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Energy poverty in China: An index based comprehensive evaluation

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Abstract: Energy poverty has got increasing attention during the latest three decades. Measuring energy poverty is the premise of policy making to alleviate energy poverty. There is no unified energy poverty measurement that has been widely accepted. This paper reviews the commonly used energy poverty measurements through classifying them into three categories: energy service availability, energy service quality, and satisfaction of energy demand for human's survival and development. This paper also analyzes the suitability of the commonly used energy poverty measurement for China from the prospective of data availability and index applicability. Furthermore, we construct a new energy poverty comprehensive evaluation index in this study, and the index is illustrated to evaluate regional energy poverty in China. The evaluation results indicate that China's energy poverty showed an alleviating trend from 2000 to 2011, and during this period, 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. In addition, China's regions show different characteristics of energy poverty. For example, Middle reaches of Yangtze River region showed the worst energy availability and Eastern coastal region showed the worst energy management completeness. Several policy implications for energy poverty alleviation are also proposed in this study, including, for instance, increasing investment on energy infrastructure, and spreading energy management organization in rural area; decreasing relative cost on household commercial energy consumption, and encourage the utilization of modern, clean and efficient household energy consumption equipment.
Keywords: Energy poverty; Energy service; Energy consumption; China

1 Introduction

Energy poverty is a pressing issue which should be addressed, as it could restrict the realization of Millennium Development Goals[†], deprive the basic rights of some society's members and hinder sustainable development of international society. In 2011, about 1.3 billion people worldwide lacked access to electricity and 2.6 billion people relied on traditional use of biomass for cooking [1]. It is predicted that, in 2030, there will still be 1 billion people lack access to electricity and 2.6 billion people lack access to clean cooking facilities [2]. Although China has experienced unprecedented economic growth in recent years, energy poverty still exists in China's household sector. Energy poverty, which performed as unfair resources distribution, unsustainable energy consumption structure and high energy costs in China, could hinder the progress of ensuring and improving the people's wellbeing, and restrict the realization of China's social economy medium and long-term development goals.

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[†]The Millennium Development Goals are eight international development goals established following the adoption of the United Nations Millennium Declaration in 2000: to eradicate extreme poverty and hunger, to achieve universal primary education, to promote gender equality and empower women, to reduce child mortality, to improve maternal health, to combat HIV/AIDS, malaria, and other diseases, to ensure environmental sustainability, and to develop a global partnership for development.

The “energy poverty” used in this paper represents the concepts of fuel poverty and energy poverty, as China’s energy poverty has the features of both of them [3]. Energy poverty concept was originated from the British fuel use rights movement in early 1970s, and the core concept was inability to purchase energy services. Boardman defined energy poverty as that households could not afford adequate energy services [4]. Hills proposed a new definition of energy poverty called “low income high cost” [5]. Both of these definitions are refined and then officially adopted by UK government [6]. The above mentioned energy poverty concepts are often used in developed countries such as the UK, which focus on energy costs and define energy poverty from economic perspectives.

Some scholars and organizations define energy poverty in terms of access to energy services. United Nations Development Program (UNDP) expanded energy poverty as “an absence of sufficient choice in accessing adequate, affordable, reliable, quality, safe and environmentally benign energy services” [7]. IEA defined energy poverty as a lack of access to clean and commercial fuels, efficient equipment and electricity and a high dependence on traditional biomass, which is mostly burned in inefficient and polluting stoves [8]. IEA’s concept of energy poverty has been widely used in developing countries.

Human basic energy needs which include lighting, cooking and heating, are considered as a significant perspective to study energy poverty. Appreciating the complex nature of energy poverty, the United Nations Secretary General’s Advisory Group on Energy and Climate Change [9] and Sovacool et al. [10] expanded the dimension of basic energy needs.

Designing and constructing an energy poverty comprehensive index is the basis to understand and identify energy poverty. Scientific evaluating energy poverty is the basis and guarantee for formulating scientific policies to alleviate energy poverty and implementing relevant policies. In order to provide the theoretical supports for constructing energy poverty comprehensive measurement index, this paper reviews the energy poverty measurements which have been used, and analyses the applicability of these energy poverty measurements for China from the prospective of data availability and content suitability. Furthermore, this paper constructed a novel energy poverty comprehensive evaluation index for China, based on those indicators which could be directly applied, and according to data availability and the characteristics of social and economic development in China. Current characteristics of energy poverty of China’s 8 economic regions and 30 provinces were summarized, and furthermore, the energy poverty alleviation policies were proposed based on the comprehensive evaluation results of China’s energy poverty.

The paper is organized as follows. The next section classifies the main energy poverty measurements into three categories: energy service availability, energy service quality, and satisfaction of energy demand for human’s survival and development. Then, this section reviews and compares the main energy poverty measurements. The third section analyses the suitability of the main energy poverty measurements for China from the prospective of data availability and index applicability. The comprehensive evaluation index for evaluating China’s energy poverty and the methodology are introduced in the fourth section. The fifth section analyses the results of energy poverty comprehensive index of China’s 30 provinces, and summarizes the main characterizes from four dimensions: energy services availability, energy consumption cleanliness, energy management completeness, and household energy affordability and energy efficiency. The sixth and seventh sections compare energy poverty of China’s 8 economic regions. Policy implications of energy poverty alleviation for China’s 30 provinces are addressed in the eighth section, and the final section concludes the whole paper.

2 Reviews on energy poverty measurements

According to the definitions of energy poverty, Table 1 summarizes and reviews the commonly used energy poverty assessment indicators and measurements, and classifies them into three categories: energy service availability, energy service quality, and satisfaction of energy demand for human’s survival and development. These three categories are further reviewed and discussed in

Sections 2.1 to 2.3.

[Insert Table 1 here]

2.1 Energy service availability based measurements

IEA's definition of energy poverty is widely accepted and applied, and the core of which is modern energy non-availability. Pachauri and Spreng considered there is a close relationship between energy poverty and energy availability and thus suggested evaluating energy poverty in terms of the access to modern energy [11]. The energy service availability based measurements were commonly constructed through a set of indicators including share of population with access to electricity, and consumption of traditional biomass etc.

Pachauri et al. presented a novel two-dimensional measure of energy poverty as well as energy distribution, and they grouped households with respect to their access to three different energy service levels in the dimension of energy availability [12]. Practical Action designed a set of indicators that assessed energy service availability from three aspects: household fuels, electricity, and mechanical power [13]. Mirza and Szirmai identified seven indicators: frequency of buying or collecting a source of energy, distance from household travelled, means of transport used, household member's involvement in energy acquisition, time spent on energy collection per week, household health, and children's involvement in energy collection [14]. Based on these factors they developed a new index that is composited of energy deficiency indicator and energy inconvenience indicator to measure energy poverty in rural Pakistani. The multidimensional energy poverty index published in Oxford Poverty and Human Development Initiative (OPHI) measures energy poverty in five dimensions: cooking, lighting, household appliances, education, and communication, and has been used in African countries [15]. IEA first evaluated energy poverty by Energy Development Index (EDI) in 2004 [16]. EDI, a composite index that is commonly used in developing countries, focuses on two key dimensions: access to electricity and commercial energy. EDI has many advantages, such as easily computable, applicable and data available. But the EDI is more appropriate for the measurements of regional differences than the assessment of energy poverty status.

Energy service availability based measurements construct and use composited indicators to measure energy poverty. The rationale for composite indicators lies in the need for aggregated information at a level that makes analysis directly and flexible. Therefore, they can be used in various contexts and help reduce influence of selecting unsuitable fixed benchmark. However, emphasizing on its indicators corresponding to the research location, this approach requires adequate data.

2.2 Energy service quality based measurements

Some methods define "energy poverty line" which is familiar with the conventional monetary poverty line to measure energy poverty (e.g., [17,18]). Energy poverty line, an energy service quality based measurement, focuses on estimating the cost of access to energy service from economic perspective. However, there is no widely accepted energy poverty line [19].

This method mainly considers household energy consumed by energy poor and non-poor with respect to their economic levels. The poorest groups always use more inefficient fuels and unclean cooking facilities than that of middle and upper income groups [20], and spend more time and money to buy and collect energy [21], so they can be termed energy poor and bear heavy economic burden.

Setting energy poverty line to measure energy poverty can be roughly divided into two categories. The first category combines energy consumption and monetary poverty. For instance, Foster et al. designed an energy poverty line by calculating the average amount of energy being consumed by Guatemala households identified as living below the national monetarily poverty line (within a plus or minus 10% range of 1$ per day) [22]. The underlying assumption of this approach is that monetarily poor households are necessarily energy poor, which was questioned by Pachauri and

Spreng [11]. The second category defines energy poverty in terms of the share of energy consumption in total household expenditures and incomes. For example, Boardman considered people who spent more than 10 percent of their income to maintain comfortable indoor temperature are energy poor [23]. This method is refined and then officially adopted by the UK government [24,25]. However, Healy and Clinch questioned the applicability and practical maneuverability of the "10%" threshold [26]. Hills proposed a "low income and high cost" energy poverty method, which defines that people who should pay higher energy cost than the average level to maintain basic welfare and whose rest income is below the official poverty line as energy poor [5].

The indicators and standards of energy service quality based measurements represent the correlation between energy poverty and economic poverty. This approach originated earlier than the others, and the "10%" and "low income and high cost" methods have been accepted and applied by the UK government. However, these measurements lack strong theoretical basis and require detailed survey data, therefore, it has relatively weak applicability.

2.3 Measurements based on satisfaction of energy demand for human's survival and development

Measurements based on satisfaction of energy demand for human's survival and development focusing on estimating the physical energy consumption and the minimum energy amount for human's survival and development. These methods also require detailed and broader household survey data.

Foster et al. estimated the energy poverty line that meets basic energy needs is 2,154 kilowatt-hours per household per year by using data from Guatemala [22]. IEA assumed that a rural household (with five members) need about 250 kilowatt-hours electricity per year and an urban household need about 500 kilowatt-hours electricity per year [2]. Pachauri et al. presented a novel two-dimensional measure of energy poverty as well as energy distribution [12]. In the dimension of energy consumption, they use cross-regional data to define four classes of physical energy consumption per capita. Barnes used a demand based approach and defined energy poverty line as the threshold point. At or below this threshold point, a household just consume a basic level of energy and it should be considered as the energy poor [19].

Some studies do not directly link energy demand with energy poverty. However, these studies employ the estimation models for energy demand to measure energy poverty. For example, Revelle used engineering calculations to estimate basic energy needs in terms of types (e.g., lighting and stove), sizes, efficiencies, and intensities of use for energy equipment [27]. Krugmann and Goldemberg applied econometric model in some developing areas (such as Latin America, Asia and Africa), considering that the basic energy consumption is 27×103~37×103 Kcal per day per capita [28]. Godemberg associated Physical Quality of Life Index (PQLI) to calculate basic energy demand [29]. Practical Action designed indicators including minimum energy demand of six energy services, which present physical energy consumption in three dimensions: household, company and society, and describe aspects of energy basic demands in detail [13]. The United Nations Environment and Climate Change Advisory Group provided an energy services and access levels model (see Table 2) that divided energy needs into three incremental levels: basic human needs, productive uses, and modern society needs, and give per capita energy consumption ranges in these three levels [9]. Based on the energy services and access levels model, Shoibal and Tavoni added a European average level and calculated the energy consumption threshold in four levels [30]. Applying this model, they found that there were still 1.8 billion people in the world that cannot get enough energy for basic needs.

[Insert Table 2 here]

Usually, the measurements based on satisfaction of energy demand for human's survival and development are indirectly energy poverty measurements, which can be applied and accepted in various regions based on large scale surveys and engineering calculations. Because this method has no unified fixed calculation model, the thresholds of energy basic demand are chosen somewhat arbitrarily in the calculation process. Furthermore, the evaluation results are heavily affected by the chosen threshold due to the single indicator this method selects.

3 Applicability analysis of existing energy poverty measurements in China

3.1 Applicability analysis based on data availability

Getting reasonable and reliable data is the foundation of energy poverty evaluation. This paper analyzes the applicability of the above indicators and standards of energy poverty measurements for China from the perspective of data availability in this section. These indicators and standards are classified into three categories.

Firstly, the core data on those measurements or indicators and thresholds can be directly got in official statistical database in China. For example, EDI is commonly used in the comparison of energy poverty at regional and national levels. The data of its indicators such as share of population has access to electricity, per capita household electricity consumption, and share of commercial energy in total final energy consumption can be directly acquired in published statistics. Pachauri et al. presented a two-dimensional measure depending on energy service and energy consumption [12]. After slightly expanding or adjusting the assessment thresholds of the above indicators, they can be directly applied in China’s energy poverty assessment.

Secondly, part of the core data of those indicators and thresholds can be got in official statistical database in China, while the other part of the core data should be collected by large scale household survey. For instance, if the UK’s “10%” threshold is utilized to measure energy poverty, data on energy prices and incomes are available in statistical database, however, the residential types and areas, family sizes, building materials, energy facility efficiencies and other relevant data only can be obtained through survey [6,24]. Similarly, Practical Action indicators (e.g., household fuel availability and electricity availability) have relevant data in database except mechanical power data [13]. In addition, the indicators designed by Nussbaumer et al. are in the same case that only part of relevant data (e.g., household appliances amount) can be found in official statistical database [15].

The core data of those hardly-applied indicators and standards completely rely on large-scale survey. There are no statistical yearbooks in China which sort household energy consumption according to household income. Therefore, the measurement provided by Foster et al. [22] that needs the data on economic poor’s energy consumption, cannot be used in the case of China. In order to estimate household basic energy consumption, Barnes [19] and AGECC [9] conducted survey to search massive microscopic family data. Mirza and Szirmai presented an inconvenience indicator that includes extremely detailed data (e.g., the frequency, distance, traffic, adult engagement, child engagement, time and health in collection of traditional biomass energy) [14]. However, these data are barely found in China’s official statistics.

3.2 Applicable analysis based on indicators suitability

3.2.1 Indicators are not suitable

Lack of access to electricity is one important feature of energy poverty [8,12,13], therefore, the share of the population who has no access to electricity is considered as an important indicator in some energy poverty measurement (e.g., [15,16,31]). In the early 1980s, the Chinese government began to carry out a series of projects, such as rural electrification pilot and anti-poverty projects of electric power. Nowadays, China has basically solved the problem of electricity unavailable, and the ratio of access to electricity has reached to 98.7% by 2009 in rural China [32]. Therefore, such indicator is no longer suitable for energy poverty measurement in China since there is virtually no electricity unavailable problem and no obvious regional differences in the ratios of accessing to electricity presently.

Large numbers of residents rely on traditional biomass and have no access to clean cooking and heating facilities in rural China. In 2011, 60% of rural households still choose firewood as their primary fuel and there are just 13.2% households have kitchen ventilators. By contrast, instead of consuming traditional biomass, the majority of China's urban residents use relatively clean fuel and modern heating facilities. Table 3 shows the population in developing countries that has no access to clean cooking in 2010 and 2030 estimated by IEA [2]. It can be seen that Chinese people who have no access to clean cooking are mainly rural residents. Hence, indicators of involving traditional biomass and having no access to clean cooking and heating facilities (e.g., [9,12,13,14,15,19,22]) are not suitable for energy poverty evaluation in China's urban areas.

[Insert Table 3 here]

China's rural people often get traditional biomass by cutting trees [33]. However, this situation has been permanently changed because the Chinese government implemented the forest conservation policy to protect forest resources since more than a decade ago. Therefore, the indicators of cutting forest proposed by Mirza and Szirmai [14] are not suitable for energy poverty measurement in China's rural areas.

3.2.2 Indicators are suitable with further effort

The UK's "10%" indicator focuses on evaluating the economic burden that caused by household energy consumption. China's urban residents mainly consume commercial energy and rural residents also consume a certain amount of commercial energy. In this case, the increasing energy demand and rising energy prices are likely to cause the social cost burden. Therefore, "10%" threshold should be modified based on China's energy poverty status, because there are gaps in the levels of social and economic development and the living standards of residents between China and the UK. In addition, the commercial energy price is tightly controlled by the Chinese government through energy subsidies, which maintains commercial energy price relatively low. On the contrary, the UK's commercial energy price is determined by the market. In 2011, the average cost on power, fuel and heating consumption per capita per year in China's urban household were RMB 719.2. This consumption accounts for just 3.3% of the household income, which is far below the UK's "10%" thresholds. Obviously, it is more reasonable to set China's energy poverty line below 10%.

Utilizing the energy demand threshold denoted energy poverty line to identify the energy poor is a suitable measurement in China. However, the threshold should be adjusted based on the real condition of China. Fosteret al. [22], Pachaur et al. [12] and Barnes [19] respectively calculated the basic energy needs of households in Guatemala, India and Bangladesh, and measured their energy poverty levels. Their thresholds for energy poverty measurement cannot be directly applied in China's energy poverty measurements due to the differences (e.g., economy, climate, culture, social development, national policy, and international help for energy poverty elimination) between China and these nations. In order to set suitable thresholds to measure China's energy poverty, the energy consumption data of China's residents should be utilized to calculate the household basic energy demand first.

3.2.3 Indicators are suitable to be applied directly

There are still several commonly used energy poverty indicators can be applied directly in the measurements of China's energy poverty. For example, except for the population that has access to electricity, other indicators (e.g., per capita household electricity consumption, per capita commercial energy consumption, and share of commercial energy in total final energy use) of IEA's EDI [2,16,31,34] can be applied in China. In addition, Multidimensional Energy Poverty Index including household appliances amounts and fuel type indicators are useful in formulating China's energy poverty measurement framework [15]. Furthermore, Pachauri and Spreng designed a set of indicators, which contains household energy expenditure, investment of energy supply, and energy import and cooking facility amount [35]. These indicators also can be taken into account for China's energy poverty measurements.

Evaluating energy poverty is a prerequisite of formulating suitable policies for alleviating energy poverty. According to the applicability analysis of indicators which have been used in other energy poverty evaluation literatures, it can be concluded that the comprehensive evaluation of China's energy poverty can't directly employ the indicators and measurements which have been used before, because of the data absence and diversified evaluation aims. Most energy poverty indicators mentioned above employed survey data at household level, which is difficult to be sequentially obtained at present, since the large scale survey for household is rare in China. In addition, most energy poverty indicators focused on signal region and signal year, but this paper aims at evaluating energy poverty for the entire China both at the national and regional (provincial) levels, and providing sustainable and comparable evaluation results over time. Based on applicability analysis of the existing energy poverty measurements, this paper employed the indicators, which are suitable for direct application and suitable with further effort from the perspectives of data and context, to construct a new energy poverty comprehensive evaluation index for China. The comprehensive evaluation index and the evaluation results were shown in following sections.

4 China's energy poverty comprehensive index

4.1 Evaluation index for energy poverty

Based on the review of the indicators which are applicable for energy poverty evaluation in China, an index for China's energy poverty comprehensive evaluation is built. The comprehensive evaluation index (see Table 4) is composed of 4 categories, which are (1) energy service availability (*ESA*), (2) energy consumption cleanliness (*ECC*), (3) energy management completeness (*EMC*), and (4) household energy affordability and energy efficiency (*EAE*).

Energy service availability represents residential access to modern energy services, which is noted by 2 indicators, residential energy consumption and residential energy supply, and 7 measurements. Energy consumption cleanliness represents structure of residential energy consumption, which is noted by 2 indicators, percentage of low-carbon and commercial energy consumption, and 3 measurements. Energy management completeness represents improvement potential on energy management, which is composed of 2 indicators, management agencies and energy investment, and 3 measurements. Household energy affordability and energy efficiency represents residential behavior and energy affordability, which is measured by 3 indicators, energy expense, energy facilities and air pollution caused by residential energy use, and 10 measurements. To sum up, this index is composed of 4 categories, 9 indicators and 23 measurements.

[Insert Table 4 here]

4.2 Calculation method for energy poverty index

Since the dimensions and properties of the 23 measurements proposed in Table 4 are different, this paper processes them to dimensionless measurements with same direction, that is, the lower value indicates the better situation on energy poverty. The benefit and cost measurements become dimensionless values by Equations (1) and (2) as following:

$$y_i^t = \frac{\max_{i,t} x_i^t - x_i^t}{\max_{i,t} x_i^t - \min_{i,t} x_i^t} \qquad (1)$$

$$y_i^t = \frac{x_i^t - \min_{i,t} x_i^t}{\max_{i,t} x_i^t - \min_{i,t} x_i^t} \qquad (2)$$

where, x_i^t means the original value of the ith measurement at year t, y_i^t represents the dimensionless value of the ith measurement at year t ($0 \le y_i^t \le 1$). There are two threshold measurements, percentage of residential energy (electricity and fuel) expense to total expense per capita in urban areas, and percentage of residential fuel expense to total expense per capita in rural areas. This paper considers 8% as the threshold (α_i) for urban households and 2.5% for rural households. The threshold measurements were processed through Equations (3) and (4), respectively.

$$y_i^t = \begin{cases} \dfrac{(\alpha - x_i^t) - \min\limits_{i,t}(\alpha - x_i^t)}{\max\limits_{i,t}(\alpha - x_i^t) - \min\limits_{i,t}(\alpha - x_i^t)}, & x_i^t < \alpha_i \\ 0 & , \ x_i^t \ge \alpha_i \end{cases} \tag{3}$$

$$y_i^t = \begin{cases} \dfrac{x_i^t - \min\limits_{i,t} x_i^t}{\max\limits_{i,t} x_i^t - \min\limits_{i,t} x_i^t}, & x_i^t < \alpha_i \\ \dfrac{\alpha - \min\limits_{i,t} x_i^t}{\max\limits_{i,t} x_i^t - \min\limits_{i,t} x_i^t}, & x_i^t \ge \alpha_i \end{cases} \tag{4}$$

The weights of measurements are calculated by data-driven approach. In order to enhance the discrimination of the energy poverty index, this study stipulates that if the variation coefficient of a measurement is relative larger than others, then this measurement is assigned a larger weight, and vice versa. The assigned weights for all the measurements are shown in the parentheses in Table 4. Based on the dimensionless and weighting processes introduced above, the China's energy poverty comprehensive evaluation index can be calculated by Equation (5). The value on comprehensive index is from 0 to 100, and the values of the four categories, *ESA*, *ECC*, *EMC*, and *EAE* range in 0-35, 0-25, 0-20 and 0-20, respectively. The higher the value indicates the worse the situation on energy poverty.

$$CEPI^t = ESA^t + ECC^t + EMC^t + EAE^t = \sum_{i=1}^{n} w_i y_i^t \tag{5}$$

Where, $CEPI^t$ represents the value of China's energy poverty comprehensive index at year t, y_i^t is the value of the ith measurements at year t, w_i is the weight of the ith measurement.

5 Comprehensive evaluation of China's energy poverty

The comprehensive evaluation of energy poverty of China and its 30 provinces and 8 economic regions from 2000 to 2011 are reported in Table 5. For calculation and comparison convenience, China's 30 provinces are classified into 8 economic regions, including (1) Southern coast region (Guangdong, Fujian, Hainan), (2) Eastern coast region (Shanghai, Jiangsu, Zhejiang), (3) Northern coast region (Shandong, Hebei, Beijing, Tianjin), (4) Northeast region (Liaoning, Jilin, Heilongjiang), (5) Middle reaches of Yangtze River region (Hunan, Hubei, Jiangxi, Anhui), (6) Middle reaches of Yellow River region (Shaanxi, Henan, Shanxi, Inner Mongolia), (7) Southwest region (Guangxi, Yunnan, Guizhou, Sichuan, Chongqing), and (8) Northwest region (Gansu, Qinghai, Ningxia, Xinjiang).

[Insert Tale 5 here]

5.1 China’s energy poverty comprehensive index shows a decreasing trend

China’s energy poverty comprehensive index shows decreasing trend from 2000 to 2011 (see Fig. 1). The value of China’s energy poverty comprehensive index in 2011 is 74, which decreases by 9 points compared to 2000.

[Insert Fig. 1 here]

Energy poverty situations in Anhui, Henan, Hebei, Shanxi and Jiangxi provinces are relatively significant, and the average value from 2000 to 2011 of Anhui province is 87, which is ranked 1st among China’s 30 provinces. The average values of energy poverty comprehensive index of Qinghai, Beijing, Tianjin, Sichuan and Guangxi are relatively low, indicating that the energy poverty situations of these provinces are not significant, and the structure of residential energy consumption is sustainable, compared with other Chinese provinces. Fig. 2 shows the mean value of energy poverty comprehensive index of China’s 30 provinces from 2000 to 2011.

[Insert Fig. 2 here]

The most significant achievement of China's effort on eliminating energy poverty is the progress of national electrification. Since 1980s, China has progressively realized national coverage of electricity. In 1994, the last 28 counties, which had no electricity before, achieved power supply, and the electricity coverage rate in rural areas had reached more than 95%. In 1996, 14 provinces and municipalities in China took the lead in extending power supply to every village and every household. By 2010, China's national electricity coverage rate had reached 99.7% and China had achieved full coverage of electricity in all urban areas. During the same period, China accelerated the rural power grid reconstruction and upgrading project. From 1998 to 2001, the Chinese government completed three major tasks: the reconstruction of rural power grid, the reformation of power supply management system in rural areas, and the unification of urban and rural electricity prices. In addition, from the beginning of 2010, the Chinese government has launched a new round of rural power grid reconstruction project. These efforts helped China to eliminate its energy poverty situation and decreased the energy poverty comprehensive index at the national level.

5.2 Energy service availability index improves slightly

China’s energy service availability index improves slightly from 2000 to 2011, the value decreases from 33 in 2000 to 31 in 2011. Fig. 3(a) shows change trend of energy service availability index of China from 2000 to 2011.

[Insert Fig. 3 here]

Based on the mean value of energy service availability index of 30 provinces from 2000 to 2011 (see Fig. 4(a)). Households in Jiangxi, Guangxi, Hainan, Hunan, and Hubei have relatively more difficulties in getting and consuming modern residential energy. Households in Tianjin, Beijing, Liaoning, Qinghai and Xinjiang consume more modern residential energy than other Chinese provinces, and the supply capacities of these provinces are larger than others. The mean values of energy service availability index of Jiangxi and Tianjin are 34 and 25, respectively.

[Insert Fig. 4 here]

The indicator of residential energy consumption is the most important measurement for energy service availability. Take the measurement of residential electricity consumption as an instance, it can be noticed that in the last 30 years, China's residential electricity consumption maintains a relatively fast growth rate and the gap of residential electricity consumption between urban and rural areas is narrowing. Chinese per capita household electricity consumption reached 417.1 kWh in 2011, which is nearly 20 times more than that in 1985 (see Fig. 5). In 2011, the residential electricity consumptions of China's urban and rural areas were 320.2 billion kWh and 241.8 billion kWh respectively, which increased by 221.2% and 258.2% compared to those in 2000. The urban and rural residential electricity consumptions took up to 57% and 43%, respectively, and the gap between these two percentages has narrowed some 5% compared to that in 2000.

[Insert Fig. 5 here]

During the study period, the residential commercial energy consumption of China experienced a sharp increase. The per capita residential commercial energy consumption in 2011 amounted to 278.3 kg of coal equivalent (kce), which is 2.33 times of that in 1997 (see Fig. 6). In specific, the per capita residential commercial energy consumption in urban areas is 322.0 kce (including 38.1 cubic meters of natural gas and 463.5 kWh of electricity), which is 1.4 times of that in rural areas (1.3 times for natural gas and 346.4 times for electricity). China's residential natural gas consumption was only 2.12 billion cubic meters in 1997, while it increased to 18.7 billion cubic meters in 2011.

[Insert Fig. 6 here]

From the perspective of regional energy service availability difference, it can be found that, firstly, the average per capita residential electricity consumptions of Beijing, Tianjin and Liaoning during the study period were 507.9kWh, 352.2kWh and 292.6kWh, respectively, which are 122%, 54% and 28% higher than the national average level. Contrarily, the average level of Jiangxi, Guangxi and Hainan were 133.9kWh, 162.2kWh, and 197.2kWh, respectively, which just account for 59%, 71% and 86% of the national average level.

Secondly, similar situation appeared in the per capita natural gas consumption measurement. The consumptions of Beijing and Tianjin, which have well-constructed natural gas supply infrastructure and government policy support, were 33.9 and 26.4 cubic meters. However the consumptions of Jiangxi, Guangxi and Hainan, which have poor natural gas resource endowment, were just 0.74, 1.12 and 0.76 cubic meters, respectively.

Thirdly, the advantage of municipal infrastructure of Beijing and Tianjin are also appeared in the capacity of steam supply in cities for centralized heating system. The average capacities of steam supply in these two metropolis areas were 1932.8 and 4910.1 tons of steam per hour. However, Jiangxi, Guangxi and Hainan are all located in southern China which has no centralized heating service at urban area during winter, and residents in these areas need to use distributed household heating systems which are considered have comparatively lower energy utilization efficiency than centralized heating system.

Fourthly, the economic less-developed provinces of Jiangxi, Guangxi and Hainan also had poor energy supply infrastructures in the rural areas. The number of rural agency for supplying high quality straws gas in these provinces were just 0.37, 0.04 and 0.02 per million people, which are quite lower than the national average level of 1.5 per million people.

5.3 Energy consumption cleanliness index shows no significant change

In this paper, energy consumption cleanliness represents the households' consumption of commercial and low carbon energy. At the national level of China, energy consumption cleanliness index shows no significant change from 2000 to 2011 (see Fig. 3(b)), and the value of index fluctuates between 15 and 17.

Fig. 4(b) shows the mean values of energy consumption cleanliness index from 2000 to 2011 of 30 provinces. The structure of residential energy consumption of Anhui, Hebei, Henan, Shanxi and

Inner Mongolia are traditional and relatively high in carbon. The mean value of Anhui is 22 which is highest among provinces. The performances of energy consumption cleanliness are high in Qinghai, Guangxi, Sichuan, Yunnan, and Hubei, and the mean value of Qinghai is 7 which is ranked first in China.

Two major indicators for energy consumption cleanliness are the percentage of non-solid fuel to commercial energy of household sector and the percentage of residential traditional biomass consumption. During the study period, it can be found that, the percentage of solid fuel consumption in the total commercial energy consumption of China's urban and rural households decreased gradually since the beginning of the 2000s (see Fig. 7). In 2001, the consumption of solid fuel took up 27.8% in commercial energy consumption of urban households, while the percentage dropped to 7.8% in 2011. It means that the electricity and other non-solid commercial energy had gradually replaced coal and other solid energy and became the major residential energy in China's urban households. In addition, in 2001, the consumption of solid fuel took up 74.9% in commercial energy consumption of rural households, while the percentage dropped to 54.8% in 2011. It indicates that solid fuel was still the major residential energy in China's rural households. In 2011, there were 60.2% and 26.1% of rural households still using firewood and coal as their main cooking fuel, and the percentage of rural households which were using coal gas and natural gas as their cooking fuel was only 11.9%, and percentage of rural households which were using electricity as their cooking fuel was only 0.8%.

[Insert Fig. 7 here]

Since 1997, the total consumption of traditional biomass in China's rural areas kept falling, but the per capita consumption of traditional biomass showed an upward trend (see Fig. 8). From 1997 to 2011, the total residential consumption of traditional biomass decreased at an average annual rate of 1%. For the same period, the per capita residential consumption of traditional biomass increased by approximate 20% and reaching 0.4 tons of coal equivalent (tce) per person. In 2011, China’s total residential consumption of traditional biomass in rural areas is about 270 million tce, accounting for 24% of world’s traditional biomass consumption.

[Insert Fig. 8 here]

Different regions also showed very different performances on non-solid fuel consumption percentages and traditional biomass consumption percentages. For example, the performances of energy consumption cleanliness are high in Qinghai and Guangxi but low in Anhui, Hebei, Henan and Shanxi. The relatively high percentages of non-solid fuel consumption, which is considered cleaner and more efficient than solid fuel, in Qinghai (52.6%) and Guangxi (93.8%), and the relatively high percentage of traditional biomass consumption, which is considered less efficient and more pollutional than commercial energy, in Anhui (90.1%), Hebei (69.8%), Henan (66.6%) and Shanxi (50.3%), explains the regional difference on the performance of energy consumption cleanliness in China.

5.4 Energy management completeness index decreases with fluctuations

Energy management completeness represents the potential of alleviating energy poverty from the perspective of government’s effort. From 2000 to 2011, China’s energy management completeness index decreases with fluctuation, the value decreases from 19 in 2000 to 16 in 2011 (see Fig. 3(c)).
At the provincial level, the performance of residential energy management in Beijing, Inner Mongolia, Liaoning, Yunnan and Guizhou are relatively higher, and the mean value of the index of Beijing is 14. However, the performance of energy management completeness in Anhui, Henan, Shandong, Hunan, and Jiangsu are lower, and the mean index value of Anhui is 19. Fig. 4(c) shows

the mean values of energy management completeness index of 30 provinces.

Government's effort on alleviating energy poverty can be measured through two major indicators: number of rural energy management agencies per million people and per capita energy investment for rural residents. High density of energy management agency distributed in rural areas helps local communities to improve their energy utilization efficiency through, for example, switching from directly burning straw for heating and cooking to utilizing methane produced by biogas digester, and utilizing solar water heater. In addition, high intensity of energy investment for rural residents provide sufficient subsidy to encourage rural residents to build biogas digesters in their backyards and install solar water heater on their roofs. During the study period, the national average levels of number of rural energy management agencies per million people and per capita energy investment for rural residents were 14.2 and 7.17 Yuan. High energy investment for rural residents in Beijing (60.7 Yuan/person) and high distribution density of rural energy management agencies in Beijing, Inner Mongolia, Liaoning and Yunnan (16.0, 23.5, 38.6 and 27.7 agencies/million people) promote the performance of energy management completeness in these regions. It should be noticed that Anhui, Henan, Shandong, Hunan and Jiangsu not only had less rural energy management agencies, which were all less than 9 agencies/million people, but invest fewer in energy management for rural residents, which were all less than 4 Yuan/person each year.

5.5 Household energy affordability and energy efficiency index improved continually

From 2000 to 2011, the situation of household energy affordability and energy efficiency of China improves (See Fig. 3(d)), which is denoted by the continuous increase in popularizing rate of clean energy facility and the decrease in air pollution caused by residential energy consumption. Furthermore, the residential energy bill becomes more affordable during this period.

According to the mean value of the index from 2000 to 2011 (see Fig. 4(d)), Guizhou, Jilin, Heilongjiang, Inner Mongolia, and Shanxi have the worst performance of household energy affordability and energy efficiency, while Beijing, Shanghai, Zhejiang, Tianjin, and Hainan have the best performance. The mean values of Guizhou and Beijing are 16 and 9, respectively.

Since 1997, China's residential clean energy supply capacity has been increasing continuously. The proportion of rural households who have biogas digesters increased from 2.7% in 1997 to 23.4% in 2011, and during the same period, solar water heater coverage increased from 6.63 million square meters to 62.32 million square meters. In urban areas, the proportion of people using manufactured gas, liquefied petroleum gas and natural gas increased from 12.1% in 1997 to 51.8% in 2011, and the urban centralized steam supply capacity reached 85274 tons per hour in 2011, which was 31 percent more than that in 1997.

In recent years, the popularization of clean cookers in China's rural areas played a positive role in reducing particulate matter produced by the combustion of solid fuels, and thus reduced the indoor air pollution and its damage to residential health. The national survey showed that, in 2000, every 100 rural households have 2.8 units of range hood, and this number increased to 14.7 units in 2012, with an average annual growth rate of 15%.

From the perspective of residential energy expenditure, there is no evident change in residential electricity prices in different regions of China over the past decade. In 2000 the average residential electricity prices in different regions varied between 0.2 to 0.7 Yuan per kWh, and in 2011 it varied between 0.4 to 0.6 Yuan per kWh. During the same period, the proportion of per capita urban residential electricity consumption in urban residential aggregate expenditure showed a downward trend that the percentage was 1.9% in 1999 and it slightly dropped to 1.7% in 2011. Furthermore, the proportion of per capita urban residential fuel expenditure in urban residential aggregate expenditure decreased from 1.6% in 1999 to 0.9% in 2011. In addition, the per capita urban residential space heating expenditure took up 0.8% of total income in 2006 and decreased to 0.6% in 2011. In contrast, the proportion of per capita rural residential fuel expenditure in rural residential aggregate expenditure showed an upward trend. The proportion was 1.6% in 2001 and it rose to 2.1% in 2011 (see Fig. 9). If we convert the amount of rural residents' use of traditional biomass into Chinese national currency and take it into account, the above proportion will be even higher than 2.1%.

[Insert Fig. 9 here]

6 Regional comparison of China’s energy poverty

6.1 Middle reaches of Yellow River and Yangtze River regions suffers the most significant comprehensive energy poverty

China’s energy poverty comprehensive index of 8 economic regions decreases from 2000 to 2011 (see Fig. 10). The values of energy poverty comprehensive index of Northern coast region and Middle reaches of Yangtze River region go down continually, which represents the situation became better. The values of Southern coast region and Middle reaches of Yellow River region fluctuate between 2000 and 2003, and keep downward trend from 2004. The values of Northeast, Southwest and Northwest regions increase slightly between 2004 and 2007, and decrease continually from 2008. Eastern coast region’s energy poverty comprehensive index value keeps a downward trend before 2008, and increases slightly with fluctuations from 2009.

[Insert Fig. 10 here]

Middle reaches of Yellow River and Yangtze River regions show the most significant energy poverty, and the energy poverty situation of Northern coast, Southwest and Northwest regions are relatively not significant. Fig. 11 shows the mean values of energy poverty comprehensive index of 8 economic regions of China from 2000 to 2011.

[Insert Fig. 11 here]

6.2 Middle reaches of Yangtze River region shows the worst energy availability

From 2000 to 2011, the values of energy service availability index of Middle reaches of Yangtze River, Southern coast, and Southwest regions are relatively high, indicating that households of these 3 regions have difficulties in enjoying residential energy service with high quality. Fig. 12(a) shows the energy service availability index of 8 economic regions of China from 2000 to 2011. It can be seen that the value of Northwest region generally keeps stable with some fluctuations, and the performances of energy services availability improve significantly in Eastern coast, Middle reaches of Yellow River, Northeast, and Northern coast regions.

[Insert Fig. 12 here]

The mean values of energy service availability index of 8 economic regions of China during 2000 and 2011 are shown in Fig. 13(a). The best to worst ranks of energy service availability index of 8 economic regions, based on the mean values, are Northern coast, Northwest, Northeast, Middle reaches of Yellow River, Eastern coast, Southwest, Southern coast, and Middle reaches of Yangtze River regions.

[Insert Fig. 13 here]

6.3 Middle reaches of Yellow River shows the worst energy cleanliness

Overall, the values of energy consumption cleanliness index of 8 economic regions keep stable from 2000 to 2011 (see Fig. 12(b)). Compared to 2000, in 2011, the values of Northeast, Eastern coast, Northern coast, Middle reaches of Yellow River, Middle reaches of Yangtze River, and Northwest regions decrease slightly; the value of Southwest region keeps the same; and the value of

Southern coast region increases slightly.

The mean values of energy consumption cleanliness index of 8 economic regions of China during 2000 and 2011 are shown in Fig. 13(b). The best to worst ranks of energy consumption cleanliness index of 8 economic regions are Southwest, Southern coast, Northwest, Middle reaches of Yangtze River, Eastern coast, Northeast, Northern coast, and Middle reaches of Yellow River regions.

6.4 Eastern coastal region shows the worst energy management completeness

From 2000 to 2011, the value of energy management completeness index of Eastern coast region keeps stable, and its capability of energy management experiences no significant change. Except for Eastern coast region, values of other 7 economic regions shows decreasing trends, and the decreasing trend of Southwest and Northwest regions are relatively most significant. Energy management completeness index of 8 economic regions of China from 2000 to 2011 is shown in Fig. 12(c).

The mean values of energy management completeness index of 8 economic regions of China during 2000 and 2011 are shown in Fig. 13(c). The best to worst ranks of energy management completeness index of 8 economic regions are Northeast, Middle reaches of Yellow River, Southwest, Northern coast, Northwest, Southern coast, Middle reaches of Yangtze River, and Eastern coast region.

6.5 Northeastern region shows the worst household energy affordability and lowest energy efficiency

The situation of household energy affordability and energy efficiency of 8 economic regions improve during the past 12 year. The values of Northern coast, Eastern coast, and Southern coast regions experience the most significant decreases. Fig. 12(d) shows the household energy affordability and energy efficiency index of 8 economic regions of China from 2000 to 2011.

The mean values of household energy affordability and energy efficiency index of 8 economic regions of China during 2000 and 2011 are shown in Fig. 13(d). The best to worst ranks of household energy affordability and energy efficiency index of 8 economic regions are Eastern coast, Northern coast, Southern coast, Northwest, Middle reaches of Yangtze River, Middle reaches of Yellow River, Southwest, and Northeast regions.

7 Current characteristics of regional energy poverty in China

In order to explore the current characteristics of regional energy poverty, this paper compares the constitution of energy poverty comprehensive index of 8 economic regions (see Fig. 14).

[Insert Fig. 14 here]

The situation of energy poverty of Middle reaches of Yellow River region is the worst, according to the mean value of energy poverty comprehensive index from 2000 to 2011. Energy poverty comprehensive index of this region is made up of high energy consumption cleanliness index, medium energy service availability index, medium household energy affordability and energy efficiency index, and low energy management completeness. Therefore, the main characteristic of energy poverty of this region is the high carbon and high pollution residential energy consumption structure, and the secondary characteristic is low household energy affordability and low energy efficiency.

Middle reaches of Yangtze River region ranked 2nd, according to its mean value of energy poverty comprehensive index. The energy service availability index and energy management completeness index are relatively high. Specifically, the capability of supplying residential energy with high quality is limited, and the energy management agencies are insufficient in this region.

Energy poverty situations in Northeast, Southern coast, Eastern coast, and Southwest regions are in the medium levels, and the characteristics of these four regions are different. In Northeast region, the household energy affordability and energy efficiency index and energy consumption cleanliness index are relatively high. Households of this region have heavier burdens on residential energy bills, and own less clean and modern household energy using facilities. Poor performance on energy service availability and energy management completeness are the main characteristics of Southern coast region. The main characteristics of Southwest region are low household energy affordability, low energy services availability, and low energy efficiency.

Northern coast and Northwest regions have the lowest energy poverty comprehensive index values, indicating energy poverty situations of these two regions are not significant. However, both of them have the potential to further alleviating energy poverty. Northern coast region could improve the energy consumption structure, and encourage households to consume more high quality residential energy. In addition, the regional and local governments in Northwest region should focus on enhancing energy management for further energy poverty elimination.

8 Policy implications of energy poverty alleviation

In order to provide the policy implications of energy poverty alleviation for 30 provinces, this paper analyzes the constitution of energy poverty comprehensive index of 30 provinces in 2011 (see Fig. 15). Take Anhui, Hebei and Guizhou (worst performed), Hainan and Inner Mongolia (medium performed), and Yunnan (best performed) as examples. The associated policy implications are discussed as follows.

[Insert Fig. 15 here]

8.1 Increasing investment on energy infrastructure, improving performance of energy management, and spreading residential management organization in rural area

In 2011, energy poverty of Anhui province is the most significant, and its energy management completeness index and energy consumption cleanliness index rank 1st and 2nd, respectively, among all Chinese 30 provinces. For energy poverty alleviation, the local government of Anhui should increase investment on energy infrastructure, improve performance of energy management, build energy management and promotion agencies in rural areas, and encourage households, especially rural households, to consume non-solid energy for basic demand of life.

8.2 Decreasing relative cost on household commercial energy consumption, and encouraging the utilization of modern, clean and efficient household energy consumption equipment

In 2011, energy poverty comprehensive index of Guizhou ranks 5th in China. Its household energy affordability and energy efficiency index ranks 1st, and its energy service availability index ranks 5th. To alleviating energy poverty, Guizhou should decrease the relative household energy cost and encourage utilizing efficient household energy consumption equipment. Specifically, it should encourage its rural households to use efficient equipment such as fuel-saving stoves, smoke exhausting ventilators, biogas digester, and solar water heaters.

8.3 Increasing consumption rate of non-solid commercial energy in total energy, and spreading modern and clean utilization of biomass

In 2011, Hebei’s energy poverty comprehensive index ranks 3rd, and its energy consumption cleanliness index ranks 1st in China. Therefore, improving residential energy consumption structure could be the primary for Hebei to alleviate energy poverty. Considering the energy resource endowments of Hebei, the local governments could increase the consumption percentage of natural gas and renewable energy.

In 2011, Inner Mongolia performed well in energy service availability and energy management completeness, but its energy consumption cleanliness index ranks 3rd. High percentage of traditional biomass consumption is the main characteristics of energy poverty in Inner Mongolia. Consuming renewable commercial energy is an effective way to alleviate energy poverty, as renewable commercial energy is superior to traditional biomass, from the perspectives of pollution reduction and efficiency promotion. Therefore, encouraging the rural households to reprocess the traditional biomass instead of consuming it directly, should be the primary work for alleviating energy poverty in Inner Mongolia and the regions that rich in agricultural biomass. For instance, encouraging households to consume biogas, which is the production from straw and animal waste, instead of consuming them directly, helps to increase the utilization efficiency of renewable energy and decrease the indoor air pollution caused by the combustion of straw and animal waste in rural area.

Energy poverty of Yunnan is relatively not significant, and its energy poverty comprehensive index ranked 25th in 2011. But, Yunnan has bad performance on energy service availability. Bad performance on energy service availability is also the main characteristic of energy poverty in Hainan in 2011. Increasing residential energy consumption, enhancing supply capabilities of natural gas for urban households and high quality straws gas for rural households should be the effective solutions to alleviate energy poverty in these two provinces.

9 Conclusions and suggestions

As an important social issue, energy poverty has caused widespread attention around the world. Energy poverty is harmful to social welfare and sustainable development. Scientific evaluation of energy poverty is the premise of formulating effective policies to alleviate energy poverty, and to identify executive energy poor for conducting the relative policies.

According to the definitions of energy poverty, commonly used energy poverty indicators and measurements can be classified into three categories: energy service availability, energy service quality, and satisfaction of energy demand for human's survival and development. In this paper, the applicability of energy poverty indicators and measurements are analyzed for China from the perspective of data availability and context suitability. And then, China's energy poverty comprehensive index is built and employed to identify the characteristics of China's energy poverty both at the national and regional levels. In addition, the policy implications of energy poverty alleviation for China are provided and discussed. The major findings of this study can be concluded as follows.

(1) China's energy poverty shows an alleviating trend in the latest decade. Associated with the rapid economic development, gradual improvement of social infrastructure and living standard of household, China's energy poverty comprehensive index decreases continually. This result is consistent with the IEA's evaluation and forecast for China. China's energy poverty alleviation is mainly due to the improvement in energy service availability, energy affordability and energy efficiency. Specifically, Chinese households could gradually get access to residential energy with high quality and low price in urban areas. However, nowadays, a large number of households in rural areas are still consuming solid fuel with high indoor air pollution. Associated with the continuous economic development, it can be predicted that China's energy poverty could alleviate to some extent, but special efforts are still needed to eradicate energy poverty in China.

(2) The distribution of regional energy poverty is not consistent with the distribution of regional economic development, and energy poverty also exists in economic well-developed areas in China. Energy poverty in some economic less-developed provinces is not significant, such as Qinghai, and some economic well-developed provinces perform badly in alleviating energy poverty, such as Shandong. Therefore, both the economic less-developed regions and some of the economic well-developed regions (with specific energy poverty problems) should be paid attention to for energy poverty alleviation policy making and resources allocation.

(3) The characteristics of energy poverty vary by provinces and regions: Middle reaches of Yangtze River region shows the worst energy availability; Middle reaches of Yellow River region shows the worst energy cleanliness; Eastern coastal region shows the worst energy management completeness; Northeastern region shows the worst household energy affordability and lowest

energy efficiency. Therefore, specific strategies and policies for energy poverty alleviation are needed for different regions in China.

It is a serious problem that, in the second decade of 21th century, there are still billions of people suffering from energy poverty. They do not have access to electricity and/or clean cooking and heating facilities. The goals to eradicate extreme poverty that have been set by the United Nations will never be fully achieved without confronting and alleviating energy poverty. By 2010, there were 1.4 billion people around the world that lack access to electricity and approximate 80% of them were in rural areas. Furthermore, the number of people that rely on using traditional biomass was 2.7 billion [31]. Most of these energy poor are living in Sub-Saharan Africa (e.g., Nigeria and Ethiopia), Developing Asia (e.g., China, India and Bangladesh) and Latin America areas (e.g., Brazil).

Several previous literatures had addressed the energy poverty evaluation issues for typical developing countries. For example, Pachauri et al. [12] presented a two-dimensional (different types of energy access and energy consumption quantity) measure of energy poverty and energy distribution, and then analyzed the extent of energy poverty and energy distribution patterns in Indian household by applying this two-dimensional method. Their assessment showed a significant reduction in the level of energy poverty in India during 1983 and 2000. By utilizing the concept of energy poverty line and demand-based approach, Barnes et al. [19] proposed a definition of energy poverty line as the threshold point at which energy consumption begins to rise with increases in household income, and below this line, households should be considered energy poor. They applied this approach to rural Bangladesh and identified that about 58% households were energy poor. In the study of Pereira et al. [36], the impact of rural electrification on the reduction of energy poverty was analyzed in Brazil. They observed a significant increase in average energy consumption during 2000 and 2004, and identified that access to electric energy, which was promoted by the rural electrification program of Brazil, was the most important factor to reduce the contingent of energy poor. Similar evaluation can also be found in the studies of Nepal [37] and African countries [38].

All the above studies had proposed good complements to energy poverty issues both from the perspective of methodology and empirical analysis, however, to our knowledge, few studies have focused on the comparative analysis of energy poverty situation of China to some other countries, in particular the emerging economics such as India and Brazil, from the perspective of comprehensive evaluation at both national and regional levels. The enormous variation on the characteristics of energy poverty in different countries is one of the difficulties. However, we point out that the index based comprehensive evaluation approach is one of the solutions for international comparative analysis, and thus, it is considered an important potential improvement of this study in the future.

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Tables and Figures

Table 1

Energy poverty indicators and measurements

Category	Assessment indicators	Measurements / Standards	Scope	Sources / Examples
Energy service availability	Energy development index	Index consisting of 5 indicators: share of population that has access to electricity, per capita commercial household energy consumption, share of commercial energy in total final energy use, per capita public sector electricity consumption, and share of productive energy in total final energy use	National	IEA [2]
	Energy access - Consumption matrix	A novel two-dimensional measure of energy access and energy consumptions	Regional	Pachauri et al. [12]
	Energy accessible indicators	Assessing energy availability from 3 aspects: household fuels, electricity, and mechanical power	National	Practical Action [13]
	Energy inconveniences indicators	Energy deficiency indicator and energy inconvenience indicator	Regional	Mirza and Szirmai [14]
	Multidimensional energy poverty index	Six equal weighted indicators: cooking, lighting, household appliances, education, and communication	Regional	Nussbaumer et al. [15]
Energy service quality	Energy poverty line or fuel poverty line	The average household energy consumption of monetarily poor (living below national monetarily poverty line)	National	Foster et al. [22]
		Energy expenditures count ten percentage of income	Regional	DTI [24], DECC [25]
	Low income and high energy cost	In order to maintain basic living, energy poor should pay higher energy cost than the average level and has the rest of money below the official poverty line	Regional	Hills [5]
Satisfaction of energy demand for human's survival and development	Satisfaction of basic energy demand	Energy basic demand associated with human development indicator is 27×103~37×103 Kcal per capita per day	National	Krugman and Goldemberg [28]
		Energy basic demand associated with Physical Quality of Life Index (PQLI) is 500W per capita	National	Godemberg et al. [29]
		The minimum basic energy need of poor people	Regional	Foster et al. [22]
		Urban and rural minimum electricity consumption	Regional	IEA [2]
		Minimum energy amount necessary to sustain daily life (the threshold point at which energy demand is invariant to income)	Regional	Barnes [19]
	Satisfaction of energy demand for human's development	Based on basic minimum a household needs in terms of energy services, four classes of physical energy consumption per capita	Regional	Pachauri et al. [12]
		Energy needs range in three incremental levels: basic human needs, productive uses, and modern society needs	National	AGECC [9]
		Energy consumption satisfy four levels of energy demand: basic human needs, productive uses, modern society needs, and the European average needs	Regional	Shoibal and Tavoni [30]

Table 2
Energy services and access levels

Level	Electricity use	kWh per person per year	Solid fuel use	Mobility	Kilograms of oil equivalent per person per year
Basic human needs	Lighting, health, education, and communication	50–100	Cooking and heating	None, walking or bicycling	50–100
Productive uses	Agriculture, water pumping for irrigation, fertilizer, mechanized tilling, processing	500–1000	Minimal	Mass transit, motorcycle, or scooter	150
Modern society needs	Domestic appliances, cooling, heating	2000	Minimal	Private transportation	250–450

Source: AGECC [9]

Table 3
People have no access to clean cooking and heating facilities (million)

	2010				2030			
	Rural	Urben	Total	Percentage of the entire	Rural	Urben	Total	Percentage of the entire
Developing countries	2155	433	2588	49	2139	456	2595	39
Africa	518	180	698	68	629	257	886	56
Sub-Saharan Africa	516	179	696	81	627	256	883	65
Developing Asian countries	1580	234	1814	51	1458	182	1640	39
China	**345**	**42**	**387**	**29**	**220**	**20**	**240**	**17**
India	698	75	772	66	680	55	735	50
Other developing Asian countries	538	117	655	61	558	106	664	50
Latin America	47	18	65	14	45	18	62	11
Middle East	9	1	10	5	8	0	8	3
Global	2155	433	2588	38	2139	456	2595	31

Source: IEA [2]

Table 4
China's energy poverty comprehensive index

Category	**Indicator**	**Measurement (weight)***	**Properties**
Energy service availability (ESA)	Residential energy consumption	Per capita electricity consumption (1.75%)	Benefit
		Per capita heat consumption (5.67%)	Benefit
		Per capita natural gas consumption (6.45%)	Benefit
	Energy supply	Per capita capacity of steam supply in cities (4.55%)	Benefit
		Per capita LPG supply in cities (2.62%)	Benefit
		Per capita natural gas supply in cities (5.84%)	Benefit
		Number of rural agency for supplying high quality straws gas per million people (8.12%)	Benefit
Energy consumption cleanliness (ECC)	Low-carbon energy consumption structure	Percentage of non-solid fuel to commercial energy of household sector (6.00%)	Benefit
		Percentage of non-hydro power generation (14.58%)	Benefit
	Commercialization of energy consumption	Percentage of residential traditional biomass consumption (4.42%)	Cost
Energy management completeness (EMC)	Management agencies	Number of rural energy management agencies per million people (4.85%)	Benefit
	Energy investment	Per capita energy investment for rural residents (10.71%)	Benefit
		Per capita investment in fixed assets of state-owned units in electricity, steam, hot water production and supply (4.44%)	Benefit
Household energy affordability and energy efficiency (EAE)	Energy expense	Percentage of residential energy expense to total expense per capita in urban areas (2.13%)	Threshold
		Percentage of residential fuel expense to total expense per capita in rural areas (0.99%)	Threshold
	Energy facilities	Ownership of air-conditions per hundred urban households (1.91%)	Benefit
		Ownership of refrigerator per hundred urban households (0.24%)	Benefit
		Ownership of smoke exhausting ventilators per hundred rural households (3.63%)	Benefit
		Ownership of fuel-saving stoves per hundred rural households (0.80%)	Benefit
		Popularizing rate of rural household biogas digester (2.20%)	Benefit
		Per capita coverage area by solar water heaters in rural areas (4.01%)	Benefit
	Air pollution caused by residential energy use	Per capita sulphur dioxide in waste gas from residential sector (2.13%)	Cost
		Per capita smoke and dust emission in waste gas from residential sector (1.96%)	Cost

* The calculation of weights will be interpreted in section 4.2.

Table 5

Energy poverty comprehensive index of China’s 30 provinces and 8 economic regions (2000-2011)

Region/Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Beijing	79	79	76	75	75	73	67	65	55	56	58	58
Tianjin	77	77	77	77	77	74	74	73	72	69	68	65
Hebei	87	87	87	87	87	85	85	85	83	82	82	80
Shanxi	89	90	88	88	87	87	84	83	82	81	79	78
Inner Mongolia	90	89	88	85	85	83	81	80	79	70	71	73
Liaoning	85	85	84	82	81	79	78	76	72	73	69	69
Jilin	84	85	85	84	83	82	85	83	77	79	76	77
Heilongjiang	85	85	85	85	84	84	84	82	79	77	75	76
Shanghai	80	80	79	79	78	77	76	76	75	65	74	72
Jiangsu	87	87	86	85	84	83	83	82	80	78	77	75
Zhejiang	82	81	80	78	77	76	76	76	74	72	71	71
Anhui	91	90	90	89	89	89	89	88	87	85	85	83
Fujian	77	78	80	82	81	78	77	78	75	76	72	73
Jiangxi	83	84	85	86	84	84	83	84	81	81	80	79
Shandong	85	85	86	85	84	83	83	82	80	78	78	78
Henan	90	90	90	89	88	88	87	87	85	85	83	81
Hubei	81	82	81	80	77	77	77	76	72	71	72	72
Hunan	81	81	80	81	81	82	81	80	78	77	76	76
Guangdong	81	80	80	79	79	77	78	78	76	76	75	75
Guangxi	76	75	75	75	76	76	76	77	72	72	73	74
Hainan	83	82	82	80	81	81	81	81	77	75	76	76
Chongqing	84	84	84	83	78	80	82	81	78	75	74	73
Sichuan	78	77	78	79	76	75	75	73	72	69	68	67
Guizhou	85	84	85	83	83	83	85	83	82	81	80	79
Yunnan	77	78	78	74	77	74	77	77	73	72	71	69
Shaanxi	85	80	86	85	85	86	84	85	79	79	78	78
Gansu	78	78	79	81	81	79	80	81	81	74	75	77
Qinghai	73	70	66	65	64	64	64	67	70	64	63	62
Ningxia	85	84	85	84	86	85	82	82	80	75	73	71
Xinjiang	85	82	82	83	83	82	81	80	78	72	72	70
China	83	82	82	82	81	80	80	79	77	75	74	74
Northeast	85	85	84	84	83	81	82	80	76	76	74	74
Northern coast	82	82	82	81	81	79	77	76	72	72	71	70
Eastern coast	83	83	82	81	80	78	78	78	76	72	74	73
Southern coast	80	80	81	80	80	79	79	79	76	76	75	75
Middle reaches of Yellow River	88	87	88	87	86	86	84	84	81	79	78	77
Middle reaches of Yangtze River	84	84	84	84	83	83	82	82	80	79	78	77
Southwest	80	80	80	79	78	78	79	78	75	74	73	72
Northwest	80	78	78	78	78	78	77	78	77	72	71	70

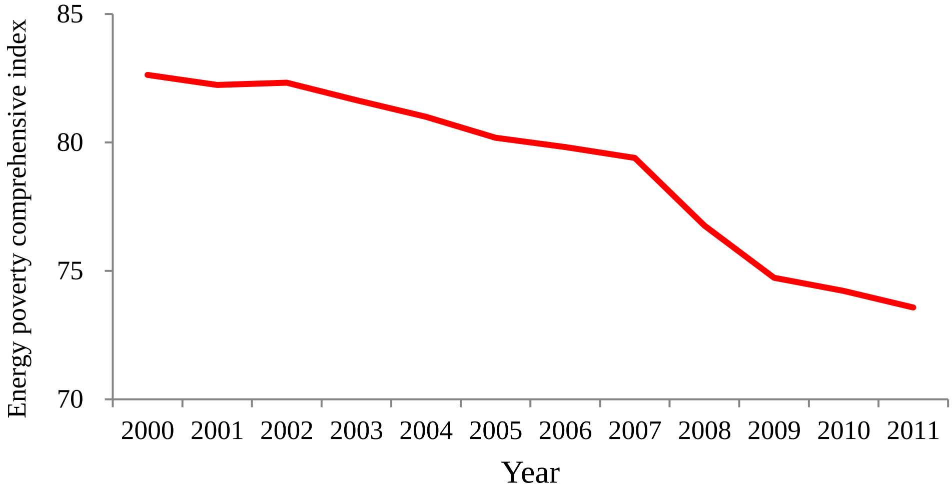

Fig. 1 Energy poverty comprehensive index of China (2000-2011)

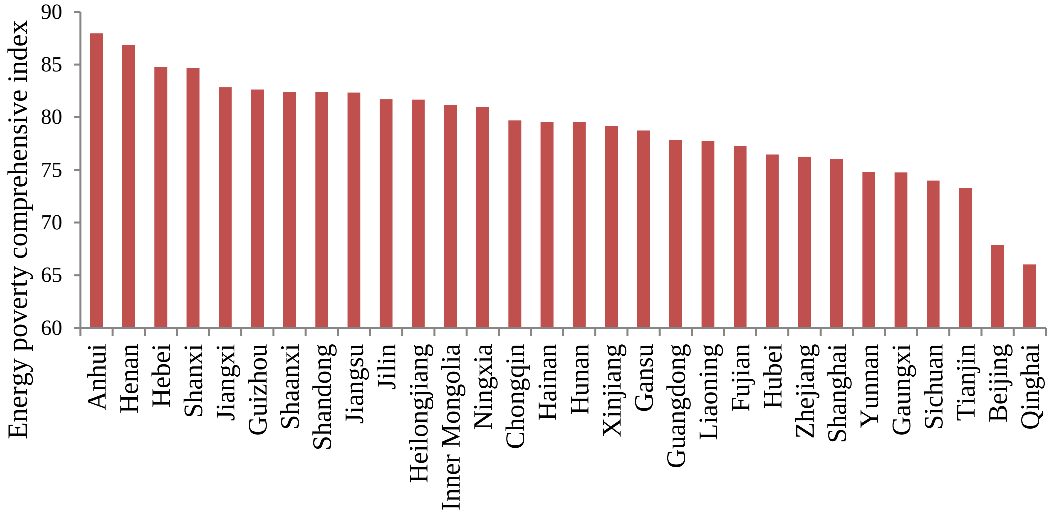

Fig. 2 Energy poverty comprehensive index of China’s 30 provinces (2000-2011 mean value)

Fig. 3 Four energy poverty categories of China (2000-2011)

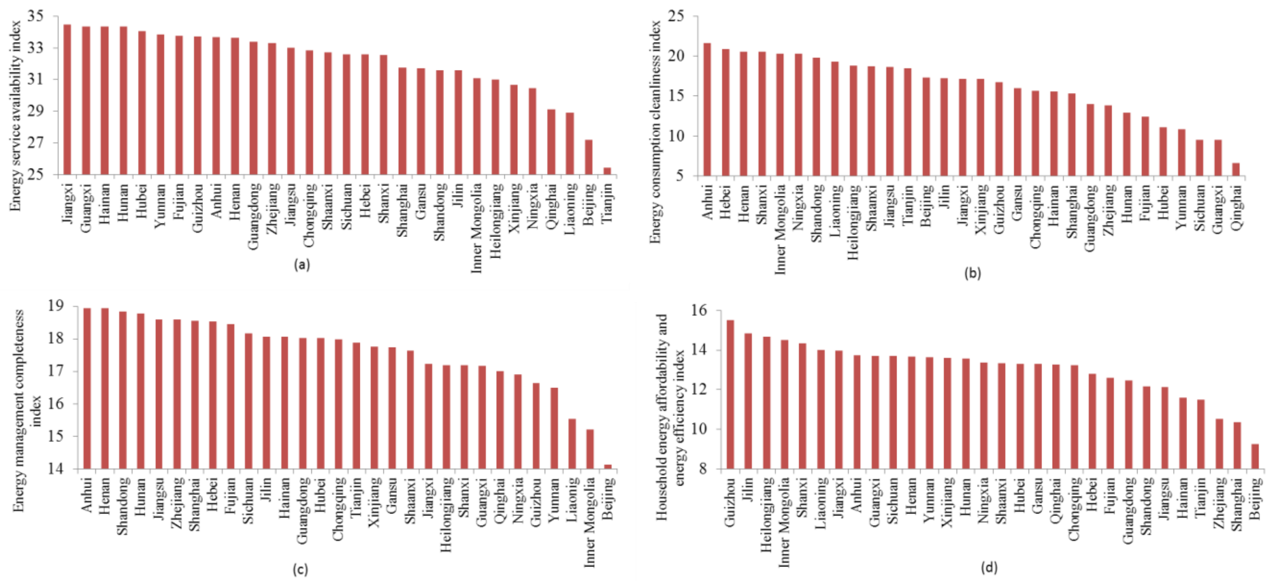

Fig. 4 Four energy poverty categories of China's 30 provinces (2000-2011 mean value)

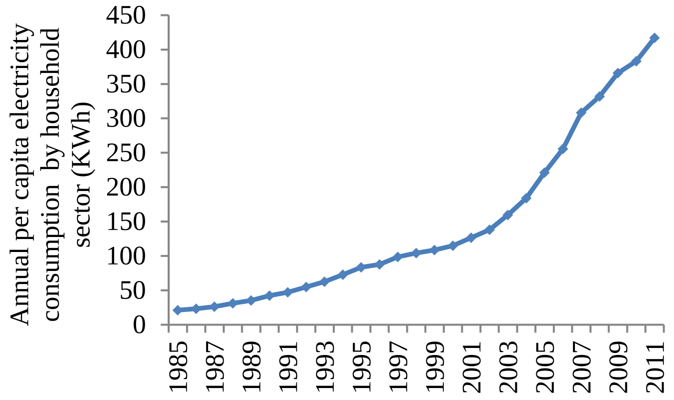

Fig. 5 Per capita electricity consumption of household sector in China (1985-2011)

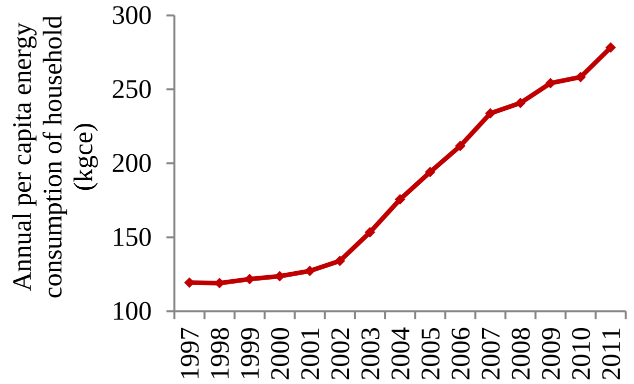

Fig. 6 Per capita commercial energy consumption by household sector in China (1997-2011)

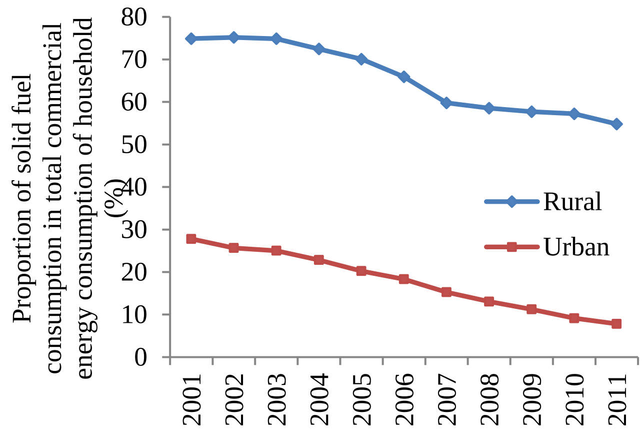

Fig. 7 Proportion of solid fuel consumption in total commercial energy consumption in China's household sector (2001-2011)

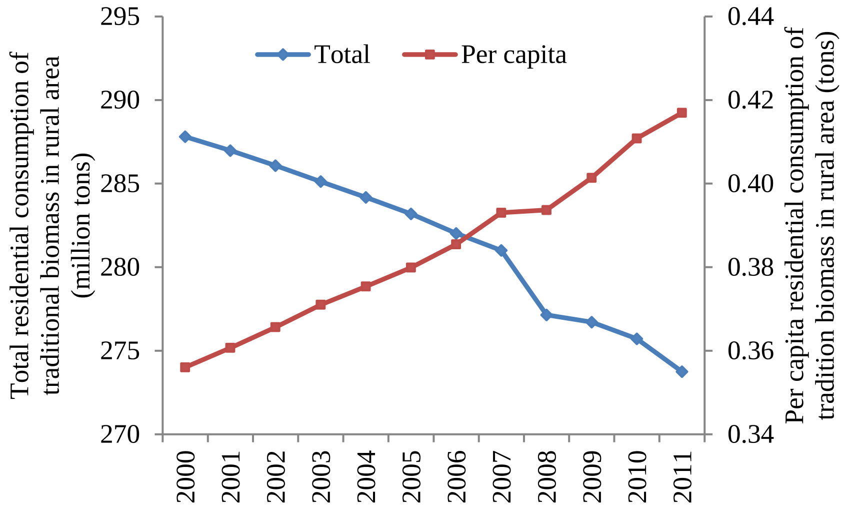

Fig. 8 Change of total and per capita residential consumption of traditional biomass in rural China (2000-2011)

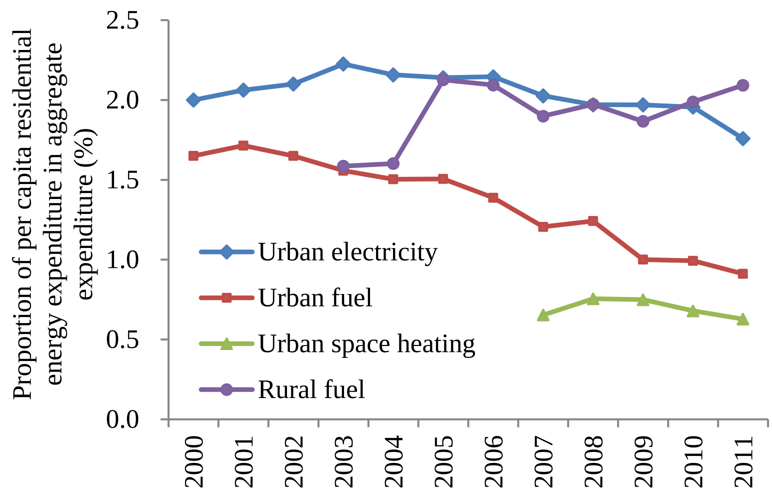

Fig. 9 Proportion of per capita residential energy expenditure in residential aggregate expenditure in China’s urban and rural areas (2000-2011)

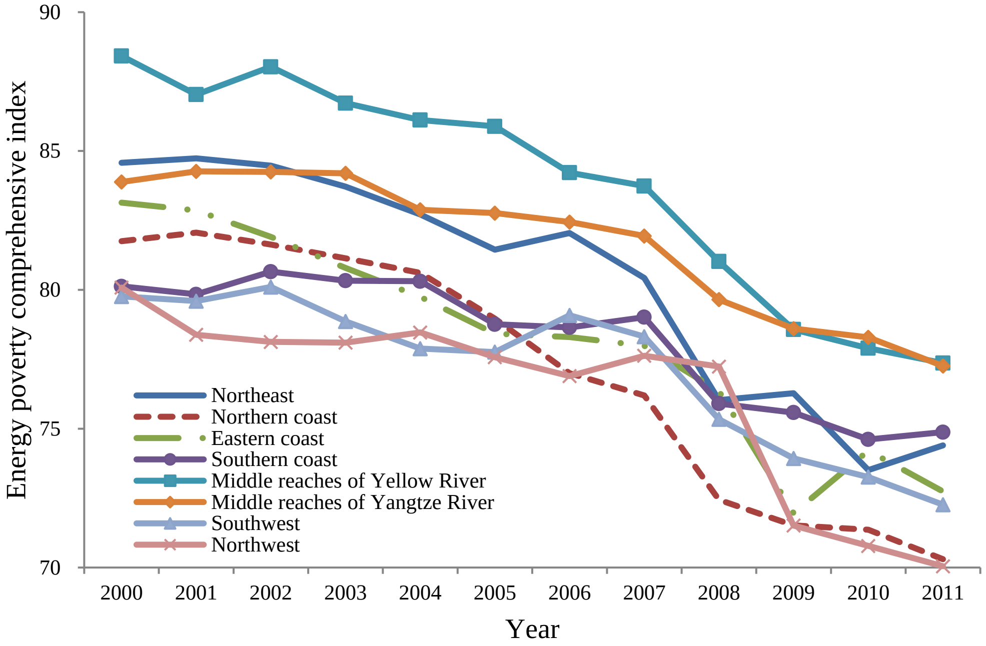

Fig. 10 Energy poverty comprehensive index of 8 economic regions of China (2000-2011)

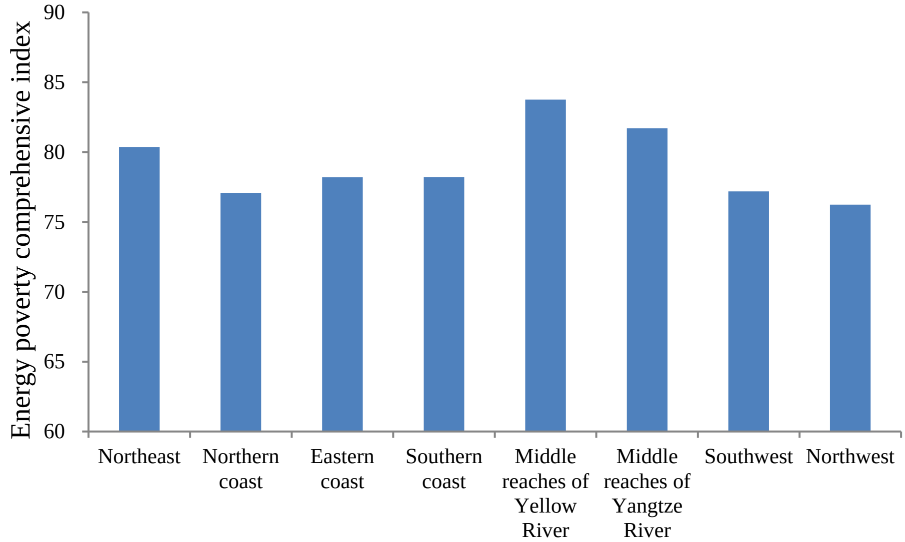

Fig. 11 Energy poverty comprehensive index of 8 economic regions of China (2000-2011 mean value)

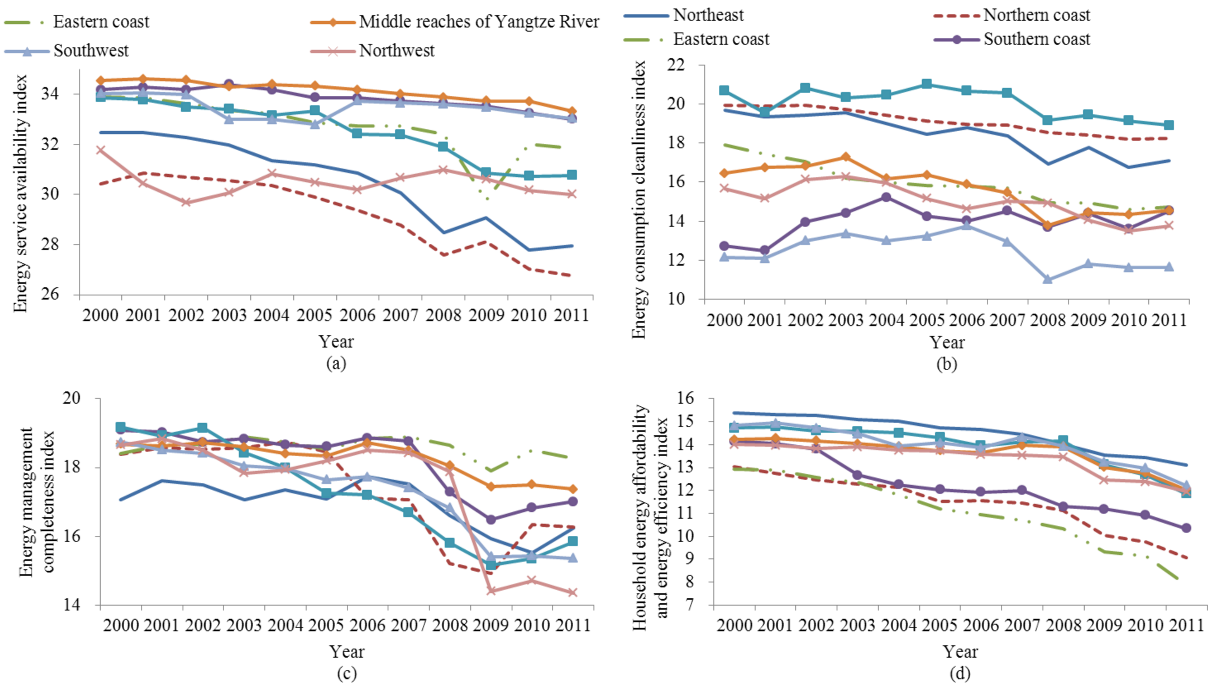

Fig. 12 Four energy poverty categories of 8 economic regions of China (2000-2011)

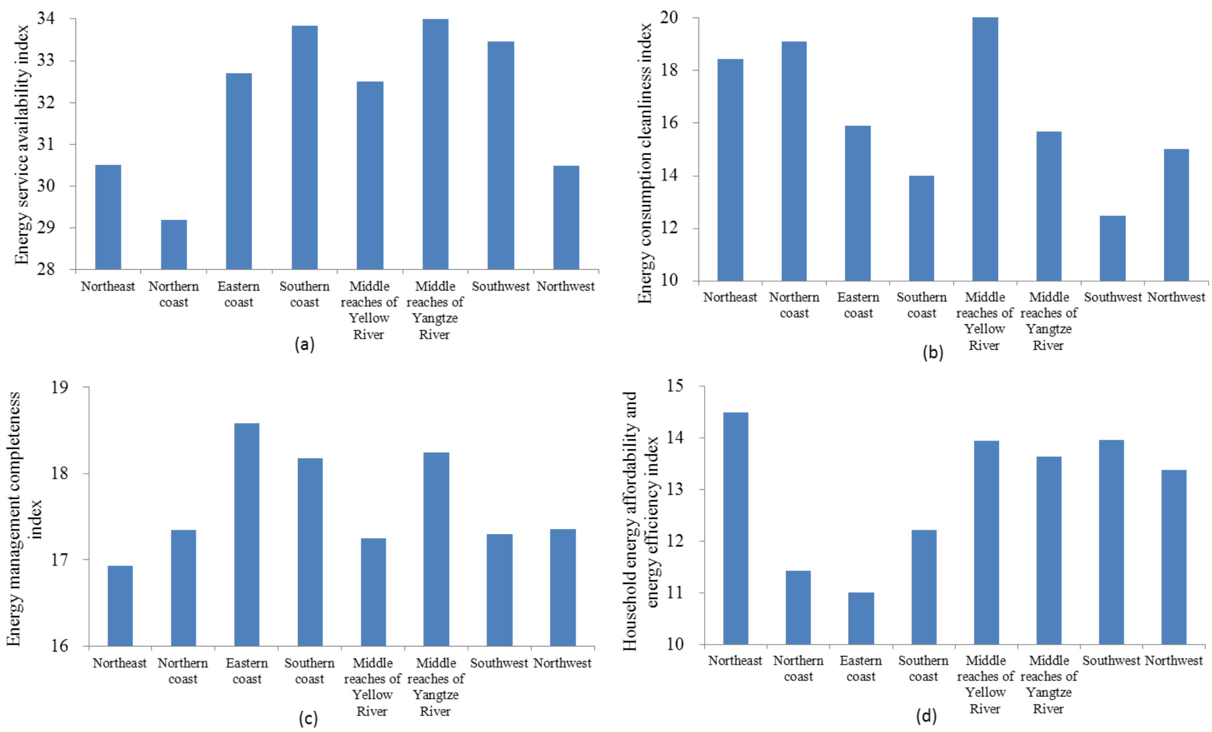

Fig. 13 Four energy poverty categories of 8 economic regions of China (2000-2011 mean value)

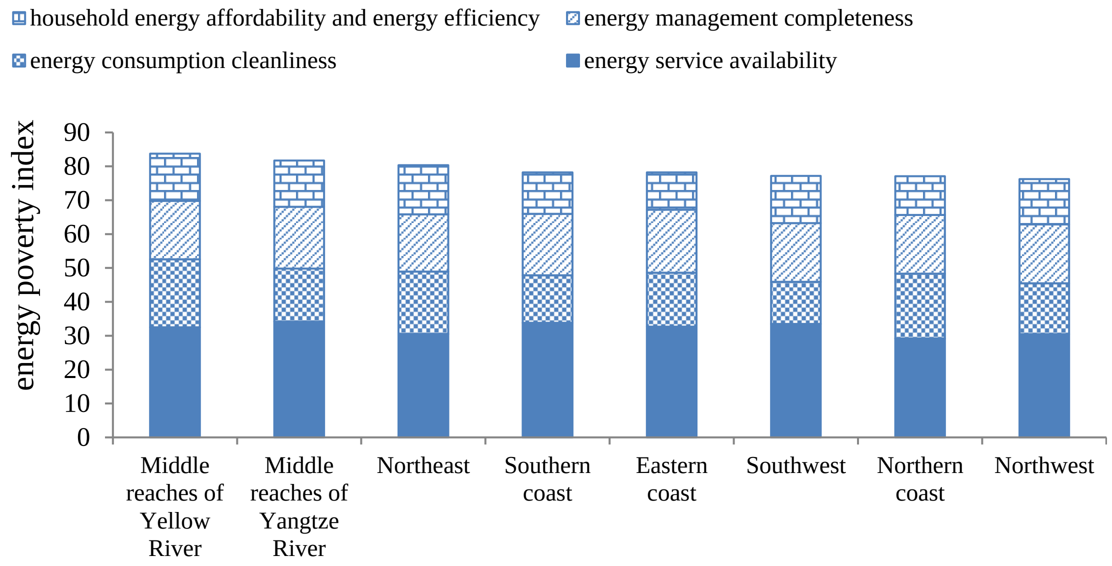

Fig. 14 Energy poverty comprehensive index and its sub-index of 8 economic regions of China (2000-2011 man value)

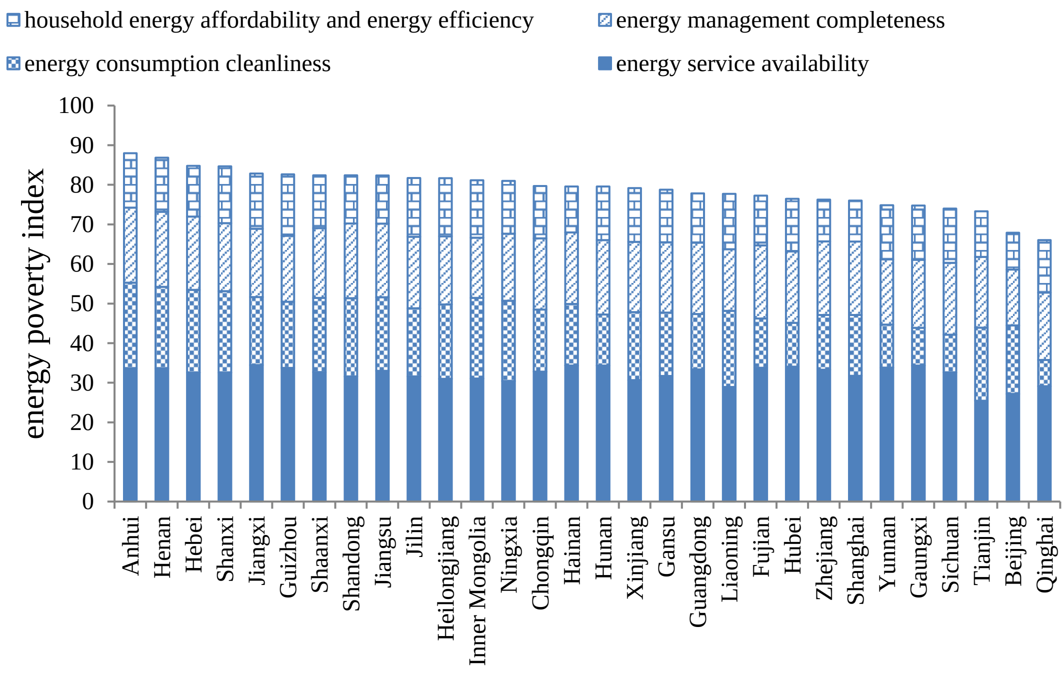

Fig. 15 Energy poverty comprehensive index and its sub-index of China's 30 provinces (2011)