loans, and purchase expenses annually. In rural areas, the median housing cost in the Liaoning and Gansu provinces has fluctuated over these five years while the other three provinces have not changed substantially. However, although the median housing expenditure has changed very slightly, China's real estate boom during

this period is reflected in the widening disparities in housing expenditure. In urban areas, the median housing cost has risen from 2010 to 2018 in Gansu, Henan and Liaoning provinces but has been almost steady in relatively developed Guangdong and Shanghai provinces. Stability in housing costs in Shanghai may be because the original households in developed Shanghai and Guangdong have a lower mobility than less developed Gansu. Housing expenditure almost doubled in urban Liaoning. In urban Shanghai and Guangdong province, the housing costs fell in 2012 compared to 2010, and remained at a low level since. However, the range of households' housing costs expanded from 2010 to 2018. In urban Henan, the maximum housing cost of 70% households reached to 1,125 yuan per capita in 2018, compared to 400 yuan per capita in 2010. Whether in rural or urban areas, households' housing cost per capita in this research are above average national levels in 2018 published in *China Statistic Yearbook 2019* (572 yuan including housing maintenance and management expenses). In this dataset, housing prices in the comparatively underdeveloped areas such as Gansu and Liaoning are growing together with households' housing expenditure. The housing price in the comparatively developed areas such as Shanghai and Guangdong province is already high, the inequality in income is mirrored in this imbalance, and highly high-value income widens the gap even further.

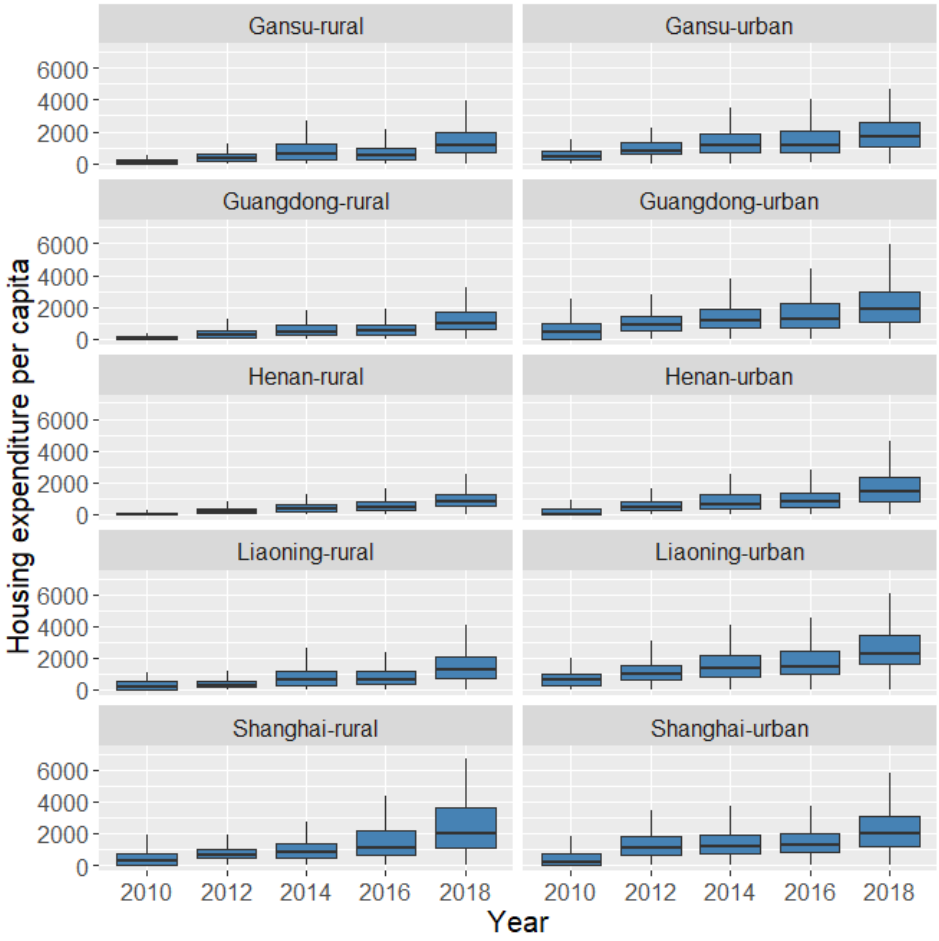

Figure 4. 5. Households' expenditure on housing among five provinces from 2010 to 2018

3) District Heating

Figure 4.6 shows the evolution of households' heating expenditure per capita from 2010 to 2018 of each province. In this dataset, the northern provinces of Gansu and Liaoning are covered by the Huai-river district heating program in China, but southern provinces like Guangdong, Henan, and Shanghai are not covered. In Gansu, Heating costs dropped due to a range of policies: government subsidy from 2014 onwards, the coal-to-electricity heating policy, and introduction off-peak electricity tariffs as well as subsidies from employers to ensure that households are heated in winter [13]. However, a lot of those who heat

13 For instance, Gansu Provincial Development and Reform Commission promotes Clean Heating Price Support Policy which indicates "one household, one meter" towards to urban and rural households (including schools and other non-residential categories that implement residential electricity prices) who

their homes with electricity do not have separate heating data in this survey sample. The situation is similar in Liaoning due to the implementation of the electricity heating policy which sets 0.562 yuan per kilowatt-hour in peak time and 0.329 yuan per kilowatt-hour in off-peak time. Rural households in Gansu and Liaoning do not have district heating as I mentioned in previous chapters (chapter 1 & 2).

In urban areas, the median heating cost per capita in Liaoning is higher than that in Gansu. Liaoning province is further north and coastal in comparison to Gansu province which always experiences a cooler climate in winter; on the other hand, Liaoning has a higher disposable income level from 2010 to 2018 than Gansu province. As a result, 75% of the households in Gansu province have a maximum heating cost per capita below 500 yuan, whereas Liaoning province's maximum heating cost per capita is always above 500 yuan.

would not be implemented the ladder electricity price policy for heating during the heating period. The off-peak policy is reducing electricity cost by 0.249 yuan per kilowatt-hour to further subsidize residential energy use. http://fzgg.gansu.gov.cn/fzgg/c1106090/202108/1765285.shtml

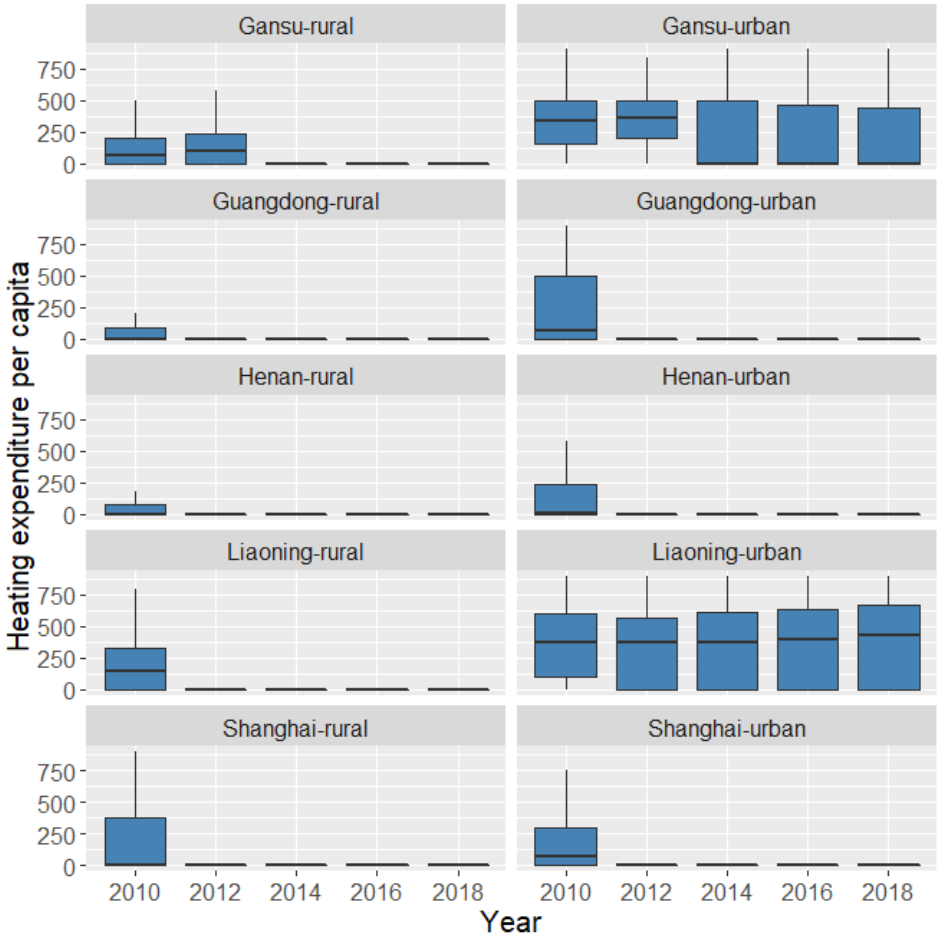

Figure 4. 6. Households' expenditure on heating among five provinces from 2012 to 2018

4) Fuels (Self-heating and cooking fuel costs, including natural gas, liquefied gas, coal, firewood, charcoal, etc.)

Figure 4.7. shows the evolution of households' fuel expenditure per capita from 2012 to 2018 of each province. Median fuel expenditure in urban areas shows minor fluctuation with the exception of Gansu which drops somewhat. In Rural areas fuel expenditure rises with the exception of Shanghai province. Guangdong Liaoning and Gansu have greater disparity than Henan and Shanghai which located more centrally. When comparing rural and urban areas in each province, the difference in disparity is smaller in Shanghai and Henan (the most economically developed provinces), but more pronounced in the economically less developed provinces.

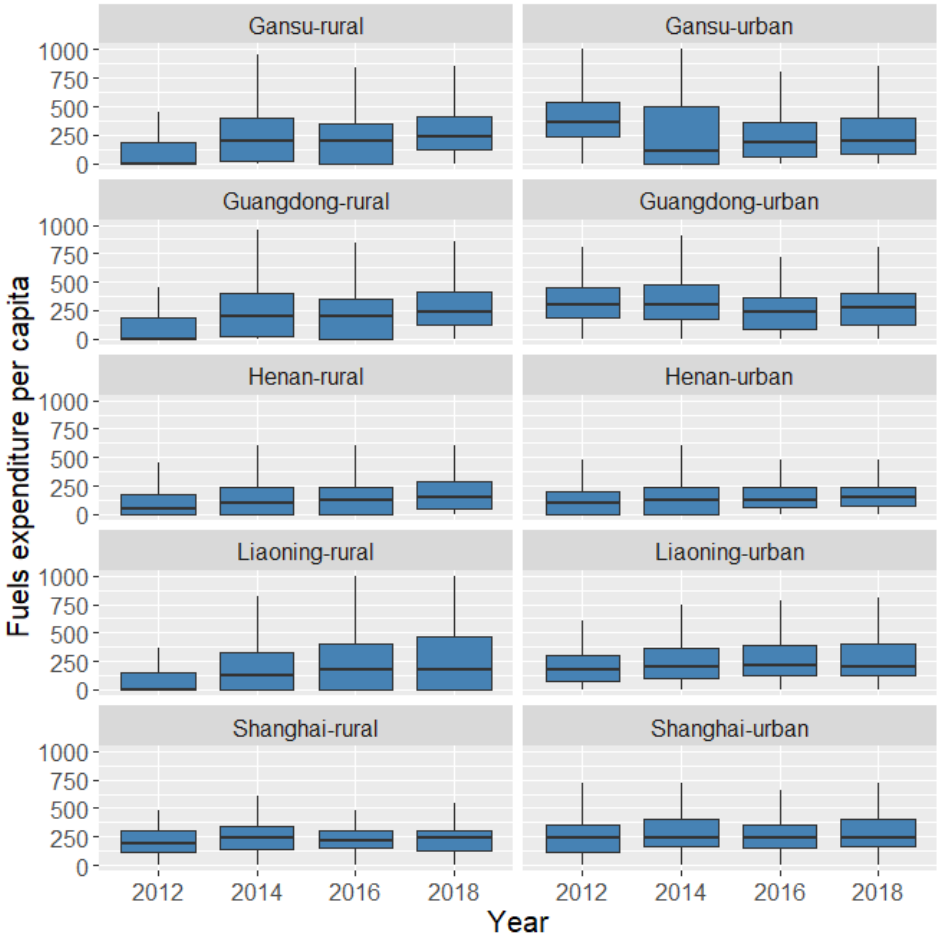

Figure 4. 7. Households' expenditure on fuels among five provinces from 2012 to 2018

4.3.3 Energy poverty using the "10% indicator"

Differences in households' income levels result in differing ability to pay for energy, however, other external factors such as the geographical location, the availability of infrastructure and local policy all have an impact on how much and what kind of energy is consumed by households, as well as what types of energy appliances they choose to use. The multi-faceted nature of household energy needs can affect households' daily life. Here I applied the "10% indicators" to this dataset using the households' income and energy expenses data to identify energy poor households and their evolution during study period (Equation 3.1-3.3).

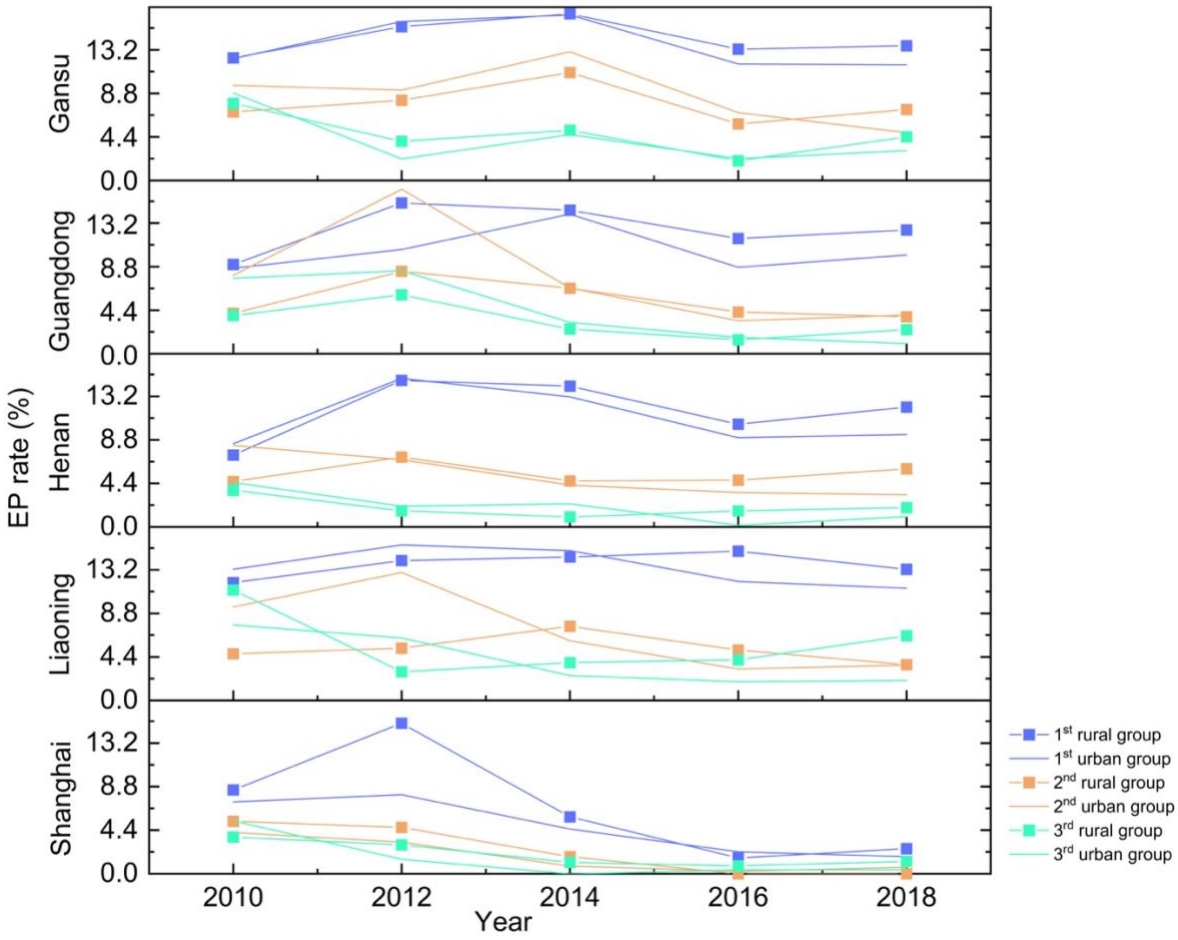

Figure 4. 8. Percentage of rural and urban energy poverty ("10% indicator") of 1st, 2nd, 3rd income quintiles in five provinces from 2010 to 2018

1) By provinces

Figure 4.8 shows the proportion of energy poverty households in rural and urban areas using the "10% indicator". Note that I present this information by documenting the proportion of people in each of the bottom three income quintiles who are energy poor. We can see that the rate of energy poverty among Chinese households varies by income, the distinction between rural and urban areas, and the provinces. Whilst overall, there is a downward trend during 2010 to 2018, there are variations. In 2018, Gansu had the highest energy poverty rate in rural or urban areas among these five provinces which was 13.62%, 11.69% respectively of the 1st quintile. By 2018, the 1st quintile group in developed

Shanghai had the lowest energy poverty rate: 2.53% and 1.73% respectively. Henan and Guangdong have similar energy poverty rates in 2018 for both rural and urban areas. The rate of energy poverty changed differently for each income level between 2010 and 2018. In rural Gansu, for the 1st quintile, energy poverty rate has slightly increased from 12.38% to 13.62% from 2010 to 2018, however, this rate has decreased from 7.79% to 4.42% for the 3rd quintile. In rural Liaoning, it has also been noticed that the energy poverty rate has increased in 1st quintile but has decreased in the 2nd and 3rd quintiles. In the 2nd quintile, the energy poverty rate was 3.61% in 2018, which was originally 4.71% in 2010. The figure suggests that energy poverty alleviation has occurred in the 2nd and 3rd income quintiles but not the lowest income quintile. This suggests that the poorest income group households should be paid more attention when formulating energy policies.

2) Urban-rural gap

It is notable here that households in urban areas do experience energy poverty, sometimes at a similar level to rural areas, however, there remains a more pronounced rural-urban divide in energy poverty amongst the 1st quintile than the 2nd and the 3rd quintiles. For example, in Gansu, energy poverty rate was 4.42% in rural areas and was 3.02% in urban areas in the 3rd quintile in 2018. In addition, the difference between rural and urban areas is larger in the 1st quintile than the 2nd and 3rd quintile groups. Also, although the rural-urban income gap mentioned above is expanding, the gap between rural and urban energy poverty ratios decreased mainly in the higher income groups during the study period. A relatively small difference between rural and urban areas can also be found in developed provinces such as Shanghai and Guangdong. The Chinese government has made progress in guaranteeing the basic energy provision to residents, also in alleviating the gap between urban and rural areas. However, our results show that there still are inequalities of energy costs and services between urban and

rural: more effort should be made into the lowest income groups which would result in a more equal distribution of energy.

4.3.4 Energy poverty using the "LIHC indicator"

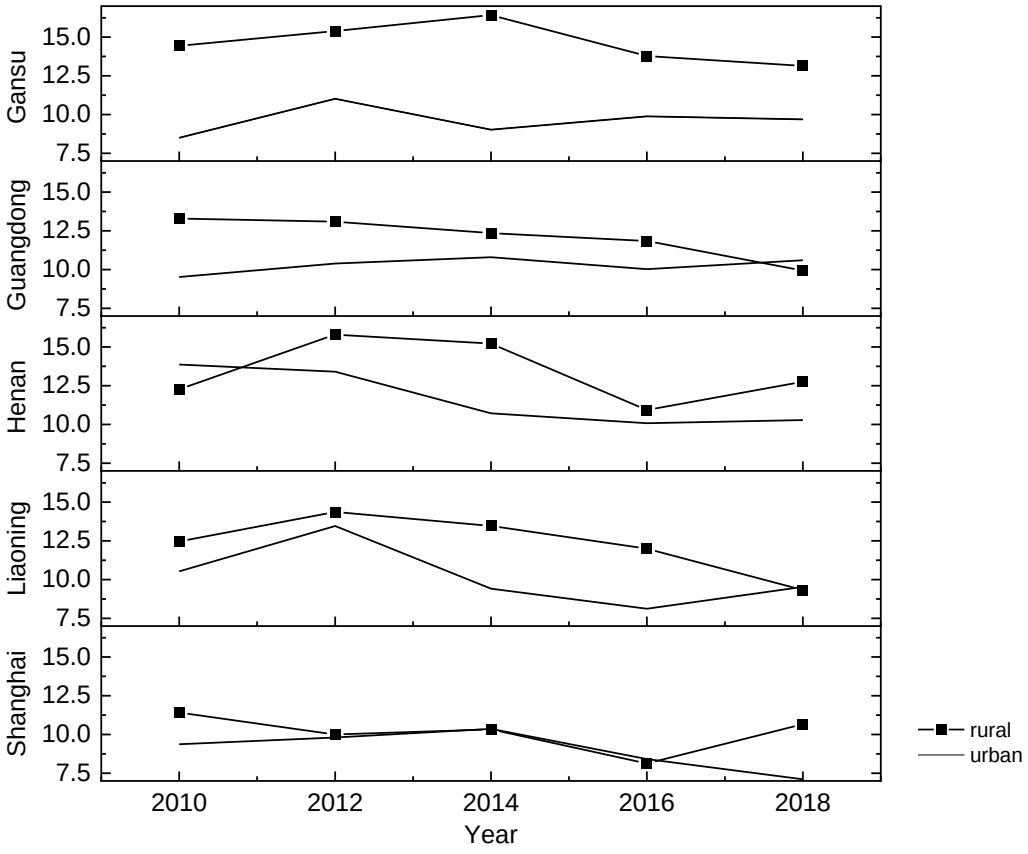

Figure 4. 9. Percentage of rural and urban energy poverty ("LIHC indicator") of households in five provinces from 2010 to 2018

As I explained in 3.3.2, the "LIHC indicator" set the 3rd of the weighted median for income After Housing Costs (AHC) as low income threshold which avoid a situation of high income and high costs, thus, I did not divide the income groups here like applied to the energy poverty calculation under "10% indicator". Figure 4.9 shows the proportion of energy poverty households by using "LIHC indicator" for rural and urban areas in these five provinces from 2010 to 2018 (Equation 3.4-3.6). In this figure, we can see that the energy poverty rate under

"LIHC indicator" also shows heterogeneities among provinces across time, and a downward trend during 2010 to 2018 except urban Gansu and urban Guangdong. In 2018, Gansu had the highest energy poverty rate in rural areas (13.14%), followed by rural Henan (12.76%). In urban areas, Guangdong, and Henan had the two highest energy poverty rates in 2018 (10.60% and 10.28% respectively). Though central and western provinces report more severe energy poverty under "LIHC indicator", the energy poverty trend is decreasing most years. The energy poverty rate in rural areas also show a downward trend from 2010 to 2018 with the exception of Henan. For example, in rural Liaoning, the energy poverty rate has changed from 12.47% in 2010 to 9.33% in 2018. In Guangdong, the energy poverty rate has decreased from 13.29% in 2010 to 9.94% in 2018. Urban areas also have a decreasing trend in Shanghai, Henan, and Liaoning from 2010 to 2018. However, Gansu and Guangzhou have a slight increase of approximately 1.00% of energy poverty rate in their urban areas. Thus, the households' energy poverty rate has decreased during the study period among all these provinces under the "LIHC indicator". Decreases were similar between provinces although their energy poverty rates varied finally in 2018.

All five provinces have been seen a reduction in the energy poverty gap between rural and urban areas since 2010, however during the study period, Gansu, Henan, and Liaoning had a wider difference than Shanghai and Guangdong. In 2014, the energy poverty gaps between rural and urban Gansu, Liaoning, and Henan are 7.40%, 4.50%, and 4.05% respectively. However, in relatively developed Shanghai and Guangdong, these figures are -0.04%, and 1.55%, which means in 2018, energy poverty in rural Shanghai was only 0.04% higher than that in urban Shanghai. The differences between urban and rural energy poverty are smaller in developed regions than undeveloped regions.

4.3.5 Comparison of "10% indicator" and "LIHC indicator"

The results of the "10% and LIHC indicators" give us insights into energy poverty in urban and rural China from 2010 to 2018. Figure 4.10, 11, 12 show the statistical tests of differences between these two indicators' results after normality tests, I compared the results of "10% indicator" by three quintile groups with the results of "LIHC indicator". The full statements of hypothesis are as follows:

Null Hypothesis: There is not a significant difference between the two metrics' results; any observed differences may be due to chance and sampling error.

Alternative Hypothesis: There is a significant difference between the two metrics' results; the observed differences are most likely not due to chance or sampling error.

First, it is noted that energy poverty does exist among Chinese households including rural and urban areas although the two indicators present different energy poverty rates in provinces for specific years. The energy poverty rates in these five Chinese provinces are all below 17.00% from either "10%" or "LIHC" indicator. The "LIHC" result corresponds best to the 1st quintile under '10% indicator' rather than the 2nd and 3rd quintiles among these provinces, which can also be proved in the t-test results that the p-value are more significant in the 2nd and 3rd quintiles rather than 1st quintiles. Even in the 2nd, and 3rd quintiles, the results of "10% indicator" show that energy poor households exist, thus, to some extent, "LIHC indicator" reduces the income sensitivity of energy poverty rates and the estimation of energy poverty household numbers in comparison to the "10% indicator".

Second, spatial, and temporal analysis in the previous sections shows that the heterogeneities exist not only between rural and urban areas but also

between developed regions and undeveloped regions. Both the "10% and LIHC indicators" show that energy poverty occurs in urban areas which rarely have been paid attention previously. Although the energy poverty rates are generally more severe in rural areas, provinces such as Liaoning, Gansu and Henan show very little difference between rural and urban areas. The rural-urban gap is also not obvious under the "LIHC indicator", for example, in Liaoning, the energy poverty rates in rural and urban areas are 13.25% and 11.35% in 2018 under the "10% indicator", however, the rates are 9.33% and 9.53% in 2018 under "LIHC indicator". The "10% indicator" therefore reflects rural-urban disparities better than "LIHC indicator". While these two indicators have slight difference with regards to the disparities among provinces, the differences between these two indicators are less obvious at a macro spatial scale. The results of "10% and LIHC indicators" both show that Gansu has suffered the most from energy poverty among these five provinces, and that the relatively developed Shanghai has suffered the least from energy poverty among households.

The results in these calculations illustrate the detailed spatio-temporal evolution of Chinese households' energy poverty problem by applying "10% and LIHC indicators" to the dataset, which are based on the income-expense perspective and have been widely used in western countries. The findings demonstrate that **1)** this dataset and the two indicators can give us a lens on energy poverty in China that is effective at capturing its evolution characteristics and geographical heterogeneities across Chinese families. **2)** However, we need to critically think about the applicability of energy poverty measurements in China due to the specific local context. I argue that the "10% indicator" is more suitable to capture this problem than the "LIHC indicator", since energy poverty rates captured under "10% indicator" are substantially different between rural and urban areas though the energy poverty rates captured in 1st income quintile under "10% indicator" are similar with that under "LIHC indictor". Besides,

differences of energy poverty rates between urban and rural areas are more substantial in 1st quintile than 2nd and 3rd quintiles under "10% indicator". And no substantial differences of energy poverty rates can be found between urban and rural areas under "LIHC indicator". Thus, "LIHC indicator" might exclude certain vulnerable households at a higher but below the median income level and may also hide some disparities of energy poverty among rural and urban areas.

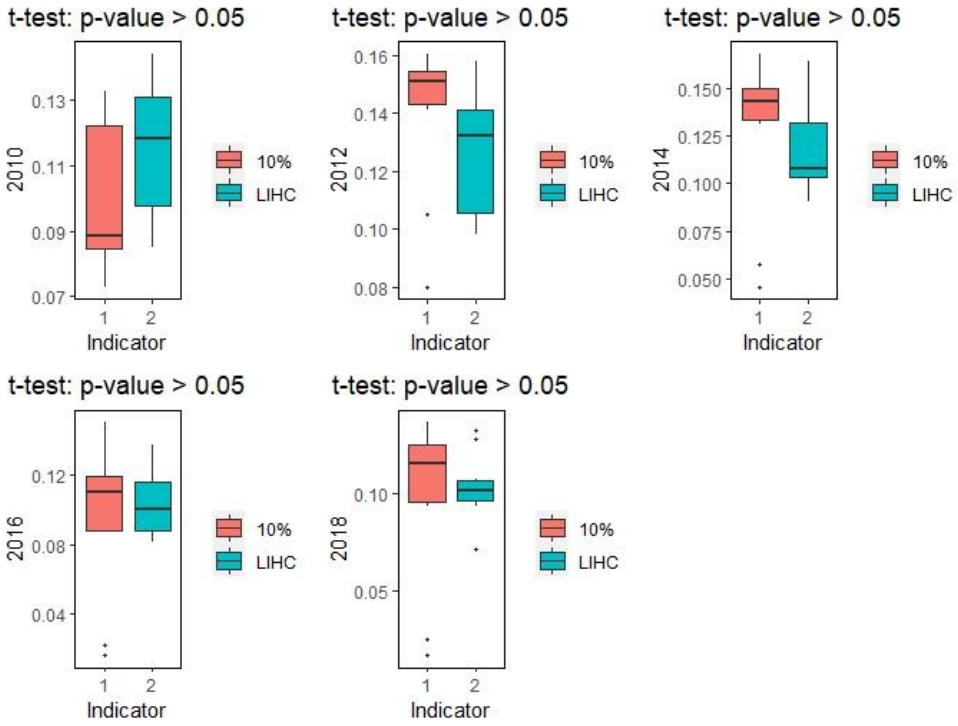

Figure 4. 10. Difference tests of energy poverty results between the "10% indicator" (the 1st income quintile) and "LIHC indicator"

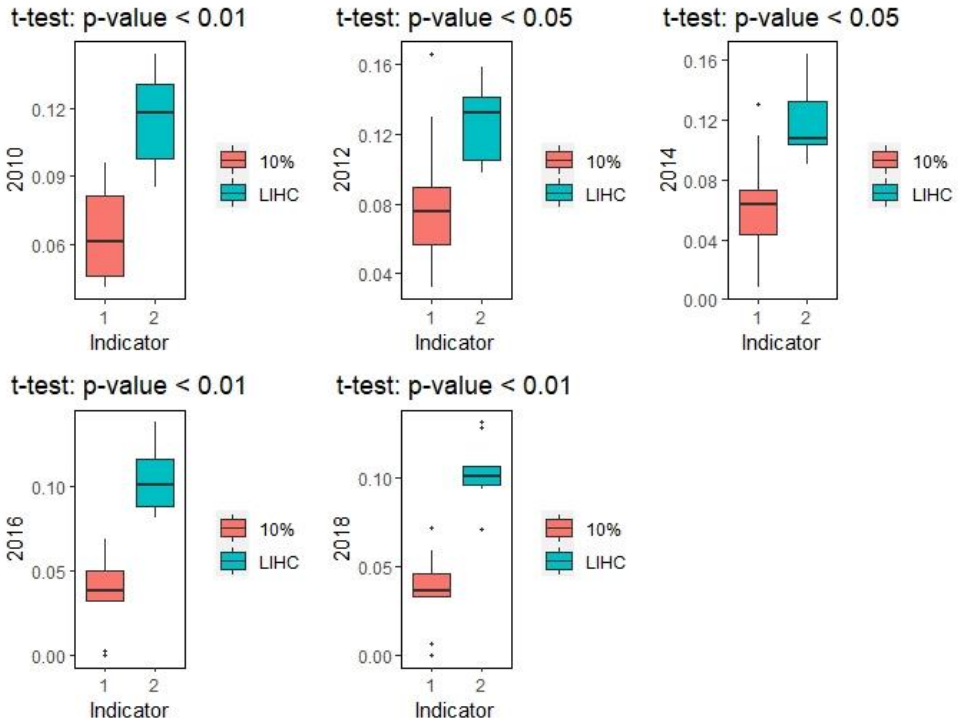

Figure 4. 11. Difference tests of energy poverty results between the "10% indicator" (the 2nd income quintile) and "LIHC indicator"

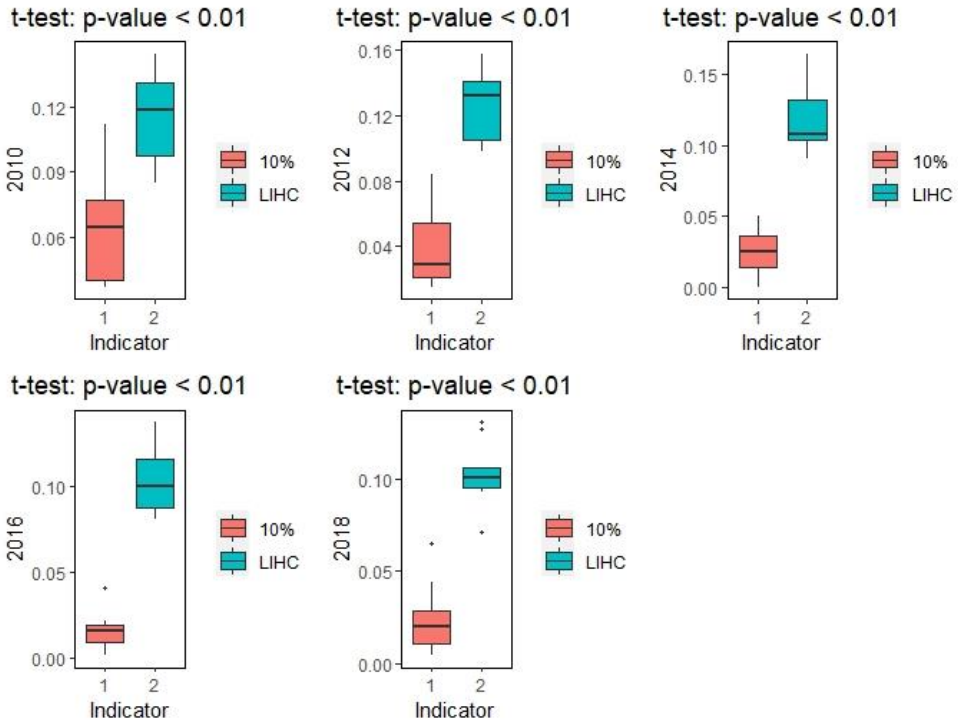

Figure 4. 12. Difference tests of energy poverty results between the "10% indicator" (the 3rd income quintile) and "LIHC indicator"

4.4 Conclusions and discussion

4.4.1 Diversity of energy poverty in China

Based on the CFPS Survey waves (2010, 2012, 2014, 2016, 2018), this chapter uses the '10% indicator' and 'LIHC indicator' to describe China's energy poverty spatially and temporally. The results highlight that energy poverty exists in Chinese households, and it shows a downward trend across all areas in the study period, which is associated with rapid economic development, and gradual improvement of social infrastructure and household living standards. This is consistent with the IEA's evaluation and forecast for China (IEA, 2010). The reason for the alleviation of energy poverty in China is mainly due to the improvement in energy access, subsidies, and efficiency, specifically, Chinese

households can now get access to modern residential energy services like electricity and heating at a low price in both rural and urban areas with subsidies from government (NEA, 2018). However, in areas which have insufficient energy infrastructures to satisfy their daily energy consumption, households may have to balance disposable income and energy use. Some evidence was found by scholars who investigated rural households' energy use for cooking, that rural households may be artificially reducing their expenditures on modern energy use as a large number of households still use cheap solid fuel with associated indoor air pollution (Tang and Liao, 2014, Dong et al., 2021). Continued economic development in China suggests that energy poverty will continue to fall but special efforts are needed to avoid leaving people and places behind.

Whilst energy poverty is not exactly analogous to income poverty (Middlemiss and Simcock, 2019), energy poverty rates are higher in western and northern China, which is consistent with the pattern of China's economic development and is reflected in the high rates according to the '10% indicator' and 'LIHC indicator' in Gansu and Liaoning provinces. Higher rates of energy poverty are also found in rural areas, though urban energy poverty does exist despite having received little attention in previous studies. This diversity is important to bear in mind in energy policy making.

4.4.2 Bundles of multiple disadvantage

Due to the gap between rich and poor, along with the differences in geographical location, climate conditions, and resource endowments, there is heterogeneity in household energy consumption in China. Energy poverty not just exists among rural households with lack of efficient modern energy services despite presence of basic energy access (Jiang et al., 2020). The results in this chapter also show that the mean energy poverty rates of these five provinces are

10.80% in rural, and 8.81% in urban areas in 2018, according to '10% indicator' of the 1st quintile. Whilst energy poverty rates are lower in urban areas than rural areas, expenditure is higher. This mainly because households in China have not reached the saturated stage in energy demand, and electricity consumption in developed urban areas is likely to increase with increasing income. Therefore, the policy of 'Ladder Electricity Prices' is reasonable in restricting the household electricity usage with high prices for higher income and higher consumption households (Lin and Wang, 2020). However, results show that such subsidies are insufficient to shield from the cold or heat those households that have a lower income. These households likely struggle to afford heating or cooling or lack access to appropriate networked infrastructures and a high quality, energy efficient built environment. In undeveloped rural areas, the enhancement of access to modern energy has improved in the past decades in China, following interventions among rural households. For example, the 'Ladder Electricity Prices' policy which attempts to cross-subsidies between different living standards while ensuring that the basic electricity demand does not rise. To guarantee affordability of electricity, provincial governments have also introduced a policy of 10-15 kW*h per month of free use for each low-income household. In addition, heating subsidies are also provided to rural families, varying according to needs of rural families between 950-1,200 yuan. Energy poverty in rural areas is more severe than in urban areas suggesting more persistent income, infrastructure, and building problems among rural households (Li et al., 2011, Luo and Liu, 2013, Zhao et al., 2018, Hao et al., 2014, Hong et al., 2022).

Energy consumption is sensitive to tariff, income, and the efficiency of home appliances in poorer areas such as Gansu and Liaoning in western and northern China. As residents in these areas suffer from both income poverty and relatively high energy costs who should be provided with extra support. Considering their

low income and household appliance possession, economic subsidies in both power consumption and appliance purchasing could be effective, and the policy of '10-15 kW*h free use' already implemented represents a kind of universal basic service for these residents no doubt addressing poverty alleviation (National Development and Reform Commission). This is not enough for subsiding the basic usage of households' energy appliance to maintain daily life such as air conditioner, fridges, TV etc. and for China to pursue a clean and low-carbon economy, especially a household energy transition from coal to electricity and natural gas. A further policy, the clean heating program, launched in 2017, pays the costs of infrastructure construction and for the replacement of heating equipment. Under this scheme, households do not bear the cost of infrastructure construction, but bear a portion of heating equipment replacement.

Another reason for the high rate of energy poverty in undeveloped areas is that the transition from coal to electricity or gas is both costly and mandatory, and the supporting subsidy is insufficient to cover the increased cost. Although the clean coal replacement program is also mandatory, clean coal is much cheaper than electricity and gas, and it does not cover the cost of infrastructure construction and heating equipment replacement. This implies that clean coal replacement would be a good transitional measure before eventually achieving heating with gas or electricity, if the government is fiscally constrained in the short term.

Identifying the level of energy poverty in a place is helpful when considering the synergy of climate and equality solutions, scholars have identified the inescapable correlations between energy poverty policies and climate policies (Sawhney, 2013, Wang et al., 2014a, Ürge-Vorsatz and Tirado Herrero, 2012). In Chinese case, basic realization of power grid coverage has a significant effect on reducing energy poverty, but the proportion of coal power in China is still high (Xie et al., 2022), which produces a large amount of greenhouse gas emissions.

Increasing natural gas coverage in remote towns and rural areas and forming a fair and reasonable natural gas pricing mechanism will significantly reduce greenhouse gas emissions and improve the clean energy use in households. Improving home energy efficiency is mainly through improving cooking and heating equipment. Increased energy efficiency reduces the amount of energy consumption per unit of output, which in turn reduces emissions. Moreover, the development and utilization of renewable energy has the dual effect of alleviating energy poverty, saving energy and reducing emissions. Seek synergy between energy poverty and climate change policies is beneficial to collaboratively realize the dual goals of just and clean energy society.

4.4.3 Overcoming policy silos

The CFPS surveys used in this chapter is one of the most complete public social surveys in China, and provides a basis for academic research and social policy analysis (CFPS, 2017). Household energy consumption data included in these surveys allow me to identify energy poor households in China spatially and temporally. Understanding the socio-demographic characteristics of these households could be one direction of future research, as it could shed light on ways to better understand energy poverty in China and to improve households' welfare by improving the design and implementation of the clean heating and similar programs. The findings in this chapter call the attention of policy makers to low-income households when designing and implementing policies, specifically households that need special attention during the implementation of energy policies concerning the heterogeneous impacts across areas.

The dataset is not explicitly designed for energy poverty evaluation, though I have shown that the data can be processed to derive '10%' and 'LIHC' measures.

I suggest that as China-specific metrics are adopted, then some questions in the survey could be adapted to gather data explicitly for these metrics.

Further useful research would include utilizing the data processing and descriptive understanding provided in this chapter for either statistical analysis or as a start point for evaluation of lived experience through mixed methods research. Data gathered at finer resolution may allow more detailed analysis of the variation within and between provinces over time.

Acknowledgements

My sincere thanks go to Lucie and Ian's professional contributions to this chapter. This work was supported by China Scholarship Council. The authors are grateful to the Institute of Social Science Survey of Peking University supporting the dataset used in this study. I also would like to thank Alice Owen, Anne Owen, and Yim Ling Siu for their valuable comments on the work in this chapter and for publishing it in the Working Paper Series.

Chapter 5 Who is vulnerable to energy poverty in China?

5.1 Introduction

Recent work on energy poverty research argues for a more nuanced insight to policy, taking into account multiple vulnerabilities of households, when identifying and delivering interventions (Ivanova and Middlemiss, 2021, Simcock et al., 2018, Robinson et al., 2018b, Middlemiss and Gillard, 2015, Bouzarovski et al., 2012, Middlemiss, 2022b). The triad of energy poverty drivers consisting of low incomes, high energy prices and domestic energy inefficiency (Boardman, 1991, Hills, 2012) risks obscuring particular socio-spatial vulnerabilities. Vulnerabilities are understood as a set of conditions distributed across space inherent within an individual, household, or social group that renders them less likely to be able to access the socially and materially necessitated amount of affordable and reliable energy services (Bouzarovski et al., 2012). More specifically, scholars use this framing to explain the differential access to energy services between societal groups (Robinson et al., 2018b, Ivanova and Middlemiss, 2021). It provides a way by which to identify and understand the traits of those most susceptible to harm from particular stressors and thus the opportunity to mitigate against these harms (Adger, 2006, Robinson et al., 2018a). This, according to Middlemiss and Gillard (Middlemiss and Gillard, 2015), establishes a household's susceptibility to energy poverty as well as its capacity to deal with and adjust to the situation.

While energy poverty is not yet clearly on the political agenda in China, there is a limited amount of research into this topic. Research on energy poverty in China has emphasized contrasting rural and urban areas and comparing different regions (Robinson et al., 2018c, Wang et al., 2015, Yang et al., 2017, Wu and Zheng, 2016, Tang and Liao, 2014, Wang et al., 2014b, Jiang et al., 2020, Xie

et al., 2022, Wei et al., 2014), existing research tends to focus on either urban or rural areas (Lin and Wang, 2020, Wang et al., 2015, Dong et al., 2021, Zhang et al., 2019), highlighting the different effects of energy poverty in one or the other, with more attention paid to rural energy poverty (Li et al., 2011, Xie, 2010, Hao et al., 2014, Tang et al., 2016, Xie et al., 2022). However, to date, there is no research to identify who is vulnerable to energy poverty in China like other nations' experiences. Painting a picture of geographical heterogeneity in levels and effects of energy poverty in China is insufficient to capture deep drivers of vulnerability to this problem, which is likely to affect different households differently.

This chapter explores vulnerability to energy poverty across various sociodemographic groups, and the spatial dynamics (covering five provinces and rural-urban differences) behind this, based on household surveys conducted in 2018 by the China Family Panel Studies (CFPS). I considered household home energy use including heating, electricity, fuel expenditure as included in measuring energy poverty in chapter 4, and potential vulnerability factors including low education, mainly female households, households with young children, old people, disabled people, low quality housing etc. based on the dataset, to map the potential vulnerability factors of domestic energy deprivation. Methodologically, I ran logistic regressions to further detect the influences of vulnerability factors on energy poverty. The results indicate that households without a car, with old people, and without pension have the strongest influence on likelihood of experiencing energy poverty, especially, the additional inequalities in social security would further exacerbate the domestic energy consumption difficulties faced by households with old people and households without pensions. This chapter's work contributes by evaluating the importance of various sociodemographic characteristics on understanding energy poverty in China at household level, adding new insights to energy vulnerability research in the nation. I focus on the five potential vulnerability

domains of housing and transport, education and employment, health, household structure, and social security, providing a comprehensive exploration of the links between household sociodemographic characteristics and energy poverty. This study is the first of its kind relating to the Chinese case.

5.2 Selected data and methods

Figure 5.1 shows the basic methods used in this chapter, I quantify the energy poverty rate by using the adapted Boardman "10% indicator" among Chinese provinces covering urban and rural areas based on comprehensive household survey data (CFPS) in 2018. The reason for choosing "10% indictor" in this chapter rather than "LIHC indicator" is that the spatial sensitivity can be well reflected under "10% indictor" (detailed comparison can be found in section 4.3.5 & 7.3.2). The reason for choosing this most recent survey (2018) to do further driver investigation rather than previous waves as showed in chapter 4, is because I found the spatial variation is more substantial than temporal changes of Chinese energy poverty rate, which may show more meaningful policy implications through that chapter. Then, I use socio-demographic information to identify potentially vulnerable groups, evidencing how the situation of different sociodemographic groups differs between EP households and non-EP households in the provinces studied. Through a logistic regression analysis, I estimate the relationship between likelihood of falling into energy poverty and various sociodemographic characteristics under five domains of potential vulnerability. I concluded by highlighting the need to take into account specific vulnerable groups when planning residential related energy policy and advocate targeted assistance to enhance energy poverty alleviation in this regard.

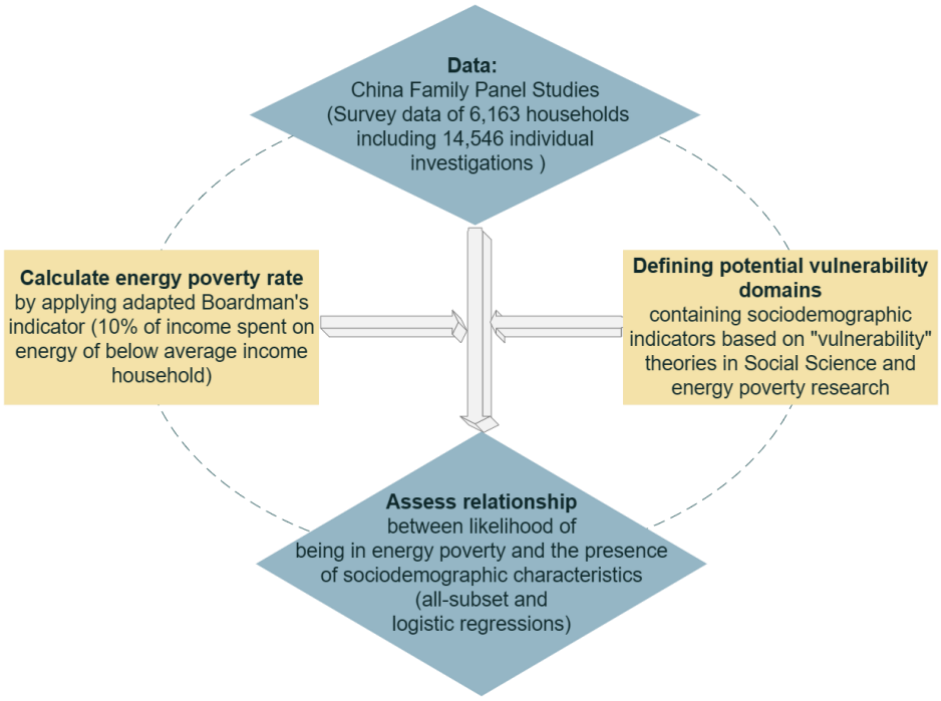

Figure 5. 1. Simple diagram of methods used in this chapter

5.2.1 Energy expenditure, income, and energy poverty calculation

Table 5.1 summarizes the data used in this chapter. Valid survey returns (6,163 households including 14,546 individual surveys) are sufficient for the analysis I conduct. I used household's expenditure data on electricity, fuels, and heating in 2018 to measure the energy poverty rate at household level like was done in chapter 4. I also calculated annual energy expenditures per capita and disposable income of each household for consistency.

Table 5. 1. Basic information of household samples from five provinces in 2018 used in this study

Sample area	**Guangdong**	**Gansu**	**Henan**	**Liaoning**	**Shanghai**
Total	1,462	1,599	1,511	1,269	851
Urban	874	496	676	699	755
Rural	539	1,089	819	585	80
Missing	49	14	16	12	16

In the calculation of energy poverty rate in this chapter, I adapted the "10% energy poverty indicator" by defining households that earn below the median level and spend over 10% on domestic energy as energy poor based on the real data in CFPS of 2018 (thereby excluding wealthier households who are "overconsuming"). I chose not to use the divided income as was done in the measurement of the "10% indicator" in chapter 4 because I wanted to place more emphasis on the investigation of vulnerability factors for energy poverty. As a result, the median income threshold had a significant representativeness when I conducted this investigation. Wang et al. (Wang et al., 2015) point out that the commercial energy price is tightly controlled by the Chinese government through energy subsidies, which maintains commercial energy price relatively low compared with marked dominated of commercial energy price in some countries, such as UK. Thus, the measurement of energy poverty in this chapter is still based on the real costs in China. This means that I am likely to lose some of the 'under consumers' who are self-disconnecting: so, called 'hidden energy poverty'[14]. This is the best available indicator according to the dataset I am working with here (comparative analysis of metric can been found in section 4.3.5), although I recognise that it does not necessarily depict the overall picture

14 Hidden energy poverty is recognized by Yip et al. (2020) and Chard and Walker (2016) as households adopt under-consumption of energy as survival mechanism, that is, households interact with the built environment and rationing the needs of family members to consume less domestic energy.

of energy poverty in China. Thus, the adapted "10% indicator" should satisfy the two conditions as follows (Lin and Wang, 2020):

$$condition\ 1:\ \frac{Domestic\ fuel\ costs/Family\ size}{Equivalized\ income\ (before\ housing\ costs)} \geq 0.1 \quad (5.1)$$

$$condition\ 2: Equivalized\ income < Median\ income \quad (5.2)$$

Where the Equivalized income is calculated as:

$$equivalized\ income = Disposable\ Income/Family\ size \quad (5.3)$$

5.2.2 Vulnerability domains and sociodemographic indicators

Vulnerabilities in households can result in the household falling into energy poverty, preventing them from accessing and affording the level of energy services needed for a decent life (Bouzarovski et al., 2012). Chambers's definition of vulnerability (1989):

> *Vulnerability thus has two sides: an external side of risks, shocks, and stress to which an individual or household is subject; and an internal side which is defencelessness, meaning a lack of means to cope without damaging loss. (Chambers, 1989: 33)*

Emmel and Hughes' (Emmel and Hughes, 2010) developed this idea, showing that vulnerability involves relations between individuals and households and the institutions and services that address their basic needs. They conceptualize a longitudinal 'social space of vulnerability' with coordinates which relate to: (i) material shortages in households, characterized by 'making do' with limited resources for basic everyday needs; (ii) a lack of capacity to address needs in the present and plan for the future; and (iii) an uncertain reliance on welfare services acting to address crises when they happen.

Here, I categorize vulnerability domains and relevant sociodemographic characteristics to energy poverty by developing the above ideas in the dataset. I

identified five vulnerability domains: housing and transport, household structure, health, education and employment, and social security. Ongoing academic research on energy poverty has already defined some of these in contextualizing work (Robinson et al., 2018a, Ivanova and Middlemiss, 2021, White and Sintov, 2019, Middlemiss and Simcock, 2019, Middlemiss, 2022a). These domains allow us to identify overlooked aspects in the Chinese context but are also constrained by the availability of the data in the CFPS. 20 sociodemographic characteristics are considered in this study which can be found in Table 5.2 below. The choice of these 20 sociodemographic variables is based on previous research on vulnerability, energy poverty (Bouzarovski et al., 2012), ongoing research on this topic (Robinson et al., 2018a, Ivanova and Middlemiss, 2021, White and Sintov, 2019, Middlemiss and Simcock, 2019, Middlemiss, 2022a), and the availability of data from CFPS.

Table 5. 2. Vulnerability domains and related sociodemographic categories to energy poverty identified in this chapter

Vulnerability domain	**Sociodemographic variable**	**Indicator**
Housing and transport	Without car	Do you have cars?
	Lack clean cooking fuels	What type is your cooking fuel (Firewood, coal)?
	Without house rights	Are you house owners (Employer real estate, public rental house, relatives and friends' houses)?
	Low house quality	What type is your house? (Bungalow, single-story house)
Education and employment	Poor own status	What extent is your satisfaction with your own status? (Low score)
	Poor life	What extent is your satisfaction with your life? (Low score)
	Poor job and income	What extent is your satisfaction with your job and income? (Low score)
	Unemployment	What is your current employment status?
	Low education	What is your latest and highest education qualifications? (Age>=18 & no college/no school/illiteracy/half-illiteracy)
Health	Disability	Can you do outdoor activities independently? (50>Age>18 & can not)[1]
		Can you eat independently? (50>Age>18 & can not)
		Can you do kitchen activities independently? (50>Age>18 & can not)
		Can you take public transportation independently? (50>Age>18 & can not)
		Can you go shopping independently? (50>Age>18 & cannot)
		Can you do cleaning activity independently? (50>Age>18 & can not)
		Can you do laundry independently? (50>Age>18 & cannot)
		Can your hands reach the base of your neck? (50>Age>18 & can not)
		Can your hands reach your lower back? (50>Age>18 & cannot)
		Can you get up from your chair right away after sitting for a while? (50>Age>18 & can not)
		Can you pick up the book on the floor? (50>Age>18 & can not)
	Poor physical health	What is your physical health? (Unhealthy)
	Poor mental health	What is your mental health? (Most/often feel depressed)
Household structure	Mainly female	What is your gender? (Female>1/2 family size)
	Large family size	How many people in your family? (Family size>=5)
	Old people	What is your age? (Age>=60)[2]
	Children	What is your age? (Age<=15)[3]
	Single parent	What is your latest marriage status? (Widowed/divorced)
Social security	Rural Hukou[4]	What is your Hukou status? (Rural or urban)
	Without gov subsidies	Do you receive government subsidies?[5] (No)
	Without pension	Do you receive pensions? (Age>=55 & no pension)

Note: **50>Age>18**[1]: we identified disabled people by two criteria: age range from 18 (legal age of adulthood in China) to 50 (the lowest threshold for retirement in China) and

unable to do the activities in daily life. **Age>=60**[2]: The statutory retirement age in China is 60 years old for male employees, 55 years old for female cadres, and 50 years old for female workers, thus, we defined people who are over 60 as old people here. **Age<=15**[3]: China's Education Law stipulates nine-year compulsory education for school-age children and adolescents and exemption of related tuition fees and miscellaneous fees. This is the average age line for completing nine-year compulsory education. **Hukou**[4]: 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. **Government subsidies**[5]: Due to lack of specificity in original dataset, the subsidies here refer to any possible subsidies family receiving from the government, including subsidies of low-income, military, disability, coal-to-electricity, etc..

5.2.3 The statistical model

In this chapter, I conduct a logistic regression analysis to determine the association between households' sociodemographic traits and their likelihood of experiencing energy poverty, and I also add new spatial insights by examining the full sample, both urban and rural, as well as each individual province separately. In the regression model, the dependent variable I include is whether a home is energy poor. Other sociodemographic variables under vulnerability domains are set as independent variables. This is the first such analysis on Chinese data. The unit of analysis is the household aggregating from 14,546 individual surveys, where we estimate the effects of various vulnerability factors on energy poverty at household level.

$$\begin{aligned} Logit(HH_{EP}) &= \ln(HH_{EP}/(1-HH_{EP})) \\ &= \beta_0 + \beta_1 \cdot low\ house\ quality + \beta_2 \cdot without\ car + \beta_3 \\ &\cdot lack\ clean\ cooking\ fuels + \beta_4 \cdot mainly\ female + \beta_5 \cdot old\ people \\ &+ \beta_6 \cdot poor\ physical\ health + \beta_7 \cdot poor\ mental\ health \\ &+ \beta_8(low\ education_i) + \beta_9 \cdot without\ pension + \beta_{10} \\ &\cdot rural\ Hukou \end{aligned} \tag{5.4}$$

HH represents household unit; EP stands for whether a household is energy poor; Low house quality, without car, lack clean cooking fuels etc. represent

significant sociodemographic variables in our model after significance tests of regressions. found significant differences between EP households and non-EP households among these 10 variables in the total regression model after sub-regression tests. For regional models such as urban, rural, and each single province, the significances are at different levels.

5.3 Results

5.3.1 Sociodemographic distribution across space

Figure 5.2 shows that sociodemographic characteristics that could potentially result in energy vulnerability are unevenly distributed among regions. Northern (Gansu and Liaoning) and central provinces (Henan) possess a greater proportion of the sociodemographic characteristics than eastern (Shanghai) and southern provinces (Guangdong). Table 5.3 categorizes the most different sociodemographic characteristics in each province in 2018. For example, households with old people, children, large family sizes, with rural Hukou, and with people of low education are more common in Henan (central China) and Gansu (western China) provinces in the sample. People in households with a disability represent 32.1% and 21.1% in Gansu and Henan. Central and western provinces have a higher proportion of old people and children in the household than eastern and southern provinces in the dataset. This is aligned with the result from The Sixth National Census [15]. Henan and Gansu have an average of 3.47 people in a household which is higher than the other three provinces we analyse. 6.8% old people in China (those over 60 years old) live in Henan. This distribution is somewhat influenced by the natural environmental conditions

15 The sixth National census is the sixth survey of the national population information in China. The State Council has decided to carry out the sixth national census in 2010. The standard time of the census is midnight on November 1. The census mainly surveys the basic situation of population and households including gender, age, education level. etc.

and historical factors that Henan province has the characteristics of a vast rural area, a large rural population, and a single industrial structure which resulted in the province including 38 'national-level poverty counties' and 15 'provincial-level poverty counties' (Wu et al., 2022). As a result, levels of cultural and economic development are tied to the spatial distribution of a particular household structure.

For other provinces, Guangdong and Gansu have the highest proportions of households with members who have poor physical and mental health, respectively. Gansu has the highest proportion of households with low housing quality. Liaoning has the highest proportion of households not receiving government subsidies or without pension. Aside from households without government subsidies and with old people, Shanghai presents the lowest proportion of other sociodemographic characteristics associated with vulnerability in these five provinces as the most developed province in our analysis. Thus, we can see, for vulnerability domain of housing and transport, Liaoning and Gansu have larger proportions of households; Liaoning also has a larger proportion of households vulnerable under the social security domain; Henan and Gansu have the highest proportion of households vulnerable under the household structure domain; however, variables in the health domain distribute across the 5 provinces. These factors could all influence how differently households use energy.

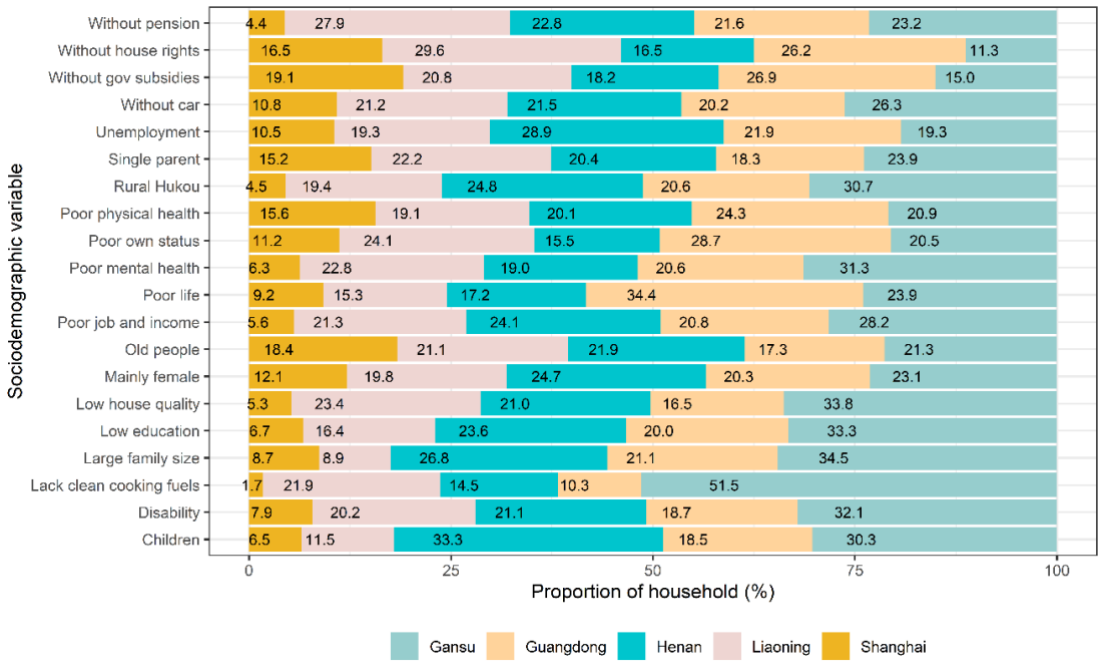

Figure 5. 2. Distribution of sociodemographic attributes associated with vulnerability among Chinese five provinces in 2018

Table 5. 3. Most common sociodemographic characteristics associated with vulnerability of five provinces in 2018

Province	More likely to include	Less likely to include
Gansu	Lack clean cooking fuels; large family size; low house quality	Without house rights; without government subsidies; unemployment
Henan	Children; unemployment; large family size	Lack clean cooking fuels; poor own status; without house rights;
Liaoning	Without house rights; without pension; poor own status	Large family size; Children; poor life;
Guangdong	Poor life; poor own status; without government subsidies	Lack clean cooking fuels; low house quality; single parent
Shanghai	Without government subsidies; old people; without house rights	Lack clean cooking fuels; without pension; rural Hukou

5.3.2 Sociodemographic variations between EP and non-EP households

I found that households living at risk of energy poverty have a higher rate of most of the sociodemographic characteristics under the vulnerability domains in our dataset, especially households with low house quality, without pension, poor mental/physical health, and that lack clean cooking fuels (see Figure 5.3). Firstly, based on income and energy expenditure data and according to Equation (5.1)-(5.3) (see section 5.2.1), I can calculate the share of households living at risk of energy poverty (defined as households below the median income, spending more than 10% of household income on energy costs by using the adapted Boardman approach, see section 5.2.1) is 16.4% in total. Urban areas show a more severe energy poverty situation (22.8%) than rural (10.7%) among these five provinces of 2018. This finding is intriguing because, with a few notable exceptions, earlier research tended to ignore China's urban energy poverty (Robinson et al., 2018c, Lu et al., 2022, Dong et al., 2021, Lin and Wang, 2020). It is also useful to disaggregate the most important vulnerability factors that impact urban and rural energy poverty differently.

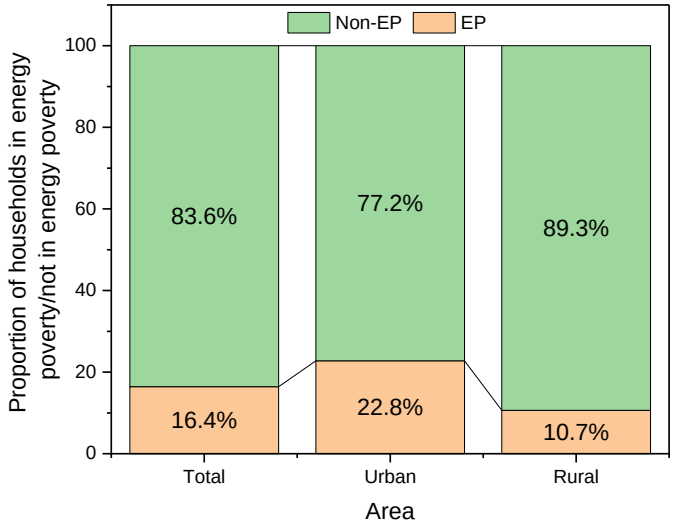

Figure 5. 3. Proportion of households in energy poverty in 2018

Figure 5.4 shows differences of five potential vulnerability domains between energy poor and non-energy poor households. In Figure 5.4, EP households have particularly high proportions of the characteristics in the housing and transport, social security, and seem to have a stronger relationship with energy poverty than education and employment, heath, and household structure. Both energy poor and non-energy poor households have a high proportion of without car, low house quality, and rural Hukou in the surveys though these factors are higher among energy poor households. Additionally, energy poor households are also more likely to lack clean cooking fuels, do not have pension, have old people and have low education level. In 2018, China's Ministry of Public Security announced that the rate of car ownership in China has reached 29.1% [16] which is roughly consistent with the data in the samples (31.9% of car ownership in non-energy poor household, and 13.8% of car ownership in energy poor households). 74.8% of energy poor households live in low quality houses where the building type is

16 The Ministry of Public Security of the People's Republic of China announced there were 409 million vehicle drivers in China of 2018 https://www.mps.gov.cn/, authors calculated the rate of car ownership based on this figure and national total population (1.405 billion people in China of 2018).

bungalow or single-/multi-storey house (Figure 5.5) which are insufficiently equipped for very cold and very hot weather (Robinson et al., 2018c). The majority of the sociodemographic characteristics we selected are higher among energy poor households, but some: household with unemployment, large family size, disability, without house rights and government subsidies are more common among non-energy poor households. 59.8% of non-energy poor households have not received government subsidies versus 40.5% of energy poor households. Due to ongoing subsidies for residential energy provision, and in contrast to research in neoliberal countries in the Global North, the price of energy is not a key vulnerability factor with regards to energy poverty in China (Robinson et al., 2018c, Xie et al., 2022), even though 59.5% of the energy poor households got government subsidies, there is still energy poverty among them. Identifying the vulnerability factors which impact Chinese households suffering from energy poverty is vital to formulate related policies in an efficient way and to add novel insights to the body of research already in existence.

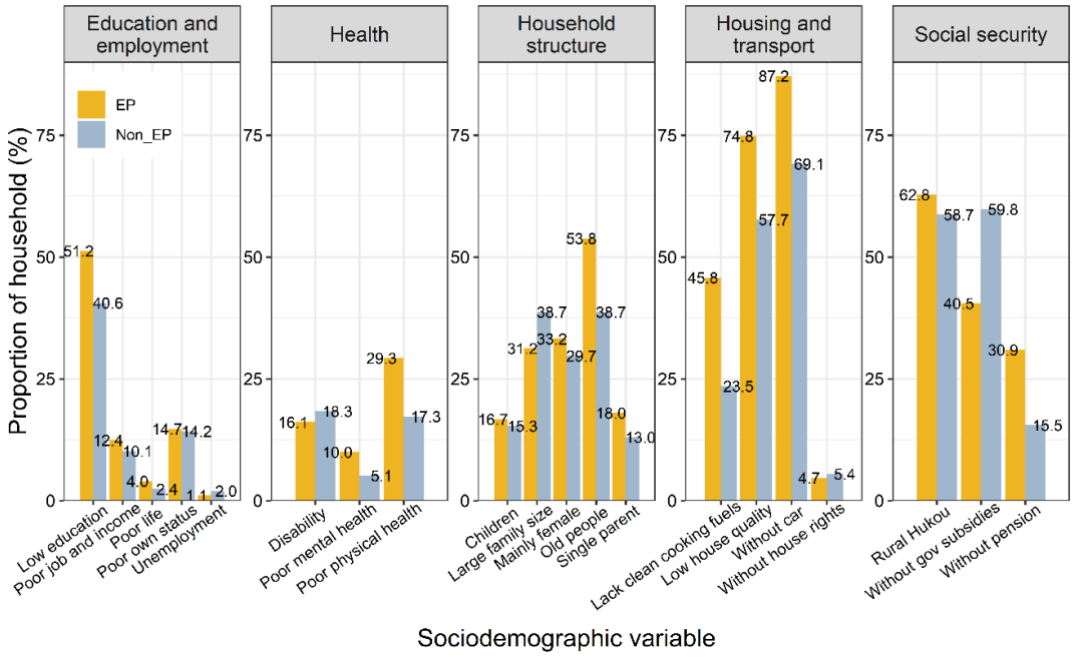

Figure 5. 4. Proportion of energy poor (EP) and non-energy poor (non-EP) households with a particular sociodemographic characteristic under vulnerability domains in Chinese five provinces of 2018

Figure 5. 5. Examples of properties in Gansu categorized as bungalow/single-storey (the left) and multi-storey house (the right)
Source: Author

5.3.3 Significance test of variables

I ran the logistic regression according to Equation (5.4) (see section 5.2.3) and visualized the regression results for the five by plotting a Forest Plot (see Figure 5.6). In the logistic regression model of the full sample, I take into account the 10 sociodemographic variables that passed the significance test. Variables right of the dashed red line in Figure 5.6 to illustrate sociodemographic variables associated with an increased likelihood of experiencing energy poverty. These ten sociodemographic traits have been linked to an increased risk of energy poverty, but the strength of the association varies. For example, households without a car, with old people, with rural-Hukou, and without pension have the strongest influence on likelihood of experiencing energy poverty. Low house quality and mainly female households have weaker effect on the likelihood of energy poverty compared to other sociodemographic characteristics. We can also find the accuracy of the estimation through the length/range of Confidence Interval on the plot of each variable. The variables lack clean cooking fuels, low education, mainly female have the most accurate estimation of the variables in the model since they have a narrower Confidence Interval than others. These statistically significant predictors of increased likelihood of energy poverty can be regarded as vulnerability factors to household energy poverty, I also tested the

impacts of these factors on energy poverty in rural, urban areas, and each single province (see Figure 5.7).

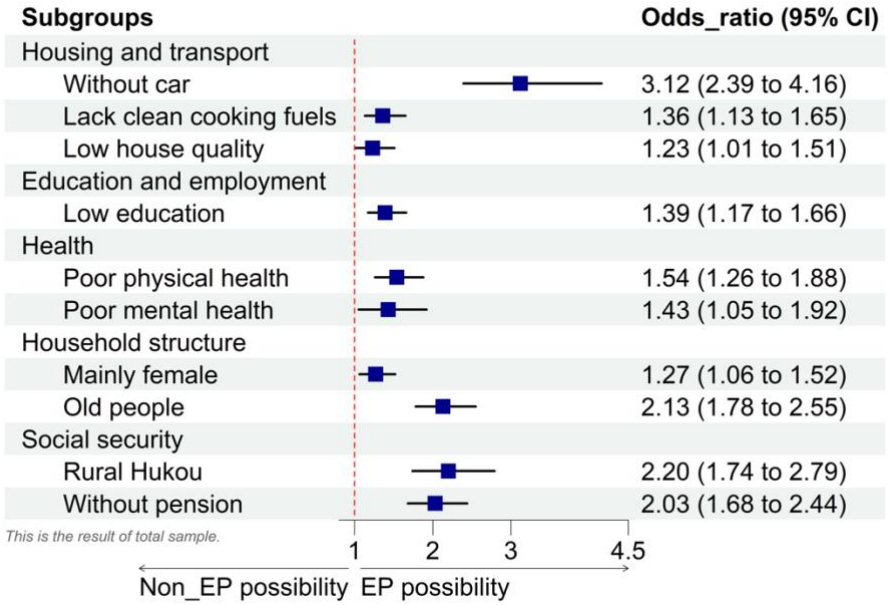

Figure 5. 6. Forest plot of logistic regression result for the total sample of five Chinese provinces in 2018

5.3.4 Logistic regressions

Figure 5.7 depicts the coefficients plot of the sociodemographic influences on energy poverty likelihood for different sample areas of China in 2018 which we can find carless, old people, without pension households are more vulnerable to energy poverty than other sociodemographic characteristics in all samples. Detailed logistic regression results for the total sample, rural, urban, and each single province are included in Table 5.4. This is in line with the distribution of five vulnerability domains to energy poverty between energy poor and non-energy poor households (see Figure 5.4) that shows a larger gap of household without car, with old people, without pension between energy poor and non-energy poor households than other sociodemographic characteristics. For the total sample, household without car (coefficient 1.139) is the strongest predictors.

Old people are vulnerable to energy poverty as many have fixed and often relatively low incomes based on superannuation or government pensions. Additional financial pressure can arise if old people have underlying health conditions that increase energy requirements (Büchs et al., 2018). In rural areas, households with old people have a greater effect on EP, with a higher coefficient of 0.891 than urban areas with a coefficient of 0.608. Though the Chinese government have implemented two types of endowment insurances [17] under the National Basic Pension Insurance System to realize social welfare and equity, there is a huge gap between the urban and rural endowment system regarding coverage and level. Yang and Yang indicate (Yang and Yang, 2022) the pensions of civil servants and intellectuals are almost 100 times higher than those of farmers: civil servants and intellectuals have a high retirement pension of up to 10,000 yuan per month, while farmers' pensions can be as low as 100 yuan and there are even some farmers who have no pension. These additional inequalities in social security would further exacerbate the domestic energy consumption difficulties faced by households with old people and definitely households without pensions. In addition, A lack of clean cooking fuels, poor physical health and rural-Hukou are other significant factors affecting likelihood of a household falling into energy poverty in both urban and rural areas. These findings give us novel understandings about urban and rural energy poverty.

Aside from the urban-rural division, different effects of vulnerability factors to energy poverty also exist among provinces. Henan and Gansu have more significant vulnerability factors than the other three provinces which is consistent with their spatial distribution of the majority of the sociodemographic characteristics as I analysed in section 5.3.1. A lack of clean cooking fuels is an important factor influencing the energy poverty situation in Henan and Gansu

17 Till 2021, National Basic Pension Insurance System presents 65.76% in China's overall pension insurance system which includes two types: The Worker's Basis Endowment Insurance since 1991 and Social Endowment Insurance for Urban and Rural residents since 2009.

with the coefficient of 0.417 and 0.257 respectively. This result partly aligns with the study from Hou et al. (Hou et al., 2017) that found that in 2011 rural households from Gansu, Liaoning, and Henan have a larger proportion of solid fuel use for cooking, (especially biomass and coal) than other provinces. Hou et al. indicate that the determining factors of the distance to the most commonly used farmer's market, education background, coal price and female labour participation to the high proportion of solid fuels use for cooking. While clean energy policy at national and local levels have been implemented since 2015, the use of solid fuel for cooking is still a limitation of energy poverty alleviation in western and central provinces in our sample. In Guangdong, there is a high proportion of mainly female household (20.3% see Figure 5.3), Mainly female household is a stronger predictor of energy poverty in Guangdong than elsewhere. Low education factor is more important in Gansu and Henan rather than other provinces. Shanghai has the least significant vulnerability factors to energy poverty as the most affluent region, however, the vulnerability factor of without pension is most significant here compared to other areas. In general, the social security vulnerability domain has significant effects on energy poverty among all these five provinces. Acknowledgement of these complex social-spatial vulnerabilities calls into question on how energy poverty can be addressed more effectively among Chinese households?

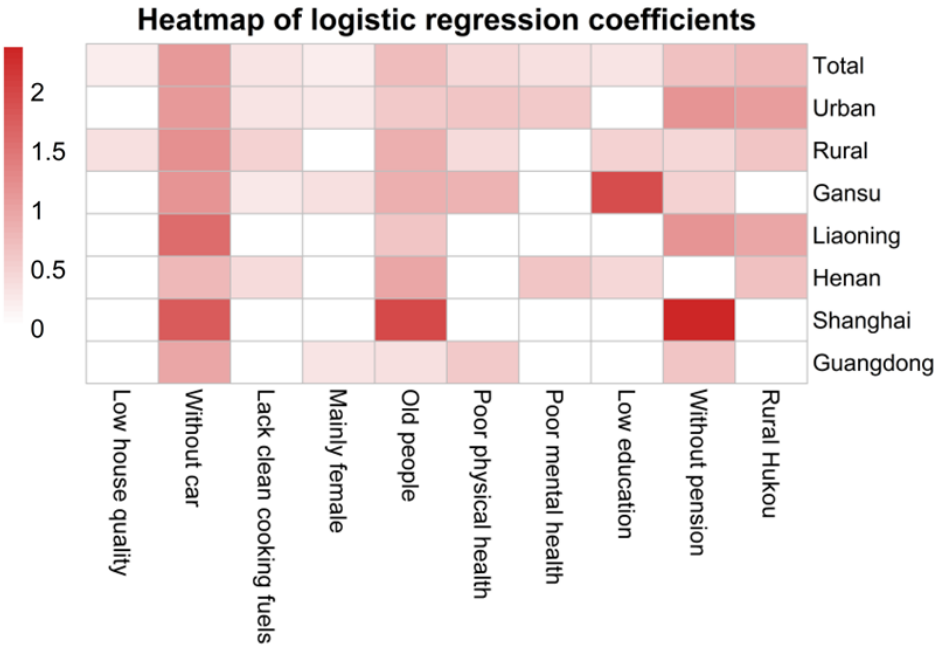

Figure 5. 7. Logistic regression coefficients visualization of the sociodemographic influences on energy poverty likelihood for different sample areas of China in 2018

Note: The significant positive influences of sociodemographic characteristics which significantly increase the likelihood of energy poverty are shaded red, the intensity of the colour indicates the magnitude of the coefficient, and the degree of influence. Sociodemographic characteristics with a negative or non-significant effect on the likelihood of energy poverty are white. Thus, the most obvious vulnerability factor of energy poverty across spaces can be found in this plot.

Table 5. 4. Logistic regression estimates across sample areas

Vulnerabilities	Variables	Total	Urban	Rural	Gansu	Liaoning	Henan	Shanghai	Guangdong
Housing and transport	Low house quality	0.206**	0.23	0.345**	0.244	0.054	0.154	0.591	-0.226
	Without car	1.139***	1.107***	1.205***	1.167***	1.575***	0.798***	1.776*	0.973***
	Lack clean cooking fuels	0.311***	0.312*	0.482***	0.257*	0.188	0.417**	-0.111	-0.056
Household structure	Mainly female	0.237**	0.243*	0.172	0.343*	0.275	-0.06	0.236	0.330*
	Old people	0.755***	0.608***	0.891***	0.872***	0.657***	0.968***	1.961**	0.353*
Health	Poor physical health	0.434***	0.620***	0.387***	0.827***	0.285	0.301	-1.189	0.610***
	Poor mental health	0.357**	0.604***	0.22	0.302	0.516	0.628*	1.01	-0.06
Education and employment	Low education	0.331***	0.169	0.480***	1.920***	-0.007	0.450**	-0.998	-0.036
Social security	Without pension	0.707***	1.188***	0.442***	0.518**	1.159***	0.284	2.378***	0.632***
	Rural Hukou	0.788***	1.066***	0.662***	0.317	0.982***	0.707***	0.585	0.331
	Constant	-4.794***	-4.797***	-5.135***	-5.725***	-5.169***	-3.924***	-7.284***	-3.526***
	Observations	6,163	3,229	2,934	1,518	1,250	1,407	781	1,207
	Log Likelihood	-1,838.02	-800.97	-1,011.09	-484.76	-374.22	-426.18	-55.97	-404.345
	Akaike Inf. Crit.	3,698.03	1,623.94	2,044.19	991.527	770.439	874.353	133.941	830.691

Note: *p<0.05, **p<0.01, ***p<0.001

5.4 Conclusions and discussion

5.4.1 The vulnerability factors of energy poverty in China

This chapter has begun to address an important gap in energy poverty and energy vulnerability research in China: the role that sociodemographic characteristics play in shaping and potentially ameliorating situations of energy poverty. Drawing on the CFPS survey data of 6,163 households in five Chinese provinces, I have demonstrated how different sociodemographic characteristics affect vulnerability to energy poverty across different area types in China. Methodologically, I classified vulnerable domains to energy poverty by using 20 sociodemographic variables based on a vulnerability framework; identifying energy poverty rates by using the adapted Boardman's "10% energy poverty

indicator" and domestic energy expenditure and income data; and assessing the relationship between likelihood of being in energy poverty and households with sociodemographic characteristics using logistic regressions. I found various sociodemographic features are disproportionately distributed across space and between energy poor and non-energy poor households. Spatially, Henan in central China, Gansu in western China have a larger proportion household with sociodemographic characteristics associated with vulnerability domains than other provinces, which is aligned to their lower levels of economic and social development in China. The sociodemographic characteristics in the vulnerability domains are more common amongst households experiencing energy poverty, illustrated through visualisation of the data and logistic regression. This pattern of vulnerability factors increasing likelihood of energy poverty is observed at household level, when comparing rural and urban areas, as well as examining 5 provinces.

5.4.2 Policy implications

The findings in this chapter point to a number of policy, practical and research implications which will allow a more nuanced understanding of who experiences energy poverty in what places as a result of which vulnerability factors. Double Energy Vulnerability (DEV) refers to the likelihood of experiencing negative impacts on wellbeing owing to the intersection of both Domestic Energy Poverty (DEP) and Transport Energy Poverty (TEP) has been found to be mostly a rural phenomenon in Europe by scholars (Robinson and Mattioli, 2020, Mattioli et al., 2019, Simcock et al., 2021, Martiskainen et al., 2020), which uncovers households will experience trade-offs between whether to spend money on higher energy bills to sufficiently heat the home, or whether to fill the car with petrol, for example (Robinson and Mattioli, 2020). The 'heat-or-eat' phenomenon is comparable to this, though it has received less attention in the

Chinese situation thus far. Our findings show carless households are found to be significantly vulnerable to energy poverty in China, while 31.9% of car ownership is in non-energy poor households, and only 13.8% of car ownership is in energy poor household in our sample (section 5.3.2). This implies an indicative role of households without car in identifying who experiencing energy poverty in China. It is important to note that that this is useful as an indicator, car ownership is indicative of relevant affluence. It would be a grave error to assume increased car ownership would cause a reduction in energy poverty. Energy poverty will not be solved by providing cars for such households, not least due to the potentially negative impacts on climate change commitments that this would represent.

There have been major achievements in energy poverty alleviation such as provision of electricity to all areas, and the pilot programme for clean heating implemented in some northern rural areas in 2017, which aims to replace coal with electricity and natural gas for heating in cold seasons. The primary findings in this work provide a more comprehensive analysis of the sociodemographic-energy poverty nexus regarding a household level distribution. Thus, "one policy for all" is likely to hurt vulnerable households in different places when helping to achieve sustainable goals. The research in this chapter contributes to developing more nuanced insights to energy poverty alleviation that calls the attention of policy makers to the most vulnerable households to energy poverty, especially with old people and those without pensions, and will also help policy makers to consider the distributional effects when designing energy transition and equality policies for a low-carbon and just economy and society.

5.4.3 Limitations and directions for further research

For further research, the study point towards an important new research agenda to develop knowledge of the socio-spatial vulnerability of energy poverty in China, and potentially a broader range of nations which lack political will to

address this problem, or research on energy poverty. This chapter reveals the influence of sociodemographic characteristics on the likelihood of energy poverty. This method is helpful for identifying people who are at risk for energy poverty and for thinking about the effects of various sociodemographic characteristics on vulnerability to household energy use and energy poverty more broadly across places. The relationship between energy and society is co-productive; on the one hand energy availability and consumption establishes the parameters around the types of lifestyles that are possible, while on the other hand cultural and political-economic value systems guide the resources from which, and end-uses toward which, energy is expended. More to the point, physical energy flows and social energy demands are co-productive of socio-spatial relations (Nye, 1999, Shove and Walker, 2010, Calvert, 2015). The development of energy infrastructure has ethical implications which are not experienced evenly across space (Bouzarovski et al., 2012), and among society (Martiskainen et al., 2020, Robinson, 2019, Robinson et al., 2018a). Decisions about which resources to prioritize and where to build new infrastructure (re)produce situations of energy poverty at more localized and household scales (Buzar, 2007). The research in this chapter is applicable not only in China but in other nations which lack this kind of insight. Further research could explore how each sociodemographic characteristic can be categorized in more detail (e.g., people with different number/kind of disabilities, household receiving different kind of government subsidies), and how they are distributed within and across households and spaces, as well as what policy and support they can access. Future studies can concentrate even more on these socio-spatial consequences on energy poverty, particularly in the many local contexts where there might be significant disparities across and within countries.

Acknowledgements

My sincere thanks go to the Editors and anonymous three Reviewers from the journal of *Heliyon*, for their valuable comments and for publishing the work from this chapter. Much thankful to Lucie and Ian's professional contributions to this chapter. The research underpinning this article was supported by China Scholarship Council. The authors are grateful to the Institute of Social Science Survey of Peking University supporting the dataset used in this study.

Chapter 6 Policy responses to energy poverty in China

6.1 Introduction

As analysed in chapters 4 and 5, stark social and spatial disparities of energy vulnerability exist among Chinese households. The existing literature has also recognized some of the spatial disparities and vulnerability of energy poverty in China (Lin and Wang, 2020, Zhang et al., 2019, Wang et al., 2015, Robinson et al., 2018c) as I evidenced in section 2.2. Chapters 4 and 5 have made an original contribution to enhancing the understanding of spatial vulnerability at household level as well as recognizing the social vulnerability factors to energy poverty.

In chapter 4, spatial vulnerability of energy poverty at household level is noted in both rural and urban areas, the latter of which has received less attention in current literature. **1)** The calculation of "10% indicator" of energy poverty (see section 4.3.3) shows that urban energy poverty rates in Gansu, Liaoning, Henan, Shanghai, Guangdong are 11.69%, 13.25%, 9.35%, 1.73%, and 9.98% respectively in 1st income quintile in 2018. The difference between rural and urban areas is larger in the 1st quintile than the 2nd and 3rd quintile groups. **2)** The calculation of "LIHC indicator" of energy poverty (see section 4.3.4) shows that urban energy poverty rates in Gansu, Liaoning, Henan, Shanghai, Guangdong are 9.69%, 9.53%, 10.28%, 7.10%, and 10.60% respectively in 2018. Despite the fact that the rural-urban income difference described in section 4.3.1 is widening, the gap between rural and urban energy poverty ratios shrank during the study period, particularly in the higher income groups under the "10% indicators" metric. Energy poverty in urban regions is comparable to that in rural areas for those in the lowest income bracket.

Moreover, among the case-study provinces in this thesis, spatial vulnerability of energy poverty at the household level is also identified. Gansu is

the province facing the most severe energy poverty among these five provinces which was 13.62% in rural area, 11.69% in urban area respectively of the 1st income quintile in 2018 under "10% indicator" (see section 4.3.3). Under "LIHC indicator" (see section 4.3.4), rural Gansu still showed the most severe energy poverty in 2018 among rural areas in these five provinces. However, urban Guangdong showed the most severe energy poverty among urban areas which was 10.60%, this figure was 9.98% under "10% indicator". Therefore, whether it is a rural-urban divide or a provincial divide, these two types of spatial vulnerability to energy poverty are all determined by the spatial differences in household income and expenditures related to energy (see sections 4.3.1 & 4.3.2), which have not been thoroughly investigated at the household level before. The energy poverty reality in China also emphasize the importance of having distinct energy poverty recognition which echo with the argument that (income) poverty and energy poverty are not precisely the same thing – and that conceptualising energy poverty as at least partially distinct has advantages (Middlemiss, 2019, Hills, 2012).

In chapter 5, social vulnerability of energy poverty at household level is revealed for the first time in the Chinese context. Lack of official recognition, comprehensive investigation, and specialized energy consumption data at household level limit the understanding of energy poverty drivers in China. In this thesis, I was inspired by research on vulnerability (Brown et al., 2017, Adger, 2006, Emmel and Hughes, 2010) and on energy vulnerability (Robinson et al., 2018a, Middlemiss et al., 2019, Nussbaum and Sen, 1993, Bouzarovski et al., 2012, Ivanova and Middlemiss, 2021), and started with the assumption that similarity or novelty on social vulnerability of energy poverty may exist in China. Through a deep mining of the dataset used in the thesis, and using a logistic regression model, I found that 10 household sociodemographic characteristics are associated with increased likelihood of energy poverty in China, including without car, rural-Hukou, lack clean cooking fuels, low house quality, low

education, poor physical/mental health, mainly female, include old people, without pension (see section 5.3.3 & 5.3.4) which has never been revealed before. Additionally, this social vulnerability interacts with spatial vulnerability, which is represented in the disproportionally uneven distribution of these sociodemographic characteristics across space. As a result, the social-spatial vulnerability examined in this thesis has influenced China's energy poverty status. So, the next topic is how policy might address the issue of energy poverty in the Chinese context after examining the measurement and social-spatial determinants of energy poverty in China.

Based on the analysis of policy studies on Chinese energy poverty in section 2.5, I propose that, energy poverty related policies can be found in initiatives to combat poverty in China despite the lack of national acknowledgement of energy poverty as a problem (Xu and Wang, 2017, NEA, 2018, Démurger and Fournier, 2011). China formulated policies to assist low-income households in the past century since the establishment of Communist Party of China (PRC, 2021), focusing on the eradication of "poverty defined in absolute terms". Indeed, absolute poverty was completely eliminated by 2021[18]. This includes energy poverty related aspects: ensuring 100% of households have access to electricity, upgrading of electricity grids and increasing clean energy production.

Thereafter, China has made clear its commitment [19] to continue an ambitious poverty alleviation and social protection agenda that will address "relative poverty" and commits to improving social assistance, and to providing higher quality employment, education offering life-long learning, health guarantees and comprehensive social security. National policy on the ground has begun to embrace a more relative understanding of poverty, especially related to

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

19 The Communique of the Fourth Plenary Session of the 19th Central Committee of the Communist Party of China issued in October 2019. http://news.xmnn.cn/xmnn/2019/10/31/100620623.shtml

local living standards including aspects on employment, education, water, medical and energy services etc. (ILO, 2020, PRC, 2021). It is widely recognised that energy is essential for satisfying people's daily needs, maintaining good health, and living comfortably (Middlemiss, 2022b, Ivanova and Middlemiss, 2021). Research evidence shows more than one in five Chinese households (roughly estimated to 280 million population based on Chinese population in 2022 which was 1.412 billion people) face energy deprivation (Lin and Wang, 2020, Hong et al., 2022, Zhang et al., 2019) which calls for an investigation of presence and absence of energy poverty responses in current and previous related policies accordingly.

In this chapter, I argue that the lack of formal national acknowledgement of energy poverty restricts the ability to fully comprehend the issue and develop appropriate solutions. To this end, I reviewed the most recent national responses to energy poverty in China through two types 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 energy poverty responses deployed by national poverty and energy planning are used as evidence to describe what aspects shape our understanding of which households can receive energy assistance. I examined the performance of energy policies to address the energy poverty problem, analysing whether the aspects of energy accessibility, the diversity of energy needs shaped by social and spatial circumstances such as those shown in this thesis, are included (chapter 4 & 5). I conclude with recommendations to advance national energy poverty alleviation in China, and in particular encourage the development and assessment of an expansive energy poverty definition, reduction objectives, integrated strategies, and comprehensive measurement and evaluation.

6.2 Analytic approach and data

6.2.1 Do policies involve energy poverty related issues?

In this chapter, drawing from the analysis in chapter 4 & 5, some questions have been raised: Is the issue of energy poverty sufficiently recognized in relevant policies? Are the policies set up to distribute benefits and burdens equally or do they further disadvantage energy poor households? Can energy-poor households fully participate in chosen ways to tackle the problem? Are they aware, informed, and involved? Are the policies spatially sensitive? Do they reflect the uneven spatial distribution of the problem? These inquiries served as the basis for three major research questions in this chapter that were then interpreted combining the analyses from chapters 4 & 5:

1) To what extent do these policies affect the distribution of access to energy?
2) Do these policies recognise different energy needs shaped by social circumstances?
3) Do these policies recognise different energy needs shaped by spatial circumstances?

In three subsections, 6.3.1, 6.3.2, and 6.3.3, I read the related policies looking for answers for these three research questions in the light of findings from previous chapters. In practice this meant reading through policy documents looking for evidence of the recognition of the unequal distribution of energy services in China and the acknowledgement of spatial or social differences in access to energy. By focusing on identifiable aspects of policies relates to energy poverty, energy accessibility, social and spatial inequality were described and then analysed within the context of the existing Chinese energy poverty literature, previous chapters, and policies. Polices were scrutinised for evidence

of energy poverty and coping strategies which greatly raised the sensitivity of empirical analysis to the policy matter being investigated.

6.2.2 Research design

To answer the research questions, I conducted a qualitative document analysis. Qualitative research allows in-depth information collection but from fewer cases (Bowen, 2009). Document analysis 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, document studies solely focus on analysing the information contained within them. There is no established energy poverty policy in China, but that there is policy which shapes energy poverty experiences that I look for the deeper understanding within the policy documents. The concept of problematisation, which grounds this analysis, is adequate 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 problem representations that lodge within public policies in order to see what they include and what they leave out (Bacchi, 2014). People experience energy poverty in China, but it isn't measured/there are no policies. This chapter shows how it is somehow governed anyway by the other kinds of polices on poverty/energy. In other words, I was looking for problematisations of energy poverty in non-energy poverty policy. Performing a general document analysis is beneficial for my thesis as it allows me to reflect on the effectiveness of policy responses on energy poverty in China, especially when where lacks official definition and recognition.

Chinese energy strategic planning mainly consists of three aspects: 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 Figure 6.1) since China's Reform and Opening Up in 1978. The Energy Five-Year Plan is formulated in accordance with the National Economic and Social Development Five-Year Plan outline, which is to design the scale and key projects of energy development in the five-year period. In the meantime, provincial level energy development has more specific Five-Year Plans for local energy development on the basis of following National Energy Five-Year Plan. Because of this, I concentrate on the most current national energy policies, the Energy Five-Year Plans from 2000 to 2020, and attempt to define the performance inherent within national energy policies to illustrate the effectiveness in reducing energy poverty.

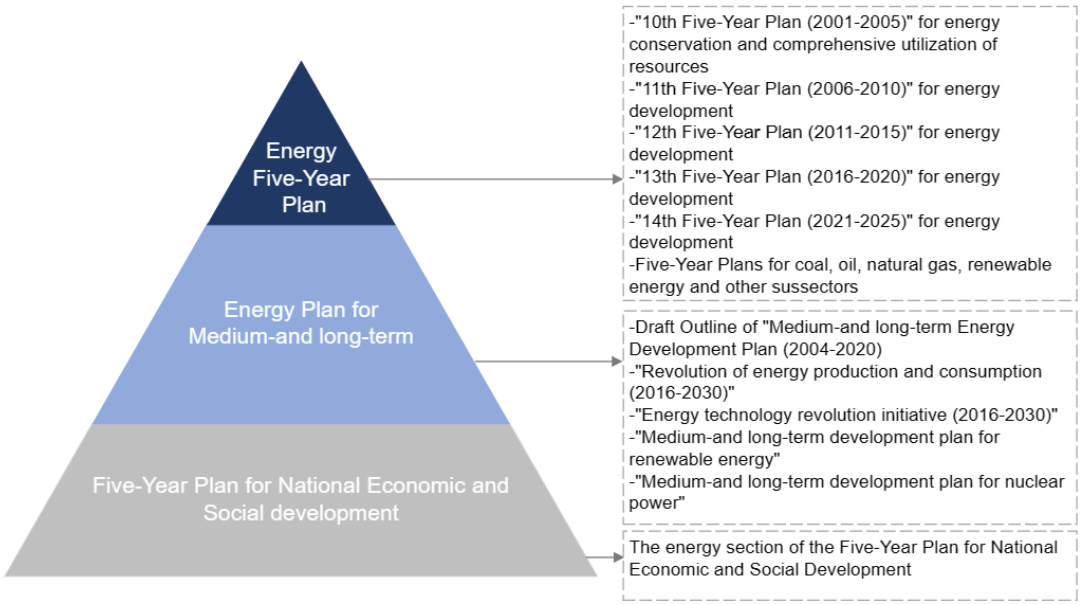

Figure 6. 1. Energy strategic planning system at national level in China

6.3 Results

As demonstrated in section 2.5, China lacks national energy poverty recognition and strategy that encompasses definitions, reduction targets/objectives and periodic evaluation. Figure 6.2 shows the main content of residential energy development plans that are included in national energy plans

from 2000 to 2020 (mainly contains five-year plan of "10th, 11th, 12th, and 13th), I note that "energy poverty" is first mentioned in a national document in 13th Energy Five-Year Plan (2016-2020): "*combine energy development with poverty alleviation, promote energy poverty alleviation projects*", However, this still emphasizes the goal of reducing poverty by improving energy planning and distribution in previously revolutionary areas, 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 (NEA, 2016). As a result, I examined and discussed energy poverty interventions in this section by tying them to research findings from earlier chapters of this study and examining whether they took into account the three factors of accessibility to energy distribution, social inequality, and spatial inequality.

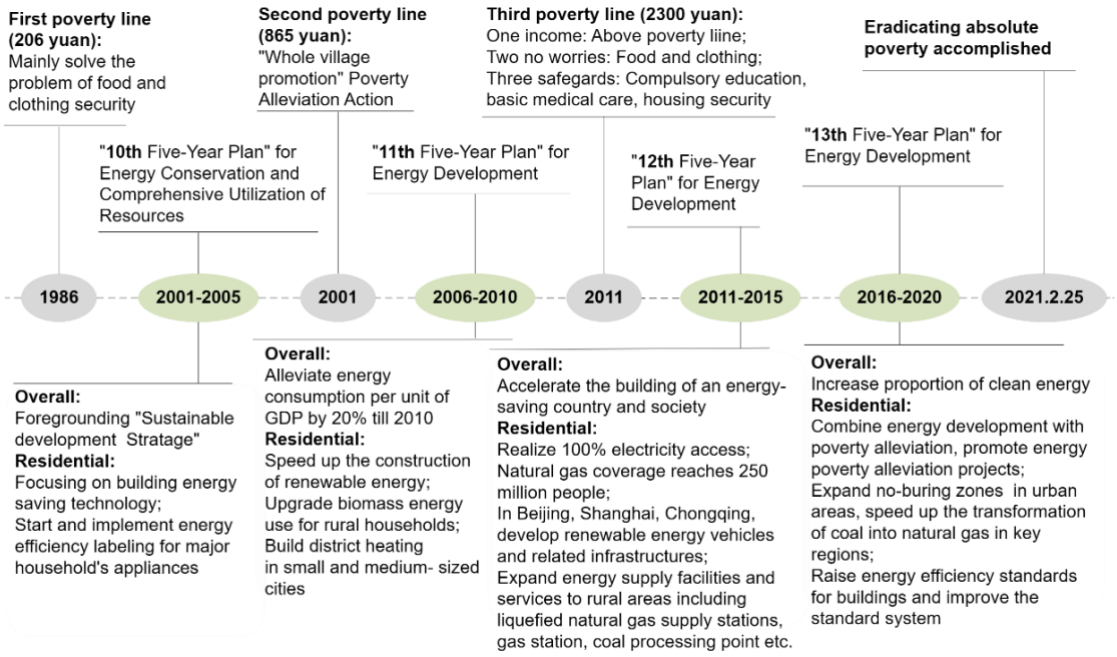

Figure 6. 2. Historical energy planning and poverty line at national level in China

6.3.1 Recognition of energy accessibility

Prior energy strategies emphasized energy accessibility primarily in terms of energy services and price to families.

1) Energy services

Over the past 20 years, China has struggled with a lack of distributional accessibility to energy services; however, improvements in power availability, with a focus on rural areas, have changed this scenario (PRC, 2021). In rural China, energy poverty is primarily characterized by three characteristics. First, the volume of energy consumed is quite modest (Li et al., 2011). Second, the energy consumption is characterised by the lack of availability of clean energy services (e.g., electricity and gas) and reliance on solid fuels. Third, it is extremely expensive 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, 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, electricity access rate in rural China has basically reached 100 percent (PRC, 2021). The Chinese government is still concentrating on ensuring a steady and continuous supply of electricity (NEA, 2016).

However, policy and research, including my own, indicate that there is still energy poverty, which is brought on by Chinese households' lack of access to associated energy services (Robinson et al., 2018c, Lin and Wang, 2020, Tang and Liao, 2014, Wang et al., 2015, Wang et al., 2023). In terms of heating provision, as we mentioned in section 1.1, due to heating policy, only the majority of northern urban areas can access district heating in 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. (2018) 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 or high-quality built environments. Also, as we presented in Figure 1-1, natural gas can replace traditional biomass energy or coal as a clean type of fuel use among households with additional benefit for the reduction of indoor/outdoor air pollution. However, China's natural gas infrastructure is weak making up 8.4% of total energy consumption. The coverage of natural gas in remote towns and rural areas is especially low. Therefore, while evaluating how to further reduce energy poverty in China by improving the accessibility of energy services, building and improving clean energy-related infrastructure is a crucial step that can also work in harmony with goals for reducing greenhouse gas emissions.

2) Energy price (example of electricity price)

Due to the welfare system[20] of Chinese electricity in residential sector, energy price shapes the distribution of energy access. Energy prices (including electricity prices) in China have been generally regulated by the government for a long time, with two main reformations of electricity price in residential sector. The first one 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 is about 0.56 to 0.62 yuan/Kwh from 1978 (the Reform and Opening Up) to 2012, which was below the average price of international level (0.897 yuan/Kwh, calculated based on the data from International Energy Agency in 2012). However, the general electricity price for industrial sector is 0.86-1.80 yuan/Kwh. The majority of countries throughout the world have

20 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.

residential electricity prices that are higher than industrial electricity prices because domestic consumers are at the end of the power infrastructure, where costs are substantially greater than those of industrial and commercial users (see Figure 6.3). But in China, consumers in the industrial and commercial sectors pay less for power supply and, on the contrary, pay more for electricity consumption than those in the residential sector, which leads to cross-subsidies for people's electricity consumption (Xie and Wu, 2022, CEY, 2021). This cross-subsidies increased electricity consumption among residents which is consistent with the findings I found in section 4.3.2 that the average level of household electricity expenditure has been rising gradually, especially in rural areas, during the eight-year study period except for in Shanghai where costs spiked in 2012. This is a comprehensive government initiative to reduce energy poverty that "*ensures people can afford electricity, fosters equity, and supports long-term, robust economic and social growth*". Cross-subsidy in the power sector make the direct environmental taxes from energy-intensive industries returned to the residents and improved the people's livelihood. 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 lower energy prices would stimulate extra energy consumption in some high-income households since distorted energy prices cannot be passed on efficiently to residents and motivate them to take energy-saving measures since distorted prices can not reflect the actual cost of energy supply. This suggests that 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.

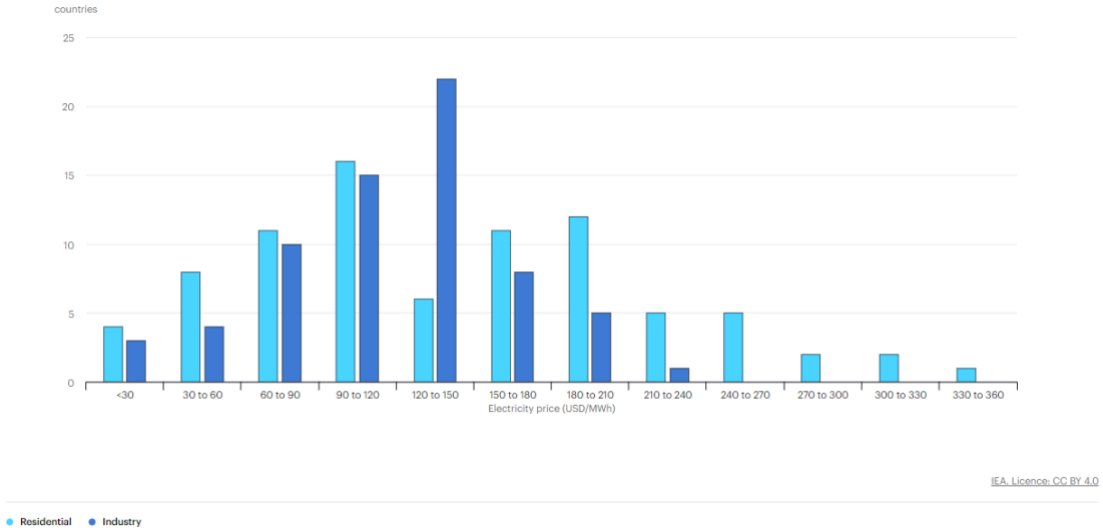

Figure 6. 3. Distribution of residential and industry electricity prices among countries in 2020

Source: IEA.

Given that the cross-subsidy and the electricity consumption inequalities exist in Chinese energy system, the Chinese government introduced the second stage of ladder electricity price schemes nationwide in 2012 (mentioned also in footnote 11 in section 4.3.2), and each province is now free to make adjustments in line with its actual circumstances (see Table 6.1). The ladder electricity price structure minimizes cross-subsidies between the residential and industrial sectors and places a focus on the consideration of inequality issues.

Table 6. 1. The residential ladder electricity price scheme in provinces and municipalities of China

Province	Evaluation period	First tier		Second tier		Third tier	
		Electricity consumption (Kw*h/household/month)	Electricity price (yuan/Kwh)	Electricity consumption (Kw*h/household/month)	Electricity price (yuan/Kwh)	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 municipals till Feb 2023.

It is worthwhile to investigate how to deal with the scenario of rising domestic electricity prices that may negatively impact some households' energy use if more cross-subsidy reductions have been implemented in the future. By linking to the analysis in chapter 4 (see Figure 6.4), I found that: **1)** the existing ladder electricity price scheme roughly corresponds to the rate of energy poverty in the case-study provinces. In Figure 6.4, Gansu, Henan, Liaoning have a higher energy poverty rate than that in Guangdong and Shanghai, additionally, the three tiers of electricity tariffs in these three provinces are often less expensive than those in Shanghai and Guangdong. **2)** rural areas typically have a higher rate of energy poverty than urban areas, but the existing tiered electricity price system does not account for these disparities. For example, in the left side of

Figure 6.4, Gansu has a low electricity price which are 0.51 yuan/Kw*h, 0.56 yuan/Kw*h and 0.81 yuan/Kw*h of three tiers, these prices are applied to both urban and rural areas in Gansu. However, the right side of Figure 6.4 reveals a significant energy poverty disparity between rural and urban areas, with rural Gansu having a rate of energy poverty of 13.6% and urban Gansu having that rate of 11.7% under the "10% energy poverty indicator" of the first income quintile. This indicate there is a potential for further adjusting energy prices considering the variations of energy poverty within each province, notably in urban and rural areas, despite the fact that differentiated energy price initiatives can reduce inter-provincial inequalities in energy poverty to a certain extent.

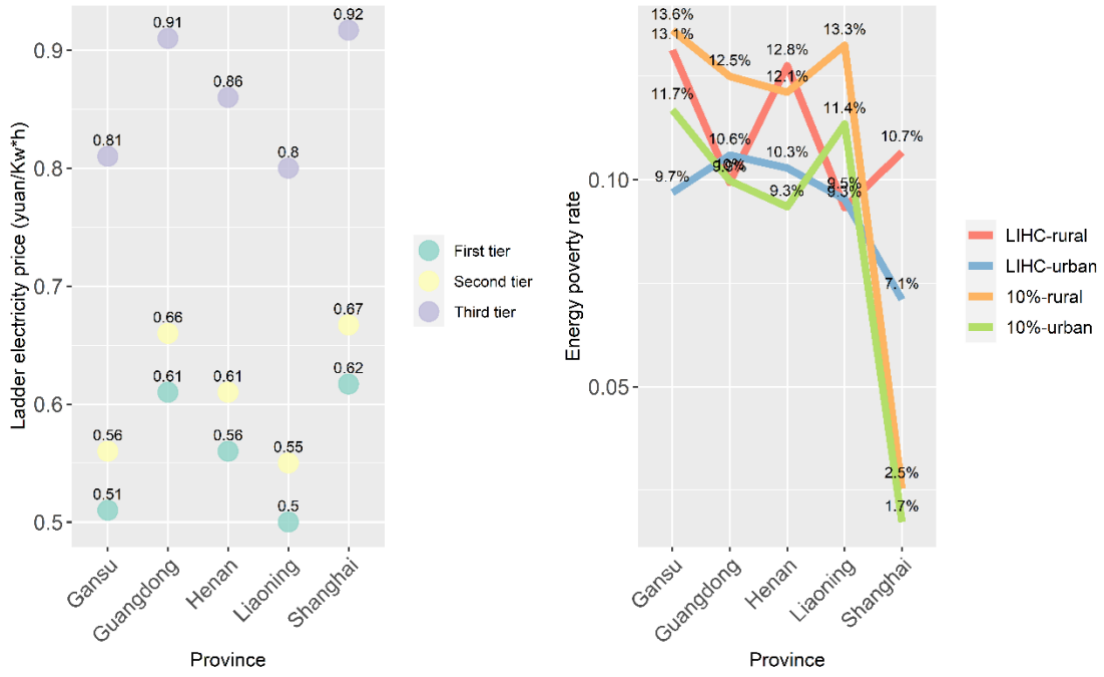

Figure 6. 4. Comparison between Ladder electricity price and energy poverty rate ("10% indicator" and "LIHC indicator") among five provinces in 2018

Note: The energy poverty rate data of "10% indicator" is from 1st quintile income group

6.3.2 Recognition of social inequality

1) (Income) poverty alleviation

As I listed above, China has embedded energy poverty alleviations in poverty interventions and has not recognized energy poverty as a distinct form of (income) poverty, thus policies that address domestic energy deprivation usually target low-income households. The poverty line is the symbol of the absolute poverty level and of the basic deprivations in people's life. Following the establishment of the People's Republic of China in 1949, there are three distinct poverty thresholds, as shown in Figure 6.2 (PRC, 2021). In 1986, China set the first poverty line at 206 yuan per household and the corresponding policy action located in the problem solving of people's food and clothing security. The second poverty line was set at 865 yuan in 2001 with the changed main aim of promoting the poverty alleviation on the basis of reducing Poverty Village[21]. At the time when setting the third poverty line (2,300 yuan) in 2011, the main objectives have a richer content including three aspects called: "one income"- to help households improve income to exceed the poverty line; "two no worries" – further eliminate food and clothing shortages; "three safeguards"- to realize compulsory education[22], basic medical care, housing security. It's worth to indicate that the third national poverty threshold (2,300 yuan) can be regarded as a comparison to the income analysis in this chapter 4 (see Figure 4.1) and most of the households of 1st quintile are below the national poverty line. However, to keep the consistency and authenticity, I only include income thresholds calculated from the survey dataset. By 2021, China had eradicated absolute poverty[23](PRC,

21 Poverty village refers to the village which cannot meet any of the standards of "11 have and 1 below", "11 have" refers to having distinctive industries, housing security, basic medical security, compulsory education security, safe drinking water, access of roads to villages, electricity access, basic public services, television, collective economic income of the village, and good governmental agencies. "1 below" means the poverty rate is less than 3%.

22 The full name of this regime is "Nine year compulsory education system" which is the current education regime in China, meaning that school-age children and teenagers will not be charged tuition and miscellaneous fees for the nine years when they begin to receive education.

23 "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.

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 lowest standards; active policies to assist people out of poverty; and supportive, redistributive fiscal policies (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. Hills led an extensive and independent review of the fuel poverty (UK's terminology of "energy poverty") launched from 2011 and produced a highly influential report which first standing point is examined the "uniqueness" of the fuel poverty problem – that is, the extent to which fuel poverty can be considered distinct from income poverty – and concluded that fuel poverty is noy synonymous with general poverty (Hills, 2012). Other scholars (Middlemiss and Simcock, 2019) also evidenced the benefits of having a separate concept of energy poverty different from poverty is that it helps reveal structural and systemic factors producing inadequate domestic energy services that go beyond low-incomes. They also emphasize avoiding a rather narrow, technocentric description of the issue, for example, focusing on buildings rather than people, while (conveniently) diminishing the impact of more contentious topics like inequality, austerity, and energy prices.

2) Other sociodemographic groups

Chinese policy has already identified and supported specific sociodemographic groups that are particularly vulnerable to energy poverty: households with low incomes, with old people, disabled people, or children (age<16) living in rural areas and heating their homes only through electricity. For low-income households, on the one hand, China, as a developing country, has struggled with absolute poverty for more than 100 years to ensure

fundamental food and clothing. As I said above, many initiatives for the general welfare of the populace focus on the low-income group. On the other hand, programs aimed at low-income groups always take into account homes with old people, or disabled people, or children (age<16), especially with more focus on those living in rural areas. And financial subsidies, which include electricity and housing, are currently the primary method for solving energy inequity among low-income groups. For instance, there are two recognised types of low-income household in China: **1)** Five-guarantee household [24] (also called "wubao" in Chinese) which refers to ensuring that the households with old people, disabled people, or children (age<16) living in rural areas have guarantees to access food, clothing, hospital, housing, burial. **2)** The Minimal Assurance Households (see section 2.5) (also called "dibao" 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 level. 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 families and the Minimal Assurance families, the government distributes 120 Kwh of free electricity each household annually.

China's provinces have different subsidy programs in place for people who heat their houses exclusively with electricity. NEA suggests 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 (NEA, 2016). Liaoning province, for instance, lowers electricity bills by 50% from 22 p.m. - 5 a.m., for residents who rely solely on electricity to heat their homes during cold seasons (from November to

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

March). Other provinces have varied price measures towards electric heating initiative.

In summary, 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 vulnerability factors related to domestic energy consumption into account, such as households with poor housing quality because this may affect how long electric heating lasts (Robinson et al., 2018c); as well as with indicators such as lower household education levels, smaller household sizes, and households with larger housing areas as recognized by Xie et al. in Chinese energy poverty research. These households were discovered to be in a worse energy poverty status after the clean heating program was implemented because they could not afford to repair or replace the equipment (Xie et al., 2022). This failure to recognise social inequality calls the attention of policy makers to various vulnerable sociodemographic households when designing and implementing policies due to the probable connections between numerous domestic deprivations and energy poverty.

My work in chapter 5 also suggests similar need for social vulnerability recognitions in energy policy agendas. I identified socially vulnerable groups consisting of 10 household sociodemographic characteristics which are associated with increased likelihood of energy poverty in China, including without car, lack clean cooking fuels, rural-Hukou, low house quality, low education, poor physical/mental health, mainly female, include old people, without pension (see section 5.3.3 & 5.3.4) which has never been revealed before. Most of these socio-demographic characteristics (with the exception of low education and old people families) have been missed in current energy related policy agendas. With regards vulnerability of low house quality, government has already noticed this issue, but current actions are not targeted at improving housing quality (such as insulation materials, access to natural gas pipelines,

etc.), and only subsidize clean heating for households, which is not conducive to long-term elimination of energy poverty.

6.3.3 Recognition of spatial inequality

1) Rural and remote areas

Chinese energy policy has been balancing the spatial inequality caused by the uneven distribution of energy infrastructure, especially towards to rural parts by improving basic energy services and energy efficiency in rural and remote areas. Firstly, the 12nd 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, policy emphasizes make 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. The Home Appliance to Rural Households Policy, which was released by the Chinese Ministry of Finance in December 2008, is a crucial step in putting these measures into effect for households. It states 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 high 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. Although these measures have increased rural consumption of electrical goods and implemented energy conservation and emission reduction, there has been no effective feedback on the effect of households' subsequent consumption, including how frequently and how much they can afford to use specific energy-saving equipment, which is essential for implementing energy efficiency inequality in rural areas.

2) Urban areas

Compared to rural and remote areas, urban areas have more advanced development in domestic energy provisions and services, especially with a focus on heating, housing, and sharing electric cars in pilot cities within policy agendas under the dual aims of 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. However, not every household living in the 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 invested 35.12 billion yuan since 2014 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, urban households are implementing energy-efficiency measures focused mostly on the built environment in order to save energy and protect the environment. 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. Despite this, since the housing market was privatized over a number of decades, there have been energy inequities for those who lack a high-quality and energy-efficient built environment, leading to disparities in the ability to buy or rent high-quality, energy-efficient dwellings (Robinson et al., 2018c). In light of this, policy makers need to begin to address some of the deep inequalities in domestic energy provision that exist in more affluent city regions in China.

My work in chapter 4 & 5 also suggests a need for spatial vulnerability recognition in energy policy agendas towards rural-urban division and among provinces. I found energy poverty levels are fairly equal in both rural and urban areas across case-study provinces, especially Gansu, Henan and Liaoning provinces during study period (2010-2018), noting that urban energy poverty has received less attention and discussion until now. Although actions on housing, heating, and sharing renewable vehicles in pilot cities have been taken for urban residents as part of policy agendas with the dual goals of social development and

climate mitigation, future policies should take into account these concrete and comprehensive measures due to the complexity of particular households. Among the five case-study provinces, I also recognized Gansu as the province with the worst energy poverty, which needs additional attention. Thus, whether it is a rural-urban divide or a provincial divide, these two types of spatial vulnerability to energy poverty are all determined by the spatial differences in household income and expenditures related to energy (see sections 4.3.1 & 4.3.2), which have not yet been thoroughly investigated at the household level and taken into account in policies.

In the section above, I identified the spatial disparities in energy policies and energy poverty that people in rural, remote, and urban areas encounter. Varying degrees of economic and infrastructure development have resulted in varied energy policies and levels of energy poverty in these areas. As I noted in section 1.1, the spatial inequalities of energy poverty also exist between provinces (Wang et al., 2015, Liao et al., 2016, Zhang et al., 2019, Liao et al., 2018, Tang and Liao, 2014, Zhang et al., 2023) ; and between the west and the east (Lin and Wang, 2020, Tang and Liao, 2014). Insights into the geographic distribution of energy poverty and related polices in China are provided by the analysis in this section, which presents a chance to focus efforts on the residents of the areas that are most in need.

6.4 Conclusions and discussion

By analysing the Energy Five-Year Plan from 2000 to 2020 combining the research findings from chapter 4 & 5, in this section, I was able to critically analyse national energy policies through three primary factors: accessibility to energy distribution, social inequality, and spatial inequality. I also talked about possible approaches to addressing energy poverty by tying in with social welfare and environmental policy goals as well as some international perspectives.

6.4.1 Presence and absence of energy poverty responses

I conclude the findings of this study by answering the questions I asked at the start of section 6.2. 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 the just energy pricing (electricity). These policies attempt to distribute benefits of energy services and burdens of energy price equally. Further policy should be vigilant about possible burdens of energy poor household's domestic consumption, if residential energy price increases as a result of further reduction of cross-subsidy is made in the future due to reformation of energy market. Especially adjustments of electricity or other energy prices on a more micro scale within each province. In current Chinese policy, some vulnerable sociodemographic groups to energy poverty, such as households with low incomes, with old people, disabled people, or children (age<16) living in rural areas, and heating their homes only through electricity, have already been recognized and provided with related supports. However, the government has not taken note of homes that lack clean cooking fuels, with rural-Hukou, have poor house quality, low levels of education, poor physical and mental health, are predominately female, contain old people, and do not receive pensions, making them vulnerable to the issue of energy poverty. In terms of recognition of spatial inequality, the spatial sensitivity of energy poverty is reflected in the differences between urban and rural energy infrastructure, services, and subsidy policies. Scholars who carried out Chinese energy poverty research also evidenced there is urban energy poverty exist in China (Lin and Wang, 2020, Robinson et al., 2018c), even in some affluent areas which has been neglected in both research and policy agenda.. In conclude, government is current missing these recognitions when thinking about energy policy, because they have not properly thought about the energy poverty problem.

Thus, I suggest it is time for Chinese government to recognize "energy poverty" as an independent policy agenda in order to address this problem in a comprehensive and efficient way, particularly by highlighting the spatial and socioeconomic inequalities of energy poverty. To ensure the effectiveness of actions and involvement, it is also critical to strengthen the national or local energy legislation and management system.

6.4.2 Synergy with climate change policy

Identifying the level of energy poverty in a place is helpful when considering the synergy of climate and equality solutions, scholars have identified the inescapable correlations between energy poverty policies and climate policies (Sawhney, 2013, Wang et al., 2014a, Ürge-Vorsatz and Tirado Herrero, 2012). In Chinese case, basic realization of power grid coverage has a significant effect on reducing energy poverty, but the proportion of coal power in China is still high (Xie et al., 2022), which produces a large amount of greenhouse gas emissions. Increasing natural gas coverage in remote towns and rural areas and forming a fair and reasonable natural gas pricing mechanism will significantly reduce greenhouse gas emissions and improve the clean energy use in households. Improving home energy efficiency is mainly through improving cooking and heating equipment. Increased energy efficiency reduces the amount of energy consumption per unit of output, which in turn reduces emissions. Moreover, the development and utilization of renewable energy has the dual effect of alleviating energy poverty, saving energy and reducing emissions. Seek synergy between energy poverty and climate change policies is beneficial to collaboratively realize the dual goals of just and clean energy society.

It can be seen that some energy poverty alleviation measures are linked to climate policies in China with the main goals of energy conservation and climate mitigation, such as increasing the share of renewable vehicles in pilot cities and

improving the energy efficiency of home appliances and housing, however, if government does not independently think about energy poverty or if "one policy for all" is implemented, climate change policy would potentially make things worse. Xie et al. showed that households in Beijing and Hebei (Chinese city and province) with lower income, less education, and smaller household size are more likely to experience energy poverty after implementing "clean heating program" in these areas (Xie et al., 2022). Scholars have identified the inescapable correlations between energy poverty policies and climate policies (Sawhney, 2013, Wang et al., 2014a, Ürge-Vorsatz and Tirado Herrero, 2012), and identified the level of energy poverty in a place is helpful when considering the synergy of climate and equality solutions (provide detailed discussion in section 4.4.2). Some studies devoted to eradicating energy poverty also consider its effects on climate change (Wang et al., 2014b, Poblete-Cazenave et al., 2021, Ürge-Vorsatz and Tirado Herrero, 2012), and show that dual goals of energy poverty alleviation and climate mitigation can be solved through policy design. The focus of rural energy policy in China has been tackling of heavy reliance on solid fuels and weak affordability for clean energy by some residents. Research show that over 30% of households still rely on solid fuels in 2016 in China which is harmful for people's well-being. Moreover, broader effects of energy poverty on people's health have been revealed by scholars (Middlemiss, 2022b, Marmot Review, 2011, Liddell and Guiney, 2015): health difficulties result from energy poverty including cardiovascular disease, respiratory conditions, anxiety depression and stress, and increased risk of influenza, pneumonia, asthma, arthritis, and accidents at home, have been summarized in Marmot Review (Marmot Review, 2011). Alongside these direct effects, Middlemiss indicates health behaviours associated with poverty more generally. For example, people in energy poverty are more likely to engage in health risk behaviours associated with stress (smoking, alcohol, and overeating) (Liddell and Guiney, 2015, Middlemiss, 2022b). In Chinese case, the high share of coal electricity in China's power structure, which will result in a

significant quantity of greenhouse gas emissions, environmental pressure and related health consequences, is one of the fundamental contradictions in the power structure, despite the country's complete grid coverage and inhabitants' full access to electricity. Therefore, one step that can improve the environment and general well-being of society is reducing the amount of coal used to generate electricity. The other steps should think about energy poverty problem independently when formulating climate change policies.

In addition, as a clean modern energy source, natural gas can replace traditional biomass energy or coal as cooking fuel, which can help reduce indoor air pollution and contribute to energy conservation and emission reduction. However, China's natural gas infrastructure is weak, especially the low coverage of natural gas pipelines in remote towns and rural areas. China should therefore increase the building of natural gas infrastructure in specific locations and adopt and improve pertinent laws and regulations in the future. Additionally, investing more in home appliances with energy-efficient technology will contribute to energy savings and climate mitigation.

6.4.3 Reflection from other nation's policy research

In other nations, energy justice has been evidenced by scholars that can serve not only as an analytical framework for examining various energy-related problems (Koďouskov´a and Boˇruta, 2022, Jenkins et al., 2016), but also as a decision-making tool to "assist energy planners in making more informed energy choices" (Sovacool and Dworkin, 2015). (Walker and Day, 2012) were among the first to understand fuel poverty (UK's terminology of energy poverty) as an expression of injustice and to describe energy justice's three core pillars by following theories of social and environmental justice, which is usually conceptualized as incorporating three distinct but interrelated forms of inequality: distribution (of goods and services among groups), procedure (for

determining and contesting distribution), and recognition (of different groups' needs and rights). Each refers to specific aspects of injustice, but they are often co-extant and mutually reinforcing, also, focusing on different local context of across nations (Jenkins et al., 2016, Hall et al., 2013), and household and community level (Gillard et al., 2017, Walker, 2011) issues import an spatial sensitivity to this justice framework (Koďouskov´a and Boˇruta, 2022). Such an integrated view of energy justice (see Figure 6.5) raises questions about how differing levels of energy needs are recognized, addressed, and neglected in society of specific local context.

Chinese policies have partially recognized distributional injustice, recognition injustice and spatial injustice, but have never addressed any aspect of procedural injustice. There is space for further research to explore a more spontaneous path to energy poverty alleviation at local or community scale. **1)** distributional injustice: over the past 20 years, China has struggled with a lack of distributional accessibility to energy services and inequalities in electricity prices, which has seen a significant improvement (see section 6.3.1). But there is potential for further enhancing energy services and adjusting energy prices considering the variations of energy poverty within each province, even at more local scales. **2)** recognition injustice: current policies have identified and supported specific sociodemographic groups that are particularly vulnerable to energy poverty: households with low incomes, with old people, or disabled people, or children (age<16) living in rural areas, and heating their homes only through electricity, however, this is insufficient and neglecting vulnerable groups such as households without car, lack clean cooking fuels, rural-Hukou, low house quality, low education, poor physical/mental health, mainly female, include old people, without pension as I evidenced in chapter 5 (see section 6.3.2), as well as hindering effective supports among these disadvantaged groups. **3)** spatial injustice: current polices recognized spatial injustice of energy poverty problem

mainly reflected in differentiated subsidies in rural and urban areas of the North, with a lack of recognition between the North and the South though I have identified that provinces located close to the boundary and in the South (Henan, Guangdong, Shanghai) also have energy poverty problems. Yip et al. also recognized the energy poverty in more southern part of China, Hongkong, which faces shortage of affordable housing has pushed many people into smaller, lower quality, less energy efficient and more precarious housing settings, amplifying their vulnerability to energy poverty in many ways. **4)** procedural injustice: huge gaps exist in procedural injustice of energy in China since the top-down energy management system. In China, the relevant national energy plans, local energy plans at provincial level and development plans for large enterprise groups must earnestly implement the intention of the national energy strategy and focus on coordinating them with the binding targets and the total energy consumption control targets which were supervised by relevant departments. Thus, there lacks platform for people to access energy information, delivery of energy demands, participation in policies, and even related legal rights. Therefore, in an age of resource depletion and energy precarity, researchers and policy actors need to pay more attention to justice and other social aspects the sustainability agenda, especially the effects of low carbon and energy policies on disadvantaged groups.

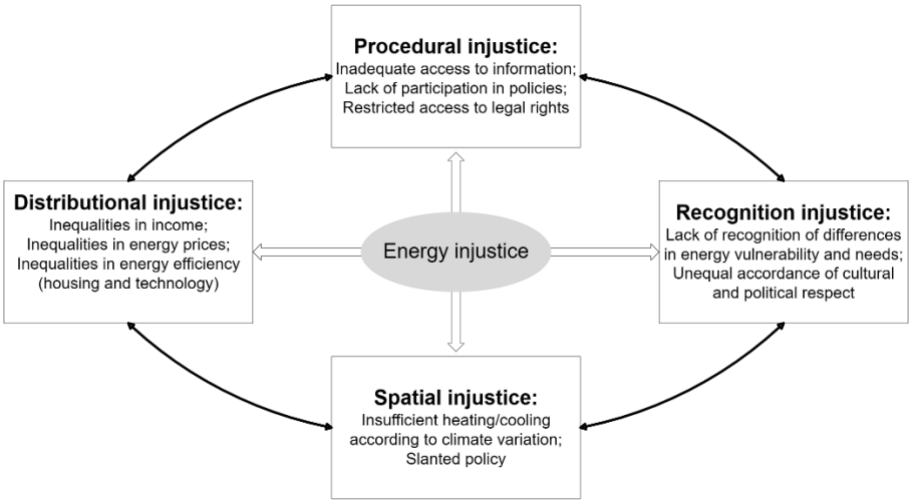

Figure 6. 5. Four interrelated forms and their component parts of energy injustice

Source: Based on (Walker and Day, 2012, Koďouskov´a and Boˇruta, 2022)

Chapter 7 Discussion and conclusions

7.1 Introduction

I begin this chapter with a summary of findings from the previous chapters. I summarize the results from chapter 4, 5 and 6, by addressing the five research questions presented in section 1.3. Then, in sections 7.3, I discuss how research done in this thesis contributes to knowledge and methodology on the subject. I discuss the novel comparison of energy poverty metrics: "10%" and "LIHC" indicators based on a household level dataset in Chinese case; and the original socio-spatial energy vulnerability research framework constructed from this thesis. Section 7.4 highlights the limitations of the work and links them with recommendations for future work. In section 7.6. I end with final conclusions and remarks.

7.2 Summary of findings

Prior to discussing the importance of the findings, I summarize the results of my research and highlight important points that are further discussed in sections 7.3 to 7.5. Here, the following subsections refer to research questions, also presented at the beginning of this thesis in chapter 1 (see Figure 1.5 of section 1.3). I take each of the research questions in turn and provide detailed evidence presented in the thesis to show how each has been answered.

7.2.1 RQ1: Can existing routinely collected administrative data be repurposed to allow the calculation of energy poverty metrics in China?

This thesis offers accurate exploration of a social household survey (China Family Panel Studies) to capture measurement and diversity of the Chinese energy poverty problem throughout the chapters. In chapter 3, I showed why I chose and how I cleaned and constructed the dataset used in this thesis from CFPS which was designed to collect household social surveys routinely and not intended to investigate household energy consumption or energy poverty problem specifically. I found that energy expenditure data and sociodemographic data of a household and individuals within this family are contained in these complete public social surveys (CFPS) and can be used to analyse energy poverty issues in China both spatially and temporally to enhance the micro level research on this subject, especially the measurement and drivers of energy poverty. In order to facilitate further development, I also summarized the dataset's advantages and disadvantages following the exercise which can be found in section 3.5.

Specifically, chapter 4 provides the calculation results of two different energy poverty metrics by using this processed dataset which has processed data on the "family economic theme" and "family common theme". Variables including household's disposable income, expenditure on electricity, fuels, heating, and housing from 2010 to 2018 are all included in the calculation of energy poverty metrics in China. Chapter 5 provides the exploration of energy poverty drivers through a social-spatial vulnerability lens by also using this processed dataset which combines household surveys ("family common theme"; 6,163 valid samples) with related individual surveys ("adult theme" and "children theme"; 14,546 valid samples). 20 sociodemographic variables related to domains

of housing and transport, household structure, health, education and employment, and social security were considered in exploring the potential vulnerability factors to energy poverty among Chinese households. Thus, this work has shown that the existing routinely collected administrative data can indeed be repurposed to energy poverty research in Chinese case, given that the nation lacks official energy investigations at a household scale.

7.2.2 RQ2: How have domestic energy use and energy poverty evolved spatially and temporally in China?

Based on the processed dataset from China Family Panel Studies (CFPS), this thesis describes three aspects of domestic energy use (electricity, heating, and fuels) spatially and temporally, as well as calculating Chinese energy poverty. In chapter 3, sections 3.1 to 3.4 show the processed dataset and measurement framework of energy poverty in China applied in chapter 4 and 5 to investigate household domestic energy use and energy poverty rates among five Chinese case-study provinces, covering both urban and rural areas from 2010 to 2018. For each of the case-study provinces, I obtained provincially representative surveys at household scale which contain domestic energy expenditure data including electricity, heating, fuels (self-heating and cooking fuel costs, including natural gas, liquefied gas, coal, firewood, charcoal, etc.), expenditure on housing and household disposable income data.

Given this, in chapter 4, the spatio-temporal evolution results of various household energy use and energy poverty are measured by provinces and rural-urban division from 2010 to 2018. In terms of household energy use, three aspects of household energy use including electricity, heating, and fuels are shown in Figure 4.4, 4.6, and 4.7 (section 4.3.2). I also depicted household income (from Figure 4.1 to 4.3 in section 4.3.1) and housing costs (in Figure 4.5) since these play

a vital role in affecting household energy choice and cost, and also in the calculation of energy poverty metrics (Robinson et al., 2018b). Key findings from analysing household energy use include:

1) Households' electricity expenditure has been rising gradually in rural areas from 2010 to 2018 except for in Shanghai where cost spiked in 2012. Rural areas have a more obvious fluctuation of electricity expenditure across provinces than urban areas (Figure 4.4).
2) The median housing cost in rural Liaoning and Gansu provinces has fluctuated over the years of the study period while the other three provinces have not changed substantially. In urban areas, the median housing cost of household has risen from 2010 to 2018 in Gansu, Henan and Liaoning provinces but has been almost steady in relatively developed Guangdong and Shanghai provinces (Figure 4.5).
3) The Huai-river district heating policy (footnote 3) in China causes injustice of heating service across provinces and between rural-urban areas, only parts of urban Gansu and Liaoning provinces in our dataset can benefit from district heating services in cold winter months. In rural Gansu and Liaoning, heating costs dropped during the study period due to a range of governmental subsidies from welfare and climate policies, such as the Ladder Electricity Price Policy and the Coal-to-Electricity Heating Policy. In urban areas, the median heating cost per capita in Liaoning is higher than that in Gansu. I also note that many people who use electricity for heating lack separate heating statistics in this survey sample which suggests a possible direction for future investigation.
4) Median fuel expenditure in urban areas shows minor fluctuation with the exception of Gansu which drops somewhat. In Rural areas fuel expenditure rises with the exception of Shanghai province. Guangdong

Liaoning and Gansu have greater disparity than Henan and Shanghai which located more centrally (Figure 4.7).

In terms of energy poverty calculation, results of energy poverty rate from "10% indicator" and "LIHC indicator" are shown in Figure 4.8 and Figure 4.9 (section 4.3.3 & 4.3.4). I adopted two classic energy poverty metrics which have been used in many European countries: "10% and LIHC indicators" (section 3.3.1 & 3.3.2). I applied these concepts to the calculation of Chinese energy poverty rate through the constructed dataset. Especially, for better understanding energy poverty situation across different income groups and the applicability of two metrics, I analysed the lowest 1st, 2nd, and 3rd quintile of household income groups when using the "10% indicator" according to its formula. The calculation of "LIHC indicator" did not adopt this income division since it defines the low income threshold is calculated as 60% of the weighted median for income After Housing Costs (AHC).

Findings show that the energy poverty rate among Chinese households varies by income, rural-urban and province divisions under both metrics of "10% and LIHC indicators". Under "10% indicator" (Figure 4.8), overall, there is a downward trend of energy poverty rate during 2010 to 2018. The figure suggests that energy poverty alleviation during the study period has occurred in the 2nd and 3rd income quintiles but not the lowest income 1st quintile. It is notable here that households in urban areas do experience energy poverty, sometimes at a similar level to rural areas, however, there remains a more pronounced rural-urban divide in energy poverty amongst the 1st quintile than the 2nd and the 3rd quintiles. Under "LIHC" the indicator (Figure 4.9), the energy poverty rate also shows heterogeneities among provinces across time, and a downward trend during 2010 to 2018 except urban Gansu and urban Guangdong.

Additionally, based on the analysis in chapter 4, I discovered that there are more significant disparities of energy poverty in terms of space rather than in

terms of time, and further efforts towards reduce spatial inequality of energy poverty can benefit to the downward trend across time. Thus, I took the most recent household survey of 2018 to do energy vulnerability factors analysis in chapter 5, and I applied the adapted "10% energy poverty indicator" (10% of income spent on energy of below average income household) to the dataset of 2018 to provide the basis for revealing vulnerability drivers of energy poverty in Chinese case. The included energy poverty rate in chapter 5 is showed in Figure 5.3 (section 5.3.1). The overall energy poverty rate using the below average income threshold of adapted "10% indicator" is 16.4%, with urban areas showing a more severe energy poverty situation (22.8%) than rural (10.7%) among these five provinces of 2018. The energy poverty rate of 2018 under adapted "10% indicator" revealed in this chapter helped me to further analyse the differences of sociodemographic characteristics between energy poor households and non-energy poor households.

7.2.3 RQ3: What are the differences in the level of energy poverty when using "10%" and "LIHC" indicators and how effective are the respective measures at capturing energy poverty in China?

By conducting statistical tests and developing a novel comparison, this thesis determined the compatibility of the "10% indicator" compared to the "LIHC indicator" while capturing energy poor households in China. In chapter 3, I showed the construction of these two energy poverty metrics based on the opinions from academics on the advantages and disadvantages of the "10% indicator" and the "LIHC indicator"(section 3.3.1 & 3.3.2). It was criticized that the "LIHC indicator" resulted in a significant decrease in the overall count of energy-poor families in the UK, which may have distorted the true count. In this

thesis, based on the calculation findings in China, the major disparities between the levels and efficacy of the two energy poverty metrics have been tested (section 4.3.5).

In chapter 4 (section 4.3.5), I applied a T-test to recognize the statistical differences between the results of two indicators ("10% indicator" and "LIHC indicator") following normality tests. I compared the results of the "10% indicator" by three quintile income groups (1st, 2nd, and 3rd) with the results of "LIHC indicator". Despite the fact that the two measures show varying levels of energy poverty in the provinces for particular years, the results show that:

- Energy poverty is a problem for Chinese households in both urban and rural locations.
- The energy poverty rates in these five Chinese provinces are all below 17.00% from either "10% indicator" or "LIHC indicator".
- The "LIHC" result corresponds best to the 1st quintile under "10% indicator" rather than the 2nd and 3rd quintiles among these provinces, which can also be proved in the T-test results that the p-value are under 0.01 which shows statistically different between "10% indicator" and "LIHC indicator" in the 2nd and 3rd quintiles rather than 1st quintile (Figure 4.10-4.12).
- To some extent, "LIHC indicator" reduces the income sensitivity of energy poverty rates and the estimation of energy poverty household numbers in comparison to the "10% indicator" in Chinese case.
- The rural-urban gap is also not obvious under the "LIHC indicator". So, this work evidenced the applicability of "10% indicator" when measuring energy poverty situation in China, which may notably reflect the most energy vulnerable groups taking into account income and the rural-urban divide.

7.2.4 RQ4: What are the sociodemographic factors driving energy vulnerability in the Chinese context?

This thesis characterized social energy vulnerability in Chinese context by applying concepts of vulnerability in Social Science and energy vulnerability framework to the dataset. The answers to this research question have been mainly covered in chapter 5. I firstly reviewed current literatures on energy vulnerability research before discussing the Chinese context (section 2.3). Research evidenced that specific vulnerabilities are often associated with people who have particular sociodemographic characteristics who have particular needs for energy, such as low-incomes, young children, old people, disabled people, single parent etc.. In the meantime, the diversity of sociodemographic characteristics associated with vulnerability and the subsequent losses of wellbeing to energy poverty also have a complex and uneven spatial distribution. Given these experiences in other nations, I expected that belonging to specific socio-demographic types would also increase the risk of a household falling into energy poverty in China.

Then, in chapter 5, section 5.2.2 shows how I constructed a series of 20 sociodemographic variables (Table 5.2) under vulnerability domains based on previous research on vulnerability from Social Science, energy poverty, and ongoing research on this topic, in relation to vulnerability to energy poverty. I identified five vulnerability domains of housing and transport, household structure, health, education and employment, and social security, with specific sociodemographic variables such as lacking clean cooking fuels, poor physical/mental health etc. under each vulnerability domain.

In sections 5.3.3 and 5.3.4, I identified 10 sociodemographic characteristics (Figure 5.6): households without a car, with old people, with rural-Hukou, and without pension, lack clean cooking fuels, with low house quality, have low

education, poor physical/mental health, mainly female, that are significantly associated with increased likelihood of energy poverty by running logistic regressions; however, the intensity of the effect is varied in the total sample, rural, urban, and each single province (Figure 5.7 and Table 5.4). Henan and Gansu have more significant vulnerability factors than the other three provinces which is consistent with their spatial distribution of the majority of the sociodemographic characteristics as analysed in section 5.3.1.

In section 5.3.1, the sociodemographic characteristics that could potentially result in energy vulnerability are unevenly distributed among regions (Figure 5.2). Northern (Gansu and Liaoning) and central provinces (Henan) possess a greater proportion of the sociodemographic characteristics than eastern (Shanghai) and southern provinces (Guangdong). I found that households living at risk of energy poverty have a higher rate of most of the sociodemographic characteristics under the vulnerability domains in our dataset from depicting sociodemographic variations between EP and non-EP households (Figure 5.4), especially households with low house quality, without pension, poor mental/physical health, and that lack clean cooking fuels.

Through these investigations, an innovative understanding of the causes of these complex social and spatial vulnerabilities is provided, and it supports the efficiency of relevant policy measures to address the issue of energy poverty in China.

7.2.5 RQ5: How can energy poverty measurement contribute to Chinese sustainability and energy justice policy agendas, and what risks of socio-spatial unjust lock-ins can energy poverty analysis help to avoid?

This thesis offers a review and reflection on governmental poverty and energy development agendas, considering the discussion of energy poverty analysed in answering the above four research questions. Firstly, in section 2.4, I reviewed the policy responses to energy poverty and related research on it concerning European nations which recognise energy poverty within the governments' policy agendas. Existing policy measures addressing the issue vary considerably across countries but can be classified into three common categories: fuels, household, and dwelling, and whether they are social-led policy or energy-led policy for energy poverty alleviation. Then, in the following section 2.5, I reflected on Chinese policy responses to energy poverty and found they have usually been linked with climate actions, environmental policies, and a rural focus.

Given the lack of energy poverty responses' research in Chinese case, I examined the energy poverty's performance embedded within national policies. I combined this examination with the earlier research on the assessment of domestic energy poverty (chapter 4) and vulnerability drivers (chapter 5) included in this thesis to demonstrate the effectiveness in reducing energy poverty on the aspects of energy accessibility, various energy needs shaped by social and spatial circumstances.

I reflected upon the energy poverty responses by reviewing the most recent national poverty and energy policy agendas (chapter 6). I found that "energy poverty" is first mentioned in national documents in the 13th Energy Five-Year

Plan (Figure 6.4) which is strongly linked with poverty alleviation policies. Especially, as in section 6.3.1, the Chinese government does not recognize energy poverty as a distinct form of poverty, however, accessibility of energy services and fair energy prices (electricity) have been recognized in national energy plans and poverty policies. These policies set up to distribute benefits of energy services and burdens of energy price equally, while further policy should be vigilant about possible burdens of energy poor household's domestic consumption. This is especially the case if further reduction of cross-subsidy and increase the residential energy price is made in the future due to reformation of energy market.

Section 6.3.2 shows that, in current Chinese policy, some vulnerable sociodemographic groups are more likely to experience to energy poverty, such as households with low incomes, with old people, disabled people, or children (age<16) living in rural areas, and heating their homes only using electricity, have already been recognized and provided related support. However, there is a lack of other vulnerability recognition, particularly when directing energy or climate activities at residents.

Regarding the acknowledgement of spatial inequality (section 6.3.3), the variations in energy infrastructure, services, and subsidy policies demonstrate how spatially sensitive energy poverty is, the government's present initiatives are mostly focused on eliminating disparities between rural and urban areas without taking provincial disparities into account. Scholars who conducted Chinese energy poverty research also evidenced a neglect aspect of urban energy poverty even in affluent areas in China (Lin and Wang, 2020, Robinson et al., 2018c). Thus, I suggest it is time for Chinese government to recognize "energy poverty" as an independent policy agenda in order to address this problem in a comprehensive and efficient way. It is also essential to strengthen the energy legislation and management system at national or local scale.

7.3 Contributions

7.3.1 Methodological contributions: evaluation of the applicability of "10%" and "LIHC" indicators.

Existing studies all identified that energy poverty does exist in China which are different geographically even with limited concern on this subject (Hou et al., 2018, Lin and Wang, 2020). The energy poverty rate recognized usually ranges from 18% to 43% under various measurements. Studies measuring energy poverty in China is basically using three main methods: expenditure approach, proportion of solid fuel use, and multidimensional method (see section 2.2). The choice of various approaches is based on what kind of data the research can access, especially the micro household survey data or macro statistical as I illustrated in the section 3.1 & 3.2. Due to the lack of micro scale data, the measurement of energy poverty emphasizes more on overall energy poverty rate and its geographical differences rather than the real lived experience of people's daily life in existing literature.

The analysis of assessment of energy poverty in this thesis shows that this dataset and the two classic energy poverty indicators can provide us with information about China's energy poverty situation on a household level and allow us to explore applicable energy poverty indicator suitable to Chinese case. The "10% indicator" and "LIHC indicator" effectively capture the evolutionary features and geographical heterogeneities of energy poverty among Chinese households as shown in section 4.3.3 and 4.3.4. In section 4.3.5, I firstly compared the results of these two metrics in capturing energy poor households in China and argue that the "10% indicator" is more suitable to capture this problem than the "LIHC indicator" since which may neglect some vulnerable households at a higher but below the median income level and may also hide the disparities

among rural and urban areas. Below Table 7.1 provides a summarised comparison of key findings from chapter 4 towards to applicability of "10% indicator" and "LIHC indicator" in China's energy poverty assessment. Based on this, I argue that the implementation of "10% indicator" derived from Chinese household surveys is a useful tool for acknowledging thee energy poverty situation and spatial variations.

Table 7. 1. The comparison of captured vulnerability to energy poverty between "10% indicator" and "LIHC indicator"

Aspect	**Vulnerability**	**"10% indicator"**	**"LIHC indicator"**
Energy service	Electricity expenditure	✓	✓
	Fuels expenditure	✓	✓
	Heating expenditure	✓	✓
Housing	Include housing cost	✓	
Disposable income	Below median income	✓	
	Below 60% median income	✓	✓
EP households	The 1st quintile low-income group	✓	
	The 2nd quintile low-income group	✓	
	The 3rd quintile low-income group	✓	
	Below median low-income group	✓	✓
Spatial disparities	Household level	✓	✓
	Urban energy poverty	✓	✓
	Rural energy poverty	✓	✓
	Most common energy poverty rate between rural and urban areas in 2nd & 3rd quintile	✓	

	Larger difference of energy poverty rate between rural and urban areas in 1st quintile	✓	
	The most severe energy poverty in Gansu	✓	✓
	The least severe energy poverty in Shanghai	✓	✓
	Smaller difference of rural-urban energy poverty rate in developed provinces (Shanghai & Guangdong) than other provinces	✓	✓
	A reduced rural-urban energy poverty difference in five case-study provinces		✓
Temporal trends	Downward trend of energy poverty during 2010 to 2018	✓	✓
	Increased in 1st income quintile group	✓	
	Decreased in 2nd & 3rd income quintile group	✓	

7.3.2 Contributions to the knowledge base: contextualized socio-spatial energy vulnerability analysis

1) Energy vulnerability thinking

Energy vulnerability thinking has been highlighted as an approach for developing a common framework for understanding the driving forces of energy poverty. (Bouzarovski and Petrova, 2015). Bouzarovski and Petrova described vulnerability as a set of conditions leading to energy poverty circumstances. It highlights 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. In section 2.3 of this thesis, I provide a review of mainstreaming practice on this vulnerability thinking mainly including the identification of particular groups of people who have specific energy needs (low-incomes, young children, old people, disabled people, single parents) (Robinson et al., 2018b, Ivanova and Middlemiss, 2021, Middlemiss, 2022b, Anderson et al., 2012, Sakka et al., 2012, Xie et al., 2022, White and Sintov, 2019, Ormandy and Ezratty, 2012, Simcock et al., 2021), as well as the complex and uneven spatial distribution of these vulnerable groups (Robinson et al., 2018b, Bouzarovski and Cauvain, 2016, Altan and Hasim, 2004, Simcock et al., 2021, Robinson and Mattioli, 2020). Such thinking is not only useful in identifying groups that may be at risk of falling into energy poverty currently or in the future, but can also help place the combination of social, economic, political and infrastructural factors that have contributed to the position of households who are facing the predicament in the present.

Available studies in Chinese energy poverty research are more concerned with the regional differences and overall situation, with no research paying attention to vulnerability drivers to energy poverty, especially taking into account spatial and social vulnerabilities which have already been revealed in other nations. This lack of recognition of spatial-social vulnerabilities hinders the better understanding of what places and what kind of people more easily fall into energy poverty, which further hinders the effectiveness of related interventions to alleviate energy poverty in China. Thus, this thesis contributes to fill this gap and complete the investigation of energy drivers following the related measurement, chapter 4 & 5 provide detailed exploration of socio-spatial energy vulnerability, and chapter 6 discussed and reflect the results from a policy perspective, I then formed the energy vulnerability framework in China throughout these investigations in previous chapters (see Figure 7.2).

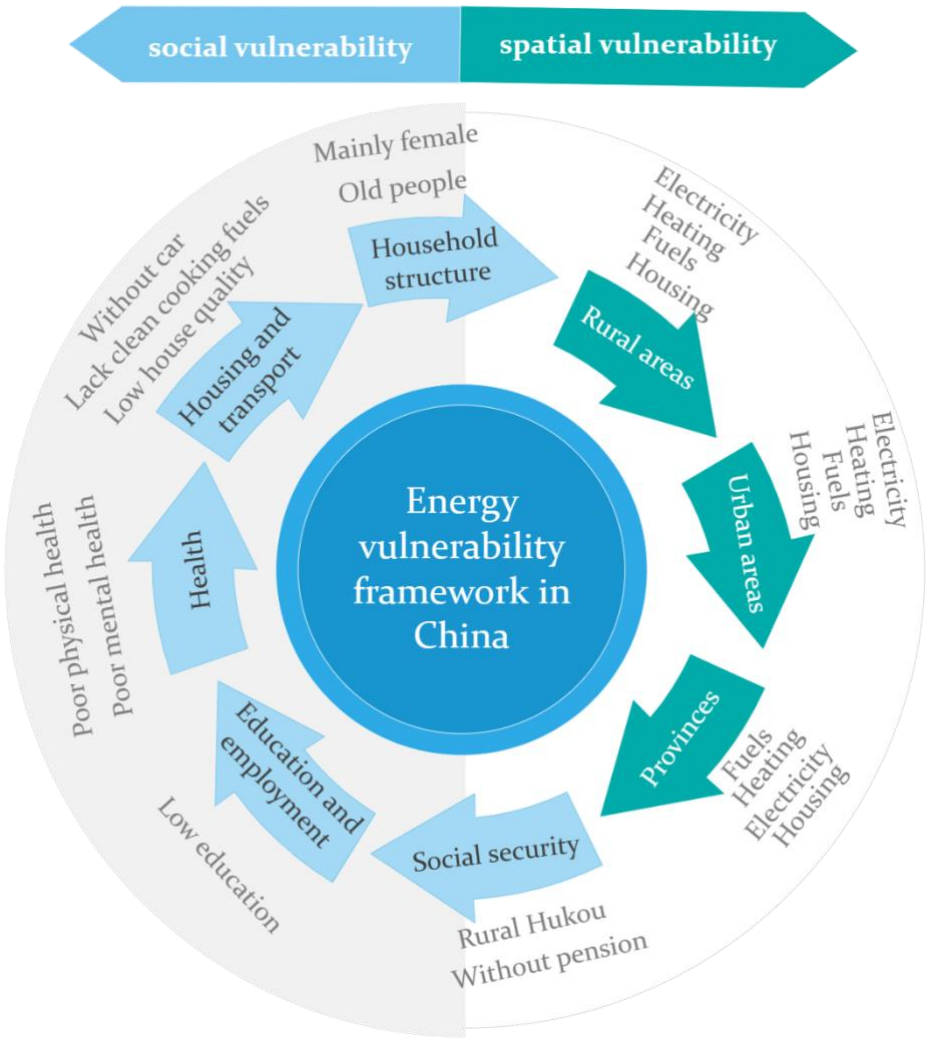

Figure 7. 1. Energy vulnerability framework in China (Towards equitable space and society)

Note: The light blue arrows on the left side represent the aspects of social vulnerability; the dark green arrows on the right side represent the aspects of spatial vulnerability.

2) Social energy vulnerability

In Figure 7.2, for the social energy vulnerability, one of the main obstacles to quantifying social vulnerabilities to energy poverty is associated with the availability of data on household sociodemographic characteristics combined with related domestic energy consumption data. In this thesis, chapter 5 contributes original social vulnerability drivers' analysis to Chinese energy poverty research, revealing a spatial effect among five case-study provinces. In section 5.2.2, I showed the process of constructing an energy vulnerability dataset

in this work, including identifying 5 vulnerability domains (housing and transport, household structure, health, education and employment, and social security) and related 20 sociodemographic indicators (Table 5-2). Based on this dataset, I mapped the uneven distribution of these sociodemographic characteristics among different places (Figure 5-2). Northern (Gansu and Liaoning) and central provinces (Henan) have a greater proportion of the relevant sociodemographic characteristics than eastern (Shanghai) and southern provinces (Guangdong). Thirdly, Figure 5-4 depicts the distribution of social vulnerabilities between energy poor and non-energy poor households which shows that energy poor households have particularly high proportions of the characteristics in the and seem to have a stronger relationship with energy poverty than education and employment, heath, and household structure. Finally, I ran logistic regressions and further evidenced the different effects of significant sociodemographic characteristics on likelihood of energy poverty across different area types including rural-urban division and five provinces. In rural areas, households with old people have a greater effect on energy poverty, with a higher coefficient of 0.891 than urban areas with a coefficient of 0.608. In addition, a lack of clean cooking fuels, poor physical health and rural-Hukou are other significant factors increasing the likelihood of a household falling into energy poverty in both urban and rural areas. Aside from the urban-rural division, different effects of vulnerability factors to energy poverty also exist among provinces. Henan and Gansu have more statistically significant vulnerability factors than the other three provinces, consistent with their spatial distribution of the majority of the sociodemographic characteristics as I analysed in section 5.3.1.

3) Spatial energy vulnerability

Chapter 4 & 5 both have included the exploration of spatial energy vulnerability, covering rural, urban areas and five case-study provinces. In

chapter 4, I first discussed the spatial distribution of households' disposable income and related energy expenditure, then I assessed the energy poverty rates across five case-study provinces (section 4.3.3). The findings imply that provinces and rural and urban areas are where energy poverty is most concentrated in terms of spatial disparity. According to the "10% indicator" of the 1st quintile, the mean energy poverty rates of these five provinces are 10.80% in rural, and 8.81% in urban areas in 2018. Although urban areas have greater residential energy costs than rural areas, urban areas have lower rates of energy poverty. This is mainly because households in China have not reached the saturated stage in energy demand, and electricity consumption in developed urban areas is likely to increase with increasing income. Therefore, the policy of 'Ladder Electricity Prices' is reasonable in restricting the household electricity usage with high prices for higher income and higher consumption households (Lin and Wang, 2020). Energy poverty in rural areas is slightly severe than in urban areas suggesting more persistent income, infrastructure, and building problems among rural households (Li et al., 2011, Luo and Liu, 2013, Zhao et al., 2018, Hao et al., 2014, Hong et al., 2022). Whilst energy poverty is not exactly analogous to income poverty (Middlemiss, 2017), energy poverty rates are higher in western and northern China, which is consistent with the pattern of China's economic development and is reflected in the high rates according to the "10% indicator" and "LIHC indicator" in Gansu and Liaoning provinces. Higher rates of energy poverty are found in rural and underdeveloped areas, noting urban energy poverty does also exist despite having received little attention in previous studies. These spatial vulnerabilities of energy poverty are important to bear in mind in energy policy making when pursuing a just development.

In chapter 5, I found various sociodemographic features are disproportionately distributed across space and between energy poor and non-energy poor households. Spatially, Henan in central China, Gansu in western

China have a larger proportion household with sociodemographic characteristics associated with vulnerability domains than other provinces, which is aligned to their lower levels of economic and social development in China. The sociodemographic characteristics in the vulnerability domains are more common amongst households experiencing energy poverty, illustrated through visualisation of the data and logistic regression. This pattern of vulnerability factors increasing likelihood of energy poverty is observed at household level, when comparing rural and urban areas, as well as examining 5 provinces. These findings indicate that when the concept of social vulnerability is combined with 'aspects of place', socio-spatial vulnerability results in a geographical expression of the likelihood of a loss of wellbeing in the household (Robinson et al., 2019).

4) Policy reflection

In chapter 6, through a policy lens, I considered the national recognition of spatial-social vulnerability in policy and in the light of the results from chapter 4 and 5. First, the Chinese government does not recognize energy poverty as a distinct form of (income) poverty, however, accessibility of energy service and just energy price (electricity) has been recognized in national energy plans and poverty policies. Second, in current Chinese policy, a few vulnerable sociodemographic groups to energy poverty, such as households with low income, with old people, or disabled people, or children (age<16) living in rural areas, and heating the home only through electricity, have already been recognized and provided related support. Finally, the spatially sensitive nature of energy poverty is reflected in the differences between urban and rural energy infrastructure, services, and subsidy policies.

Overall, the thesis developed the energy poverty framework from the perspective of vulnerability through representative household surveys. Bouzarovski emphasized the ability of vulnerability thinking to encapsulate the driving forces of domestic energy deprivation via a comprehensive analytical

matrix (Bouzarovski and Petrova, 2015). Moreover, inspirations from examples of the revealed spatial-social dynamics in other nations as listed above has also been included in the construction of the Chinese energy poverty framework in this thesis work. Through the construction of the household-level dataset, comparison of energy poverty metrics, and analysis of socio-spatial energy vulnerability in China, I developed this energy vulnerability framework in China which starting from household's energy and not include the 'systems and infrastructures of provision paradigm' (the institutional dynamics and material cultures surrounding the rise of commodity-specific chains that connect production, distribution and consumption activities) as demonstrated from Bouzarovski and Petrova's work.

7.4 Suggestions for further research

There are many areas of further research and policy that could follow from the limitations and research presented in this thesis. In the first place expanding this research to other case-study provinces and even countries with the use of the energy vulnerability model presented here is the most obvious. There is a need for more studies on energy poverty research and vulnerabilities on a household level in other places, but not limited to different places in China. In this thesis, I presented some examples in China, but a similar analysis may be found in other Asian nations with different socioeconomic and climatic conditions that have received less attention than western nations in the field of energy poverty research.

Secondly, findings in this thesis provide a more comprehensive analysis of spatial-social energy poverty nexus regarding a household level distribution, thus, "one policy for all" such as Clean Heating Program (see chapter 6) is likely to hurt vulnerable households in different places when helping to achieve sustainable goals. There is a substantial evidence base that suggests that people

with particular impairments or conditions may have elevated energy needs as a result of (amongst other things) higher indoor temperatures; longer periods of warmth; the use of air conditioners and other energy intensive equipment; and additional washing and drying facilities. The research contributes to developing more nuanced insights to energy poverty alleviation in Chinese case that calls the attention of policy makers to the most vulnerable households to energy poverty as a starting point, especially with old people and those without pensions, and will also help policy makers to consider the distributional effects when designing energy transition and equality policies for a low-carbon and just economy and society.

In order to uncover lock-ins and enablers of interventions to alleviate energy poverty in local level, future research should provide evidence using community-level studies. Although China lacks participatory practice in energy design, the need for further community-level studies for energy poverty would be beneficial for at least two reasons. Firstly, some evidence (Busch et al., 2021) has indicated that community energy initiatives can strengthen local democratic processes or economic development for marginalised communities, which may be beneficial for people's participation practices in reporting their most pressing need for energy consumption at local level and actively engaging in energy transition as China has also been implementing democratization in national governance[25]. Also, grassroots initiatives to seek energy poverty solutions could be invariably conceived, initiated and enacted within communities (Middlemiss and Parrish, 2010). Secondly, community-level studies of energy consumption can contribute to the multi-scale dataset of domestic energy investigation combining other

25 The 18th National Congress of the Communist Party of China (Oct. 2016) put forward the system of socialist core values: prosperity, democracy, civilization and harmony are the value goals at the national level; freedom, equality, justice and rule of law are the value orientation at the social level; patriotism, dedication, integrity and friendliness are the value criteria at the individual level of citizens.

provincial or national level data, the multi-scale dataset can provide insights about processual aspects of multilevel policy change.

The potential research avenue (pursued in this thesis through quantitative analysis) could be strengthened by a qualitative analysis. This thesis developed from a national survey dataset that benefitted from investigation across years in Chinese provinces and suggested vulnerability factors of households rather than previous focus on economic indicators should be paid particular attention to when formulating related response. While qualitative approaches can further enhance this understanding through investigating people's lived experiences in energy poor homes, their coping practices, as well as outlining the effects of energy poverty on health, social life, and home finances (Middlemiss, 2022b, Middlemiss et al., 2019, Middlemiss and Gillard, 2015). Other important dimensions for qualitative analysis are various stakeholders' roles when implementing the energy poverty interventions.

Finally, it became clear from this study that there are critical analyses of energy poverty and its determinants that were not fully investigated in this thesis at a micro scale. Disaggregating the data by household members is one very significant viewpoint to take into account while conducting an analysis, for instance. Further research could narrowly analyse this dimension while examining individual sociodemographic characteristics such as their education status, marriage status, social relations etc. particularly when qualitatively investigate their description of own lived experiences.

7.5 Concluding remarks: a just transition

Overall, I found that Chinese energy poverty investigation done in this Ph.D. provided some insights into the distinctions and overlaps among poverty alleviation, energy poverty alleviation, and climate mitigation when pursuing

sustainable development, though current polices have not recognized energy poverty as a distinct problem in China. Having a separate recognition of energy poverty (different from poverty alleviation and climate mitigation) would help to reveal structural and systemic factors producing inadequate domestic energy services that go beyond low-incomes and the lack of accessibility to clean fuels. On the one hand, energy poor households in China are more likely to have vulnerabilities of low housing quality, low education, old people, poor mental/physical health, be mainly female, be rural-Hukou, be without pension, and lack clean cooking fuels. On the other hand, these vulnerabilities may be neglected when the state provides "one size fits all" policy of only financial support. Recognizing energy poverty helps to understand the social impacts of policy on poverty alleviation and climate mitigation, identifying most vulnerable groups who are facing energy deprivations.

Only when we understand the distinct energy poverty problem scientifically, can we explore effective ways to reduce energy poverty and integrate it with welfare and climate policies to produce advantageous synergies. Findings in this thesis suggests that current polices emphasized a limited financial subsidy to household for substitution of solid fuels, rather than the actions and investments on improving housing efficiency and developing clean energy infrastructure, which would lead to a fundamental shift away from energy poverty resulting from poor home environments. In the meantime, we need also to pay attention to socio-spatial vulnerabilities during the practice of energy poverty alleviation. At a time of rapid environmental change and a drive for decarbonisation, it is increasingly important that policymakers have the appropriate tools to conduct assessments of social and environmental impacts of energy transition, the insights from this study would be a good start for policymakers to produce a just transition in society.

References

ABBAS, K., BUTT, K. M., XU, D., ALI, M., BAZ, K., KHARL, S. H. & AHMED, M. 2022. Measurements and determinants of extreme multidimensional energy poverty using machine learning. *Energy,* 251.

ADGER, W. N. 2006. Vulnerability. *Global environmental change,* 16**,** 268-281.

ALTAN & HASIM. 2004. *Energy efficiency in housing : drivers and barriers to improving energy efficiency and reducing carbon dioxide emissions in private sector housing.* University of Sheffield.

ANDERSON, W., WHITE, V. & FINNEY, A. 2012. Coping with low incomes and cold homes. *Energy Policy,* 49**,** 40-52.

ATHUKORALA, W., WILSON, C., MANAGI, S. & KARUNARATHNA, M. 2019. Household demand for electricity: The role of market distortions and prices in competition policy. *Energy Policy,* 134**,** 110932.

BACCHI, C. 2014. *Analysing Policy: What's the problem represented to be?*, Pearson Australia

BAILEY, I., HOPKINS, R. & WILSON, G. 2010. Some things old, some things new: The spatial representations and politics of change of the peak oil relocalisation movement. *Geoforum,* 41**,** 595-605.

BAKER, K. J., MOULD, R. & RESTRICK, S. 2018. Rethink fuel poverty as a complex problem. *Nature Energy,* 3**,** 610-612.

BARRINGTON-LEIGH, C., BAUMGARTNER, J., CARTER, E., ROBINSON, B. E., TAO, S. & ZHANG, Y. 2019. An evaluation of air quality, home heating and well-being under Beijing's programme to eliminate household coal use. *Nature Energy,* 4**,** 416-423.

BEDNAR, D. J. & REAMES, T. G. 2020. Recognition of and response to energy poverty in the United States. *Nature Energy,* 5**,** 432-439.

BIROL, F. 2007. Energy economics: a place for energy poverty in the agenda? *The energy journal,* 28.

BOARDMAN, B. 1991. *Fuel poverty: from cold homes to affordable warmth*, Pinter Pub Limited.

BOARDMAN, B. 2010. *Fixing fuel poverty: Challenges and solutions*, Earthscan.

BOARDMAN, B. 2012. Fuel poverty synthesis: Lessons learnt, actions needed. *Energy Policy,* 49**,** 143-148.

BOUZAROVSKI, S. 2018. Energy Poverty (Dis)Assembling Europes Infrastructural Divide.

BOUZAROVSKI, S. & BASSIN, M. 2013. Energy and identity: Imagining Russia as a hydrocarbon superpower. *The New Geographies of Energy.* Routledge.

BOUZAROVSKI, S. & CAUVAIN, J. 2016. Spaces of exception: governing fuel poverty in England's multiple occupancy housing sector. *Space and Polity,* 20**,** 310-329.

BOUZAROVSKI, S. & PETROVA, S. 2015. A global perspective on domestic energy deprivation: Overcoming the energy poverty–fuel poverty binary. *Energy Research & Social Science,* 10**,** 31-40.

BOUZAROVSKI, S., PETROVA, S. & SARLAMANOV, R. 2012. Energy poverty policies in the EU: A critical perspective. *Energy policy,* 49**,** 76-82.

BOUZAROVSKI, S., THOMSON, H. & CORNELIS, M. 2021. Confronting Energy Poverty in Europe: A Research and Policy Agenda. *Energies,* 14.

BOUZAROVSKI, S. & TIRADO HERRERO, S. 2017a. The energy divide: Integrating energy transitions, regional inequalities and poverty trends in the European Union. *European Urban and Regional Studies,* 24**,** 69-86.

BOUZAROVSKI, S. & TIRADO HERRERO, S. 2017b. Geographies of injustice: the socio-spatial determinants of energy poverty in Poland, the Czech Republic and Hungary. *Post-Communist Economies,* 29**,** 27-50.

BOUZAROVSKI, S., TIRADO HERRERO, S., PETROVA, S. & ÜRGE-VORSATZ, D. 2016. Unpacking the spaces and politics of energy poverty: Path-dependencies, deprivation and fuel switching in post-communist Hungary. *Local Environment,* 21**,** 1151-1170.

BOWEN, G. A. 2009. Document analysis as a qualitative research method. *Qualitative research journal,* 9**,** 27-40.

BRIDGE, G., BOUZAROVSKI, S., BRADSHAW, M. & EYRE, N. 2013. Geographies of energy transition: Space, place and the low-carbon economy. *Energy Policy,* 53**,** 331-340.

BRIDGEN, P. & ROBINSON, C. 2023. A decade of fuel poverty in England: A spatio-temporal analysis of needs-based targeting of domestic energy efficiency obligations. *Energy Research & Social Science,* 101.

BROWN, K., ECCLESTONE, K. & EMMEL, N. 2017. The Many Faces of Vulnerability. *Social Policy and Society,* 16**,** 497-510.

BRUNNER, K.-M., SPITZER, M. & CHRISTANELL, A. 2012. Experiencing fuel poverty. Coping strategies of low-income households in Vienna/Austria. *Energy Policy,* 49**,** 53-59.

BÜCHS, M., BAHAJ, A., BLUNDEN, L., BOURIKAS, L., FALKINGHAM, J., JAMES, P., KAMANDA, M. & WU, Y. 2018. Sick and stuck at home–how poor health increases electricity consumption and reduces opportunities for environmentally-friendly travel in the United Kingdom. *Energy Research & Social Science,* 44**,** 250-259.

BUSCH, H., RUGGIERO, S., ISAKOVIC, A. & HANSEN, T. 2021. Policy challenges to community energy in the EU: A systematic review of the scientific literature. *Renewable and Sustainable Energy Reviews,* 151.

BUZAR, S. 2007. Erratum to "The 'hidden' geographies of energy poverty in post-socialism: Between institutions and households" [Geoforum 38 (2) (2007) 224–240]. *Geoforum,* 38.

CALVERT, K. 2015. From 'energy geography' to 'energy geographies'. *Progress in Human Geography,* 40**,** 105-125.

CAMPBELL, B. M., VERMEULEN, S. J., MANGONO, J. & MABUGU, R. 2003. The energy transition in action: urban domestic fuel choices in a changing Zimbabwe. *Energy Policy,* 31**,** 553-562.

CASTAÑO-ROSA, R., SOLÍS-GUZMÁN, J., RUBIO-BELLIDO, C. & MARRERO, M. 2019. Towards a multiple-indicator approach to energy poverty in the European Union: A review. *Energy and Buildings,* 193**,** 36-48.

CEY, C. E. Y. 2021. *In:* ADMINISTRATION, C. S. (ed.). China.

CFPS 2017. CFPS User's Manual (3rd+Edition) (ENG). *In:* XIE, Y., ZHANG, X., TU, P., REN, Q., SUN, Y., LV, P., DING, H., HU, J. & WU, Q. (eds.). Peking University: Institute of Social Science Survey,.

CLARK, G. L., FELDMAN, M. P., GERTLER, M. S. & WÓJCIK, D. 2018. *The new Oxford handbook of economic geography*, Oxford University Press.

CONSORTIUM, E. 2009. Tackling Fuel Poverty in Europe. Recommendations Guide for Policy Makers. *Retrieved,* 28**,** 2019.

CRANG, P. 1997. Cultural turns and the (re) constitution of economic geography. *Geographies of economies*.

DAY, R., WALKER, G. & SIMCOCK, N. 2016. Conceptualising energy use and energy poverty using a capabilities framework. *Energy Policy,* 93**,** 255-264.

DBEIS 2022. Annual Fuel Poverty Statistics in England, 2022. *In:* DEPARTMENT FOR BUSINESS, E., INDUSTRIAL STRATEGY (ed.).

DÉMURGER, S. & FOURNIER, M. 2011. Poverty and firewood consumption: A case study of rural households in northern China. *China Economic Review,* 22**,** 512-523.

DESNZ, D. F. E. S. N. Z. 2023. Annual Fuel Poverty Statistics LILEE Report 2023 (2022 data).

DEVINE-WRIGHT, P. & WIERSMA, B. 2013. Opening up the “local” to analysis: exploring the spatiality of UK urban decentralised energy initiatives. *Local Environment,* 18**,** 1099-1116.

DOBBINS, A., FUSO NERINI, F., DEANE, P. & PYE, S. 2019. Strengthening the EU response to energy poverty. *Nature Energy,* 4**,** 2-5.

DONG, K., REN, X. & ZHAO, J. 2021. How does low-carbon energy transition alleviate energy poverty in China? A nonparametric panel causality analysis. *Energy Economics,* 103.

DOROW, S. & O'SHAUGHNESSY, S. 2013. Fort McMurray, Wood Buffalo, and the Oil/Tar Sands: Revisiting the Sociology of" Community". *Canadian Journal of Sociology,* 38**,** 121-140.

DUBOIS, U. 2012. From targeting to implementation: The role of identification of fuel poor households. *Energy Policy,* 49**,** 107-115.

DUBOIS, U. & MEIER, H. 2016. Energy affordability and energy inequality in Europe: Implications for policymaking. *Energy Research & Social Science,* 18**,** 21-35.

EBRD, E. B. F. R. A. D. 2005. Can the Poor Pay for Power? The Affordability of Electricity in Southeast Europe.

EMMEL, N. & HUGHES, K. 2010. ‘Recession, it's all the same to us son’: the longitudinal experience (1999–2010) of deprivation. *Twenty-First Century Society,* 5**,** 171-181.

ENERGY POVERTY ACTION, W. 2019. Moving beyond the state of the art in energy poverty measurement. *In:* SAREEN, S. & THOMSON, H. (eds.) *Working Group 2 - Implementation: Developing an operational energy poverty framework.*

FINKELMAN, B. R., OREM, W., CASTRANOVA, V. & TATU, A. C. 2002. Health impacts of coal and coal use possible solutions. *International Journal of Coal Geology*.

GILLARD, R., SNELL, C. & BEVAN, M. 2017. Advancing an energy justice perspective of fuel poverty: Household vulnerability and domestic retrofit policy in the United Kingdom. *Energy Research & Social Science,* 29**,** 53-61.

GRANT, W. 2008. *Research methods in politics*, Bloomsbury Publishing.

GUAN, Y., YAN, J., SHAN, Y., ZHOU, Y., HANG, Y., LI, R., LIU, Y., LIU, B., NIE, B., BRUCKNER, B., FENG, K. & HUBACEK, K. Burden of the global energy price crisis on households. *Nature Energy*

HALL, S. M., HARDS, S. & BULKELEY, H. 2013. New approaches to energy: equity, justice and vulnerability. Introduction to the special issue. *Local Environment,* 18**,** 413-421.

HAO, Y., YIN, J. & YANG, D. 2014. The study on energy poverty's regional differences in China. *Research and Approach,* 36**,** 34-38.

HARRISON, C. 2013. The historical–geographical construction of power: electricity in Eastern North Carolina. *Local Environment,* 18**,** 469-486.

HE, L.-Y., HOU, B. & LIAO, H. 2018. Rural energy policy in China. *China Agricultural Economic Review,* 10**,** 224-240.

HEALY, J. D. 2017. *Housing, fuel poverty and health: a pan-European analysis*, Routledge.

HEALY, J. D. & CLINCH, J. P. 2002. Fuel poverty, thermal comfort and occupancy: results of a national household-survey in Ireland. *Applied Energy,* 73**,** 329-343.

HEINDL, P. 2015. Measuring fuel poverty: General considerations and application to German household data. *FinanzArchiv/Public Finance Analysis***,** 178-215.

HELM, D. 2005. The Assessment: The New Energy Paradigm. *Oxford Review of Economic Policy,* 21**,** 1-18.

HELTBERG, R. 2004. Fuel switching: evidence from eight developing countries. *Energy economics,* 26**,** 869-887.

HERNÁNDEZ, D. 2016. Understanding 'energy insecurity'and why it matters to health. *Social Science & Medicine,* 167**,** 1-10.

HILLS, J. 2011. Fuel poverty: the problem and its measurement.

HILLS, J. 2012. Getting the measure of fuel poverty.

HONG, X., WU, S. & ZHANG, X. 2022. Clean energy powers energy poverty alleviation: Evidence from Chinese micro-survey data. *Technological Forecasting and Social Change,* 182.

HOSIER, R. H. & DOWD, J. 1987. Household fuel choice in Zimbabwe: an empirical test of the energy ladder hypothesis. *Resources and energy,* 9**,** 347-361.

HOU, B., LIAO, H. & HUANG, J. 2018. Household cooking fuel choice and economic poverty: evidence from a nationwide survey in China. *Energy and Buildings,* 166**,** 319-329.

HOU, B.-D., TANG, X., MA, C., LIU, L., WEI, Y.-M. & LIAO, H. 2017. Cooking fuel choice in rural China: results from microdata. *Journal of Cleaner Production,* 142**,** 538-547.

HUANG, J. 2011. Discussion on game of power construction and energy-saving emission reduction. *Technological Development of Enterprise,* 30**,** 196-197.

IEA 2010. World Energy Outlook 2010. Paris.

ILO, I. L. O. 2020. International Labour Organization Research Brief 1.

ISOLDE, D. 2015. *Définition de la Précarité Energétique* [Online]. Available: https://expertises.ademe.fr/batiment/quoi-parle-t/precarite-energetique-suivie-lonpe-sein-lademe [Accessed].

IVANOVA, D. & MIDDLEMISS, L. 2021. Characterizing the energy use of disabled people in the European Union towards inclusion in the energy transition. *Nature Energy,* 6**,** 1188-1197.

JENKINS, K. 2018. Energy poverty and vulnerability: A global perspective. *Energy,* 147**,** 388-389.

JENKINS, K., MCCAULEY, D., HEFFRON, R., STEPHAN, H. & REHNER, R. 2016. Energy justice: A conceptual review. *Energy Research & Social Science,* 11**,** 174-182.

JIANG, L., YU, L., XUE, B., CHEN, X. & MI, Z. 2020. Who is energy poor? Evidence from the least developed regions in China. *Energy Policy,* 137**,** 111122.

KAREKEZI, S. & MAJORO, L. 2002. Improving modern energy services for Africa's urban poor. *Energy policy,* 30**,** 1015-1028.

KARPINSKA, L. & ŚMIECH, S. 2020. Invisible energy poverty? Analysing housing costs in Central and Eastern Europe. *Energy Research & Social Science,* 70.

KATSOULAKOS, N. 2011. Combating energy poverty in mountainous areas through energy-saving interventions. *Mountain Research and Development,* 31**,** 284-292.

KERR, N., GILLARD, R. & MIDDLEMISS, L. 2019. Politics, problematisation, and policy: A comparative analysis of energy poverty in England, Ireland and France. *Energy and Buildings,* 194**,** 191-200.

KOĎOUSKOV´A, H. & BO˘RUTA, D. 2022. Energy poverty in Slovakia Officially defined but misrepresented in major policies.

KUHN, T. S. 1961. The function of measurement in modern physical science. *Isis,* 52**,** 161-193.

KUHN, T. S. 1970. *Criticism and the growth of knowledge: Volume 4: Proceedings of the International Colloquium in the Philosophy of Science, London, 1965*, Cambridge University Press.

KYPRIANOU, I. & SERGHIDES, D. 2021. Energy Price Crisis impacts on Energy Poverty in Cyprus.

LEACH, G. 1992. The energy transition. *Energy policy,* 20**,** 116-123.

LEGENDRE, B. & RICCI, O. 2015. Measuring fuel poverty in France: Which households are the most fuel vulnerable? *Energy Economics,* 49**,** 620-628.

LI, H. 2009. China's fossil energy subsidies and carbon reduction. *Low Carbon Economy Research***,** 92-96.

LI, K., LIU, C. & WEI, Y. 2011. Analysis of the current situation of energy poverty in China. *Research and Approach,* 33**,** 32-35.

LIAO, H., TANG, X. & WEI, Y.-M. 2016. Solid fuel use in rural China and its health effects. *Renewable and Sustainable Energy Reviews,* 60**,** 900-908.

LIAO, H., WANG, C., LIU, Y., GAO, Y. & WANG, F. 2018. Revision on China's energy data by sector and fuel type at provincial level. *Energy Efficiency,* 12**,** 849-861.

LIDDELL, C. & GUINEY, C. 2015. Living in a cold and damp home: frameworks for understanding impacts on mental well-being. *Public health,* 129**,** 191-199.

LIN, B. & WANG, Y. 2020. Does energy poverty really exist in China? From the perspective of residential electricity consumption. *Energy Policy,* 143.

LIU, H. & MAUZERALL, D. L. 2020. Costs of clean heating in China: Evidence from rural households in the Beijing-Tianjin-Hebei region. *Energy Economics,* 90**,** 104844.

LU, S., REN, J., LEE, C. K. M. & ZHANG, L. 2022. Spatial-temporal energy poverty analysis of China from subnational perspective. *Journal of Cleaner Production,* 341.

LUO, G. & LIU, T. 2013. The exposion of non-electricity customers, renewable energy, power poverty problems of the rural areas of western China *Journal of North China Electric Power University (Social Sciences)***,** 6-12.

LUO, Z. & HUO, Z. 2007. The effect of energy saving and emission reduction of solar water heater is remarkable. *Solar Energy***,** 4-5.

MARMOT REVIEW, T. 2011. The health impacts of cold homes and fuel poverty.

MARTINS, J. 2005. The impact of the use of energy sources on the quality of life of poor communities. *Social Indicators Research,* 72**,** 373-402.

MARTISKAINEN, M., SOVACOOL, B. K., LACEY-BARNACLE, M., HOPKINS, D. & BOUZAROVSKI, S. 2020. New Dimensions of Vulnerability to Energy and Transport Poverty. *Joule,* 5.

MASERA, O. R., SAATKAMP, B. D. & KAMMEN, D. M. 2000. From linear fuel switching to multiple cooking strategies: a critique and alternative to the energy ladder model. *World development,* 28**,** 2083-2103.

MATTIOLI, G., PHILIPS, I., ANABLE, J. & CHATTERTON, T. 2019. Vulnerability to motor fuel price increases: Socio-spatial patterns in England. *Journal of Transport Geography,* 78**,** 98-114.

MIDDLEMISS, L. 2017. A critical analysis of the new politics of fuel poverty in England. *Critical Social Policy,* 37**,** 425-443.

MIDDLEMISS, L. 2019. Energy poverty or just poverty A response to 'what's the problem'. *LJMU Research Online*.

MIDDLEMISS, L. 2022a. Who is vulnerable to energy poverty in the Global North, and what is their experience? *Wiley Interdisciplinary Reviews: Energy and Environment,* 11**,** e455.

MIDDLEMISS, L. 2022b. Who is vulnerable to energy poverty in the Global Northand what is their experience.

MIDDLEMISS, L., AMBROSIO-ALBALÁ, P., EMMEL, N., GILLARD, R., GILBERTSON, J., HARGREAVES, T., MULLEN, C., RYAN, T., SNELL, C. & TOD, A. 2019. Energy poverty and social relations: a capabilities approach. *Energy Research & Social Science,* 55**,** 227-235.

MIDDLEMISS, L. & GILLARD, R. 2015. Fuel poverty from the bottom-up: Characterising household energy vulnerability through the lived experience of the fuel poor. *Energy Research & Social Science,* 6**,** 146-154.

MIDDLEMISS, L., GILLARD, R., PELLICER, V. & STRAVER, K. 2018. Plugging the Gap Between Energy Policy and the Lived Experience of Energy Poverty: Five Principles for a Multidisciplinary Approach. *Advancing Energy Policy.*

MIDDLEMISS, L., MULDER, P., HESSELMAN, M., FEENSTRA, M., HERRERO, T. S. & STRAVER, K. 2020. TNO-2020-energiearmoede-Dutch white paper, energy poverty and energy transition.

MIDDLEMISS, L. & PARRISH, B. D. 2010. Building capacity for low-carbon communities: The role of grassroots initiatives. *Energy Policy,* 38**,** 7559-7566.

MIDDLEMISS, L. & SIMCOCK, N. 2019. UK POVERTY. *Energy poverty or just poverty? A response to 'what's the problem?'* [Online]. Available from: https://www.whatstheproblem.org.uk/blog/energy-poverty-or-just-poverty-a-response-to-whats-the-problem.

MINIACI, R., SCARPA, C. & VALBONESI, P. 2014. Energy affordability and the benefits system in Italy. *Energy Policy,* 75**,** 289-300.

MOORE, R. 2012. Definitions of fuel poverty: Implications for policy. *Energy Policy,* 49**,** 19-26.

NAGEL, E. 1962. The structure of science: problems in the logic of scientific explanation. *Philosophy,* 37.

NATIONAL STATISTICS, U. 2022. Anuual Fuel Poverty Statistics in England. *In:* DEPARTMENT FOR BUSINESS, E. I. S. (ed.). England UK Government.

NEA, N. E. A. 2016. "13th Five-Year Plan (2016-2020)" for energy development. China.

NEA, N. E. A. 2018. Observation on the growth path of China's power grid reform and opening up.

NGUYEN, C. P. & SU, T. D. 2022. The influences of government spending on energy poverty: Evidence from developing countries. *Energy,* 238.

NIEROP, S. 2014. Energy poverty in Denmark. *Denmark: Aalborg University*.

NUSSBAUM, M. & SEN, A. 1993. Capability and well‐Being.

NUSSBAUMER, P., BAZILIAN, M. & MODI, V. 2012. Measuring energy poverty: Focusing on what matters. *Renewable and Sustainable Energy Reviews,* 16**,** 231-243.

NYE, D. E. 1999. Consuming power: a social history of american energies. 42**,** 137-138.

ONS 2011a. Neighbourhood statistics: Census 2011.

ORMANDY, D. & EZRATTY, V. 2012. Health and thermal comfort: From WHO guidance to housing strategies. *Energy Policy,* 49**,** 116-121.

PACHAURI, S. & JIANG, L. 2008. The household energy transition in India and China. *Energy Policy,* 36**,** 4022-4035.

PACHAURI, S., MUELLER, A., KEMMLER, A. & SPRENG, D. 2004. On measuring energy poverty in Indian households. *World Development,* 32**,** 2083-2104.

PACHAURI, S. & SPRENG, D. 2011. Measuring and monitoring energy poverty. *Energy Policy,* 39**,** 7497-7504.

PELZ, S., PACHAURI, S. & GROH, S. 2018. A critical review of modern approaches for multidimensional energy poverty measurement. *WIREs Energy and Environment,* 7.

PENG, W., HISHAM, Z. & PAN, J. 2010. Household level fuel switching in rural Hubei. *Energy for Sustainable Development,* 14**,** 238-244.

PERREAULT, T. & VALDIVIA, G. 2010. Hydrocarbons, popular protest and national imaginaries: Ecuador and Bolivia in comparative context. *Geoforum,* 41**,** 689-699.

PHIMISTER, E., VERA-TOSCANO, E. & ROBERTS, D. 2015. The dynamics of energy poverty: evidence from Spain. *Economics of Energy & Environmental Policy,* 4**,** 153-166.

POBLETE-CAZENAVE, M., PACHAURI, S., BYERS, E., MASTRUCCI, A. & VAN RUIJVEN, B. 2021. Global scenarios of household access to modern energy services under climate mitigation policy. *Nature Energy,* 6**,** 824-833.

POPPER, K. 2005. *The logic of scientific discovery*, Routledge.

PRC, T. S. C. I. O. O. T. P. S. R. O. C. 2021. China's practice of poverty alleviation white paper (In Chinese).

PYE, S. & DOBBINS, A. 2015. Energy poverty and vulnerable consumers in the energy sector across the EU: analysis of policies and measures.

REAMES, T. G. 2016. Targeting energy justice: Exploring spatial, racial/ethnic and socioeconomic disparities in urban residential heating energy efficiency. *Energy Policy,* 97**,** 549-558.

REAMES, T. G., REINER, M. A. & STACEY, M. B. 2018. An incandescent truth: Disparities in energy-efficient lighting availability and prices in an urban U.S. county. *Applied Energy,* 218**,** 95-103.

REN, B., LI, H., SHI, J., MA, N. & QI, Y. 2022. Detecting the control and dependence relationships within the global embodied energy trade network. *Energy,* 238**,** 121678.

ROBINSON, C. 2019. Energy poverty and gender in England: A spatial perspective. *Geoforum,* 104**,** 222-233.

ROBINSON, C., BOUZAROVSKI, S. & LINDLEY, S. 2018a. Multiple vulnerabilities? Interrogating the spatial distribution of energy poverty measures in England. *Energy Poverty and Vulnerability A Global Perspective.* Routledge.

ROBINSON, C., BOUZAROVSKI, S. & LINDLEY, S. 2018b. Multiple vulnerabilities? Interrogating the spatial distribution of energy poverty measures in England. *Energy Poverty and Vulnerability A Global Perspective.* Routledge.

ROBINSON, C., LINDLEY, S. & BOUZAROVSKI, S. 2019. The Spatially Varying Components of Vulnerability to Energy Poverty. *Annals of the American Association of Geographers,* 109**,** 1188-1207.

ROBINSON, C. & MATTIOLI, G. 2020. Double energy vulnerability: Spatial intersections of domestic and transport energy poverty in England. *Energy Research & Social Science,* 70.

ROBINSON, C., YAN, D., BOUZAROVSKI, S. & ZHANG, Y. 2018c. Energy poverty and thermal comfort in northern urban China: A household-scale typology of infrastructural inequalities. *Energy and Buildings,* 177**,** 363-374.

ROMERO, J. C., LINARES, P. & LÓPEZ, X. 2018. The policy implications of energy poverty indicators. *Energy Policy,* 115**,** 98-108.

SAHEB, Y., CALCAGNO, S., KOSTOV, P., BODIS, K., VONDUNG, F. & THEMA, J. 2019. European energy poverty index (EEPI).

SAKKA, A., SANTAMOURIS, M., LIVADA, I., NICOL, F. & WILSON, M. 2012. On the thermal performance of low income housing during heat waves.

SALMAN, M., ZHA, D. & WANG, G. 2022. Assessment of energy poverty convergence: A global analysis. *Energy,* 255.

SANTAMOURIS, M., PARAVANTIS, J. A., FOUNDA, D., KOLOKOTSA, D., MICHALAKAKOU, P., PAPADOPOULOS, A. M., KONTOULIS, N., TZAVALI, A., STIGKA, E. K. & IOANNIDIS, Z. 2013. Financial crisis and energy consumption: A household survey in Greece. *Energy and Buildings,* 65**,** 477-487.

SAREEN, S., THOMSON, H., TIRADO HERRERO, S., GOUVEIA, J. P., LIPPERT, I. & LIS, A. 2020. European energy poverty metrics: Scales, prospects and limits. *Global Transitions,* 2**,** 26-36.

SAWHNEY, A. 2013. Renewable energy policy in India: Addressing energy poverty and climate mitigation. *Review of Environmental Economics and Policy,* 7**,** 296-312.

SHOVE, E. & WALKER, G. 2010. Governing transitions in the sustainability of everyday life. *Research Policy,* 39**,** 471-476.

SIKA, P., VIDOVÁ, J. & RIEVAJOVÁ, E. 2020. Regional View on Housing of the Marginalized Roma Population in the Slovak Republic. *Sustainability,* 12**,** 5597.

SIKSNELYTE-BUTKIENE, I., STREIMIKIENE, D., LEKAVICIUS, V. & BALEZENTIS, T. 2021. Energy poverty indicators: A systematic literature review and comprehensive analysis of integrity. *Sustainable Cities and Society,* 67**,** 102756.

SIMCOCK, N., JENKINS , K., LACEY-BARNACLE, M., MARTISKAINEN, M., MATTIOLI, G. & HOPKINS, D. 2021. Identifying double energy vulnerabilityA systematic and narrative review of groups at-risk of energy and transport poverty in the global north. *Energy Research & Social Science*.

SIMCOCK, N., THOMSON, H., PETROVA, S. & BOUZAROVSKI, S. 2018. *Energy Poverty and Vulnerability A Global Perspective*, Routledge.

SIMOES, S. G., GREGÓRIO, V. & SEIXAS, J. 2016. Mapping Fuel Poverty in Portugal. *Energy Procedia,* 106**,** 155-165.

SNELL, C. & BEVAN, M. Fuel poverty and disability: a review of existing knowledge conducted for Eaga Charitable Trust.

SNELL, C., BEVAN, M. & THOMSON, H. 2015. Justice, fuel poverty and disabled people in England. *Energy Research & Social Science,* 10**,** 123-132.

SOKOŁOWSKI, J., LEWANDOWSKI, P., KIEŁCZEWSKA, A. & BOUZAROVSKI, S. 2020. A multidimensional index to measure energy poverty: the Polish case. *Energy Sources, Part B: Economics, Planning, and Policy,* 15**,** 92-112.

SOVACOOL, B. K. 2012. The political economy of energy poverty: A review of key challenges. *Energy for Sustainable Development,* 16**,** 272-282.

SOVACOOL, B. K. 2015. Fuel poverty, affordability, and energy justice in England: Policy insights from the Warm Front Program. *Energy,* 93**,** 361-371.

SOVACOOL, B. K. & DWORKIN, M. H. 2015. Energy justice: Conceptual insights and practical applications. *Applied Energy,* 142**,** 435-444.

SOVACOOL, K. B., UPHAM, P., MARTISKAINEN, M., JENKINS, E. H. K., CONTRERAS, A. T., GERARDO & SIMCOCK, N. 2023. Policy prescriptions to address energy and transport poverty in the United Kingdom. *Nature Energy*.

SPINNEY, J., GREEN, N., BURNINGHAM, K., COOPER, G. & UZZELL, D. 2012. Are we sitting comfortably? Domestic imaginaries, laptop practices, and energy use. *Environment and Planning A,* 44**,** 2629-2645.

STRAKOVA, D. 2014. Energy poverty in Slovakia.

TANG, X., CHEN, X. & YANG, C. 2016. A study on the system dilemma and countermeasures of energy poverty in constructing new agricultural and pastoral areas in Tibet. *Journal of Leshan Normal University,* 31**,** 93-100.

TANG, X. & LIAO, H. 2014. Energy poverty and solid fuels use in rural China: Analysis based on national population census. *Energy for Sustainable Development,* 23**,** 122-129.

TARDY, F. & LEE, B. 2019. Building related energy poverty in developed countries – Past, present, and future from a Canadian perspective. *Energy and Buildings,* 194**,** 46-61.

THOMSON, H. 2020. Quantification beyond expenditure. *Nature Energy*.

THOMSON, H. & BOUZAROVSKI, S. 2018. Addressing energy poverty in the European Union: State of play and action. *EU Energy Poverty Observatory.*

THOMSON, H., BOUZAROVSKI, S. & SNELL, C. 2017a. Rethinking the measurement of energy poverty in Europe: A critical analysis of indicators and data. *Indoor and Built Environment,* 26**,** 879-901.

THOMSON, H., BOUZAROVSKI, S. & SNELL, C. 2017b. Rethinking the measurement of energy poverty in Europe: A critical analysis of indicators and data. *Indoor Built Environ,* 26**,** 879-901.

THOMSON, H. & SNELL, C. 2013. Quantifying the prevalence of fuel poverty across the European Union. *Energy Policy,* 52**,** 563-572.

UN. 2015. *Sustainable Development Goals-7 Affodable and Clean Energy* [Online]. Available: https://www.undp.org/sustainable-development-goals#affordable-and-clean-energy [Accessed].

UNDP 2019. Human Development Report 2019. Beyond income, beyond averages, beyond today: Inequalities in human development in the 21st century. New York.

ÜRGE-VORSATZ, D. & TIRADO HERRERO, S. 2012. Building synergies between climate change mitigation and energy poverty alleviation. *Energy Policy,* 49**,** 83-90.

VAN DER KROON, B., BROUWER, R. & VAN BEUKERING, P. J. H. 2013. The energy ladder: Theoretical myth or empirical truth? Results from a meta-analysis. *Renewable and Sustainable Energy Reviews,* 20**,** 504-513.

VANDENTORREN, S., BRETIN, P., ZEGHNOUN, A., MANDEREAU-BRUNO, L., CROISIER, A., COCHET, C., RIBÉRON, J., SIBERAN, I., DECLERCQ, B. & LEDRANS, M. 2006. August 2003 heat wave in France: risk factors for death of elderly people living at home. *The European Journal of Public Health,* 16**,** 583-591.

VOGEL, E. 2016. Regional Power and the Power of the Region: Resisting Dam Removal in the Pacifi c Northwest. *Contentious Geographies.* Routledge.

WALKER, G. 2011. The role for 'community' in carbon governance. *Wiley Interdisciplinary Reviews: Climate Change,* 2**,** 777-782.

WALKER, G. & DAY, R. 2012. Fuel poverty as injustice: Integrating distribution, recognition and procedure in the struggle for affordable warmth. *Energy Policy,* 49**,** 69-75.

WALKER, R., MCKENZIE, P., LIDDELL, C. & MORRIS, C. 2012. Area-based targeting of fuel poverty in Northern Ireland: An evidenced-based approach. *Applied Geography,* 34**,** 639-649.

WANG, B., KE, R.-Y., YUAN, X.-C. & WEI, Y.-M. 2014a. China's regional assessment of renewable energy vulnerability to climate change. *Renewable and Sustainable Energy Reviews,* 40**,** 185-195.

WANG, J. & DONG, R. 2005. The influence of the comprehensive rural energy construction on indoor air quality in western rural area. *Renewable Energy,* 5**,** 1-4.

WANG, K., WANG, Y.-X., LI, K. & WEI, Y.-M. 2015. Energy poverty in China: An index based comprehensive evaluation. *Renewable and Sustainable Energy Reviews,* 47**,** 308-323.

WANG, Q., FAN, J., KWAN, M.-P., ZHOU, K., SHEN, G., LI, N., WU, B. & LIN, J. 2023. Examining energy inequality under the rapid residential energy transition in China through household surveys. *Nature energy*.

WANG, Q., WANG, L., MI, Z. & LI, K. 2014b. Impact of China's energy poverty eradication policy on climate change. *Climate Change,* 36**,** 39-43.

WANG, X. & FENG, Z. 2002. Retrospection and expectation on energy consumptions of rural households in China. *Journal of Agricultural Machinery,* 33**,** 125-128.

WEI, Y. 2013. *Energy Economics*

WEI, Y., LIAO, H., WANG, K. & LIANG, Q. 2014. China Energy Report (2014): Energy Poverty Research. Science Press: Beijing, China.

WHITE, L. V. & SINTOV, N. D. 2019. Health and financial impacts of demand-side response measures differ across sociodemographic groups. *Nature Energy,* 5**,** 50-60.

WU, G., PU, Y. & SHU, T. 2021. Features and evolution of global energy trade network based on domestic value-added decomposition of export. *Energy,* 228**,** 120486.

WU, S. & ZHENG, X. 2016. Elimination of rural energy poverty requires attention to systematic assessment. *China Energy News***,** 1-2.

WU, W., LI, Y. & LIU, Y. 2022. What constrains impoverished rural regions: A case study of Henan Province in central China.

XIA, W., MURSHED, M., KHAN, Z., CHEN, Z. & FERRAZ, D. 2022. Exploring the nexus between fiscal decentralization and energy poverty for China: Does country risk matter for energy poverty reduction? *Energy,* 255.

XIE, L., HU, X., ZHANG, X. & ZHANG, X.-B. 2022. Who suffers from energy poverty in household energy transition? Evidence from clean heating program in rural China. *Energy Economics,* 106.

XIE, L. & WU, T. 2022. The effects of energy price distortions on household consumption in China. *Journal of Natural Resources (in Chinese)*.

XIE, L., WU, T. & AN, L. 2021. The impact of electricity price distortion on household consumption. *Journal of Environmental Economics,* 6**,** 40-64.

XIE, M. 2010. Research on the problem about energy poverty and rural energy build in the underdeveloped resource-rich region of China. *Economic Research Guide***,** 29-31.

XU, S. & WANG, T. 2017. On energy equity and China's policy choices. *Energy & Environment,* 28**,** 288-301.

XUE, B. 2017. Cooperative prevention and control of air pollutants and greenhouse gases. *Reform***,** 78-80.

YANG, L. & YANG, L. 2022. The change logic and future development of the Minimum Living Security System -- Based on the analysis of policy dependency (In Chinese). *Social Development Research***,** 18.

YANG, Z., YAN, S., ZHANG, H. & MA, M. 2017. Economic analysis of household energy poverty in Inner Mongolia pastoral areas based on differences in environmental endowments. *Resources and Environment***,** 226-227.

YIP, A. O.-N., MAH, D. N.-Y. & BARBER, L. B. 2020. Revealing hidden energy poverty in Hong Kong: a multi-dimensional framework for examining and understanding energy poverty. *Local Environment,* 25**,** 473-491.

YUAN, L., GAN, S. & LI, W. 2018. Measurement analysis on village energy poverty in Xuanwei city of Yunnan province. *Journal of Kunming University of Science and Technology,* 18**,** 63-69.

ZHANG, D., LI, J. & HAN, P. 2019. A multidimensional measure of energy poverty in China and its impacts on health: An empirical study based on the China family panel studies. *Energy Policy,* 131**,** 72-81.

ZHANG, L., MIDDLEMISS, L. & PHILIPS, I. 2023. Quantifying the spatio-temporal evolution of energy poverty in China from 2010 to 2018 through a representative household survey. *In:* (SRI), S. R. I. (ed.) *No. 124, SRI Papers (Online) ISSN 1753-1330.* The University of Leeds, Leeds, United Kingdom.

ZHANG, P. & WANG, G. 2005. Contribution to reduction of CO_2 and SO_2 emission by household biogas construction in rural China: analysis and pr ediction. *Transactions of the CSAE,* 21**,** 147-151.

ZHAO, X., CHEN, H., MA, Y., GAO, Z. & XUE, B. 2018. Spatio-temporal variation and its influencing factors of rural energy poverty in China from 2000 to 2015. *Geographical Research,* 37**,** 1115-1126.

ZHENG, X. & FU, L. 2015. Electricity cross-subsidy is a "double dividend" with Chinese characteristics. *China Energy News*.

ZHOU, Q. & SHI, W. 2019. Socio-economic transition and inequality of energy consumption among urban and rural residents in China. *Energy and Buildings,* 190**,** 15-24.

ZHU, C. 2007. Accelerate the construction of energy and electricity in rural China. *Shanxi Energy and Conservation,* 44**,** 12-14.

ZHU, L. & YE, H. 2012. Analysis of emission reduction effect and cost benefit of rural biogas project. *China population, resources and environment,* 22**,** 426-429.

ZHU, L. & ZHAO, Y. 2012. Analysis of Methane Emission Reduction Effect and Factors on Farmers'Adoption Behavior. *China population, Resources and Environment,* 22**,** 35-39.

ZOU, X., WAN, Y., LI, Y. & GAO, Q. 2010. The effect of energy-saving and emission reduction of solar energy resource utilization in rural areas of china. *Renewable Energy Resources,* 28**,** 93-98.