Gauging energy poverty: A multidimensional approach

著者別名	奥島 真一郎
journal or publication title	Energy
volume	137
page range	1159-1166
year	2017-10-15
権利	(C) 2017 Elsevier Ltd. All rights reserved.
URL	http://hdl.handle.net/2241/00148517

doi: 10.1016/j.energy.2017.05.137

Gauging energy poverty:

A multidimensional approach

Shinichiro OKUSHIMA

Graduate School of Systems and Information Engineering, University of Tsukuba,

1-1-1, Ten-nodai, Tsukuba-science-city, Ibaraki, 305-8573, Japan.

E-mail: okushima@sk.tsukuba.ac.jp

ABSTRACT

This study presents a new approach to gauging energy or fuel poverty for developed countries. It develops a multidimensional energy poverty index (MEPI), which can evaluate energy poverty from a multidimensional angle. The MEPI is composed of three attributes (dimensions) of energy poverty, specifically for developed countries: energy costs, income, and energy efficiency of housing. The study applies this measure to gauge energy poverty in Japan after the 2000s, focusing on the years around the 2011 Great East Japan Earthquake (GEJE) and the Fukushima nuclear accident. Based on unique microdata, the results show that energy poverty has been aggravated in Japan since the 2000s. Mother-child and single-elderly households (vulnerable households) are in a serious situation and the elderly are at high levels of energy poverty. In addition, the results indicate the grave impact of energy price escalation after the Fukushima accident on energy poverty aggravation, especially for vulnerable households or the elderly.

Keywords: Energy poverty, fuel poverty, Fukushima nuclear accident, Great East

Japan Earthquake, Japan, multidimensional poverty, vulnerability

1. Introduction

More than two decades since Boardman's [1] seminal book, energy (or fuel) poverty has now become a widely recognized policy concern in developed countries [2][3].[1] Despite varying definitions, energy poverty can now be expressed as the inability to attain a socially and materially necessitated level of domestic energy services, as defined by Bouzarovski and Petrova [3], or as the inability of certain households to acquire the energy services required to live a decent and healthy life, as per Middlemiss and Gillard [4]. The concept of energy poverty is typically divided into "availability" and "affordability." As such, the problem of inadequate access to modern types of energy (e.g., electricity) is usually the central issue in the context of developing countries [5][6], while various issues that prevent people from obtaining a socially and materially necessitated level of domestic energy services, specifically the affordability issue, are the focus of developed countries.[2] Even in these countries, energy poverty can

[1] In this study, "energy poverty" is synonymously with "fuel poverty" for simplicity like in many studies [3]. "Energy poverty" is more suitable for the context of Japan, as well as Germany's, because both countries face problems stemming from higher expenses for electricity (for the situation in Germany, see [7][8][9]).

[2] That said, the affordability issue is also important in developing countries and the "access-affordability binary" is gradually disappearing [3][5][17]. See also the discussion in Section 6.

be a major social issue that affects millions of households and individuals, and may cause hardships, negative health impacts, and additional carbon emissions [10]. However, literature on energy poverty in developed countries is insufficient [2][11][12].[3]

Regarding the energy poverty problem, Japan faces an unparalleled situation among developed countries. After the Great East Japan Earthquake (GEJE) and the Fukushima nuclear accident in March 2011, nuclear power plants have scarcely operated, making Japan much more dependent on imports of fossil fuel, especially liquefied natural gas, for electricity generation. Moreover, the Japanese government encourages renewable energy production through measures such as the feed-in tariff (FIT) scheme. Such factors have already pushed Japan's energy costs up, despite a recent plunge in international energy prices, and eventually increased the burden on households [13][14][15][16]. Adding to the "denuclearization" movement, the government introduced a type of carbon tax on fossil fuels to address climate change and increased consumption tax to sustain social security systems. All these factors raise energy costs, which pass on to households in the form of higher energy prices, especially of electricity.

---

[3] The UK, however, is exceptional and several studies have been published since Boardman's classical work [1]. In recent years, further studies such as [2][18][[10][19][4][20][21][22] have come forth. There is also literature on other European Union (EU) countries such as Austria [12], France [23], Germany [9][24], Italy [25], Spain [26], and a comparative study across the EU [27], whereas there are few studies outside European countries, such as in Japan [28].

Another problem relating to energy poverty in Japan is the growth in the share of low-income households reflecting the aging and sluggish economy [29][30]. Particularly, vulnerable households, such as lone-parent-with-dependent- child (ren), elderly, and single-person, are much more sensitive to rising living costs, including higher energy expenses. From such perspectives, energy poverty may prove a difficult problem for Japan over the middle- or long-term.

Against this background, there are two scopes for this study. The first is to suggest a novel approach for gauging energy poverty for developed countries like Japan. This study reconsiders the definitions of energy poverty and proposes a new measure of energy poverty from the perspective of multidimensional poverty [31][32][33]. In the field of poverty research, it is common to recognize that poverty is a multidimensional phenomenon [34]. As such, this study presents a unique measure of energy poverty in a multidimensional setting, which is adequate and applicable for gauging energy poverty in developed countries such as Japan.

The second purpose of this study is to analyze the situation of energy poverty in Japan since the 2000s, focusing on the years around the 2011 GEJE and Fukushima nuclear accident. Few studies examine the problem in Japan, although Okushima [28] shows definite signs of energy poverty in Japan, especially for low-income and vulnerable households, using traditional energy poverty measures. This study applies a new approach to evaluate the actual situation of energy poverty in Japan after the 2000s, which is an invaluable subject for study from the perspective of multidimensional poverty.

The remainder of the paper is organized as follows. Section 2 provides a brief overview of Japan's situation after the 2000s. Section 3 reviews the concepts and definitions of energy poverty, and suggests a new measure of multidimensional energy poverty. Section 4 explains the data. Section 5 illustrates and discusses the results, and the final section provides concluding remarks.

2. Overview of Japan's situation after the 2000s

Figure 1 describes the changes in energy prices and household income in Japan from 2000 to 2015. Here, "energy price" means a composite index of CPIs (consumer price index) for electricity, gas, and other fuels with the 2010 weights. The figure shows that domestic energy prices climb gradually in the 2000s, except after the global financial crisis, although the trend spikes after 2011, the year of the GEJE and the Fukushima accident. As mentioned, nearly all nuclear power plants in Japan have shut down and Japan has become more dependent on fossil fuel imports with higher international energy prices and a weaker yen after 2011 [14][15]. However, the domestic energy price has dropped in 2015 due to the plunge in international energy prices; nonetheless, the price is higher than in 2013.

[Please insert Figure 1 here]

In addition to these difficult conditions, the figure shows the continuous decline of income in the same period, reflecting Japan's aging and sluggish economy [29][30]. As such, it depicts the gradual decrease of household income, a sharp decline after 2008, and a leveling off after 2012.

Next, Figure 2 describes the trends in the "vulnerability index" after the 2000s. The index is a simple measure composed of "energy price" and "income" in Figure 1, that is, the ratio of energy CPI to household income.[4] The index indicates the level of vulnerability to energy poverty, in other words, the risk of energy poverty at a macro level, annually. In Figure 2, the index shows that vulnerability continuously climbs after the 2000s, and it goes up sharply after the GEJE due to the increase in energy prices. The index drops in 2015 due to an energy price downturn after mid-2014 although the level of vulnerability remains high.

[Please insert Figure 2 here]

At just the sight of such figures, it is understandable that the situation regarding energy poverty has been aggravated since the 2000s.

---

[4] For more details on this vulnerability index, see [28]. Okushima [28] develops this "vulnerability index" in line with the definition of vulnerability in the field of climate change: vulnerability is a function of exposure, sensitivity, and adaptive capacity [35, p. 89].

3. Methodology

Despite the passage of several decades since Boardman's [1] seminal book, there is room for progress in the measurement of energy poverty. Boardman [1] gives the first quantified definition of energy poverty for the United Kingdom: households are in energy poverty when they are unable "to have adequate energy services for 10% of income." This definition is known as the "10% measure" in this research field. Specifically, this measure defines a household in energy poverty as one that needs to spend more than 10% of its income on energy costs. The energy costs include energy expenses for space heating, water heating, lights and appliances, and cooking, but exclude those for driving cars. The 10% measure has been widely used in previous studies, e.g., [2][24][26][28][36], although it has drawbacks. Most notably, with the 10% measure, it is possible that rich households that are overconsuming energy are identified as energy poor [10][19]. Therefore, the UK government now uses another two-dimensional measure: the low income high cost (LIHC) indicator [10], along with the 10% measure. Nonetheless, researchers have criticized the LIHC indicator too. For example, Heindl and Schuessler [24] prove that the LIHC indicator has counter-intuitive dynamic properties, which may cause false policy implications, and recommend the so-called "capped 10% measure," that is, applying the 10% measure only for the lower income strata to avoid this specific drawback.

Going back to the root of the definition, Boardman [1], the *de facto* founder of energy poverty measurement, focuses on three factors; namely, energy price, low income, and energy efficiency (of the house) to consider the energy poverty problem in developed countries [2]. Other seminal studies by Hills [10][19] also stress three main drivers of energy poverty, such as fuel prices, low income, and energy efficiency. Such studies indicate that energy poverty is a kind of multidimensional poverty in its nature, rather than a unidimensional problem of energy costs or income.

Therefore, this study develops a multidimensional approach for a rigorous evaluation of "energy poverty in developed countries" such as in Japan. The approach closely relates to recent literature on multidimensional poverty measurement, such as [31][32][33]. Recent years have seen the development of theoretical and empirical poverty research in a multidimensional setting, albeit primarily for developing countries [37][38], although there are studies on developed countries, such as Peichl and Pestel [39][40], which evaluate multidimensional affluence or well-being for Germany and the United States.

This study suggests a new comprehensive measurement of energy poverty in the multidimensional poverty framework. The methodology itself is described as follows. Assume a population with n households $(i = 1, \cdots, n)$, and $d \geq 2$ dimensions (attributes) of poverty $(j = 1, \cdots, d)$. Subsequently, it can define the matrix of achievements in a multidimensional setting:

$$\mathbf{Y} = \left[y_{ij} \right]_{n \times d}, \tag{1}$$

where y_{ij} is the achievement of household i in dimension j.

A multidimensional poverty approach considers poverty as a shortfall from a threshold (cut-off) for each attribute [32]. Let z_j denote a threshold of dimension *j*, and define dimension *j*'s specific poverty, that is, the deprivation of attribute *j*, of household *i* if $y_{ij} < z_j$. Following Alkire and Foster [33], it can construct the 0-1 matrix of dimensional poverty, $\mathbf{g}_{ij} = \left[g_{ij} \right]_{n \times d}$, whose elements are defined by $g_{ij} = 1$ when $y_{ij} < z_j$ and $g_{ij} = 0$ otherwise. In other words, $g_{ij} = 1$ means that household *i* is poor in dimension *j* or deprived in attribute *j*, and $g_{ij} = 0$ vice-versa.[5] Subsequently, $\mathbf{g}_i$ means household *i*'s dimensional poverty (deprivation) vector and $c_i = |\mathbf{g}_i|$ counts the number of dimensional poverty of household *i*, which shows how many dimensions household *i* is poor in.

For measuring energy poverty in a multidimensional setting, this study first needs to define the dimensions or attributes that can specify the condition of "energy poverty in developed countries." This choice is essential for multidimensional poverty analysis and cannot become free to the researchers' value judgment. The study defines three dimensions of energy poverty in developed countries: the first is the dimension of "energy" or "energy cost," the second is "income," and the third is the "energy efficiency of housing." Specifically, the share of energy cost to income in each household represents the first attribute y_{i1}, income is the second attribute y_{i2}, and age of housing is the third attribute y_{i3}. For equivalization, the energy costs and income are divided by

---

[5] Notably, the matrix can be defined in the case of ordinal or categorical data; "deprived" needs to be separated from "not deprived" using these types of data [33].

the square root of household size. Although this choice of dimensions is by no means perfect and there is room for improvement, it is reasonable and acceptable in the context of energy poverty measurement for developed countries, as it also matches the original concept of energy poverty by Boardman [1].

Consequently, after selecting dimensions, the threshold z_j for each dimension *j* needs to be defined. In this study, the threshold for "energy" is defined as $z_1 = 0.1$; the threshold for "income," z_2, is the boundary income between the third decile and the fourth decile; the threshold for "energy efficiency of housing," z_3, is whether their houses are built after 1980 or not. The specific reasons for this are discussed in Section 5.

Moreover, this study needs to define "energy poverty in developed countries" in a multidimensional setting. The choice of dimensions and thresholds is insufficient to identify the households in energy poverty. As such, it requires identification of poverty. Following Alkire and Foster [33], an identification function $\rho(y_{ij}; z_j)$ is set up, which maps from household *i*'s achievements, y_{ij}, and thresholds, z_j, to an indicator variable in such a way that $\rho(y_{ij}; z_j) = 1$ when household *i* is energy poor and $\rho(y_{ij}; z_j) = 0$ otherwise. In this study, the "intersection" approach is used to identify the energy poor [31][33]. Formally, household *i* is in energy poverty $\rho(y_{ij}; z_j) = 1$, if and only if $c_i = |\mathbf{g}_i| = 3$. Otherwise, household *i* is *not* in energy poverty $\rho(y_{ij}; z_j) = 0$, when $c_i = 0,1,2$. In other words, household *i* is identified as energy poor if only it is poor in all three dimensions. Figure 3 shows the concept of multidimensional energy poverty in this study. This “intersection” approach also matches Boardman’s [1] original idea of energy poverty, which focuses on all three dimensions.

[Please insert Figure 3 here]

Finally, this study can now define a multidimensional energy poverty index (MEPI). In terms of “aggregation,” a simple headcount ratio, *H,* is used, which measures the extent of poverty in society by the number of “poor,” *q*, to the total population, *n*,

$$H = q / n, \tag{2}$$

where $q = \sum_{i=1}^{n} \rho(y_{ij}; z_j)$. The headcount ratio is categorized as one of the Foster-Greer-Thorbecke (FGT) measures [41], widely used as a general income poverty measure. [6,7] *H* is what the study calls the MEPI.

---

[6] The class of the FGT measure is defined as $P_\alpha = \frac{1}{n}\sum_{i=1}^{q}\left(\frac{z-y_i}{z}\right)^{\alpha}$, where *n* is the total population $(i = 1, \cdots, n)$, y_i is the i^{th} lowest income, *z* is the income poverty line, *q* is the number of the poor($q = \left|\{i \mid y_i < z\}\right|$) and $\alpha(\geq 0)$ is a poverty aversion parameter. If $\alpha = 0$, $P_0 = q/n$; the measure reduces to the headcount ratio. Alkire et al. [37] emphasizes the importance of the FGT measure, which makes a significant change in poverty measurement. For more information on the FGT measure, see also [42], and for the FGT measure in a multidimensional setting, see [33][37].

[7] The headcount ratio, however, has some well-known problems; for example, it pays no attention to the “depth” of poverty. It evaluates the marginally poor the same as the miserably poor. For more information on poverty measures in general, see e.g. [43][44].

4. **Data**

This study tackles the research question using unique microdata of household income, expenditure, and characteristics, including housing status, with a sample of approximately 50,000 households covering Japan. The dataset is created from anonymized data based on the 2004 National Survey of Family Income and Expenditure. The anonymized data is provided by the National Statistics Center for its research purposes. The dataset allows an in-depth analysis of energy poverty, focusing on detailed characteristics of households.

For the purpose of this study, it needs to perform two types of modifications on the data (For more details, see [28]). The first is seasonal adjustment. The anonymized microdata are based on the National Survey of Family Income and Expenditure, whose expenditure data was collected in autumn (from September to November). It is notable that energy poverty is aggravated in winter, above all in January, the coldest month in Japan. Hence, constructing seasonally adjusted expenditure data is necessary, using another governmental household survey, the Family Income and Expenditure Survey of 2004, which has smaller samples but contains a monthly data. In particular, seasonally adjusted data on household expenses is constructed for three energy goods (electricity, gas, and kerosene) using the monthly figures for the same goods from the Family Income and Expenditure Survey of 2004. As such, the annual average expenditure data and the winter average data are obtained.[8]

---

[8] Unlike expenditure data, the income-related and other variables are on a yearly basis; therefore, no seasonal adjustment is required.

Second, the data were extended to the latest period of 2013 with the help of the Family Income and Expenditure Survey, which includes monthly and annual data on the income and expenditure of Japanese households by income decile group. Using these data and so on, the study constructs extended data on household income and expenditure by each income decile from 2004 to 2013, triennially. Consequently, it is possible to historically examine energy poverty in Japan after the 2000s, drawing fully upon the strength of the original dataset and the official Family Income and Expenditure Survey.

The dataset includes a large sample of 47,797 households (43,861 two-or-more-person households and 3,936 one-person households) covering the entire Japan. They have been anonymized with no detailed information about the living places. For the superiority of this dataset, each household has a sampling weight which is designed to replicate the whole population of Japan. These "replicating" weights are used in all calculations to obtain unbiased estimates on poverty rates in Japan. [9]

5. Results

The first result is that of dimensional-poverty for "energy" in Japan, using the 10% measure (Figure 4). Here, the 10% measure (M_1) is,

$$M_1 = \frac{1}{n}\sum_{i=1}^{n} a\left(\frac{E_i}{I_i} > 0.1\right), \qquad (3)$$

[9] For more details about the dataset, see also [28].

where n is the total number of households, E_i is the energy cost (energy expenditure) of household i, I_i is the household income i, and $a(\cdot)$ is an indicator function that takes the value 1 if the condition in parentheses is true and 0 otherwise. Energy costs include energy expenses for electricity, gas, and other fuels (kerosene), but exclude those for driving cars. As explained in Section 3, the 10% measure is commonly used for measuring energy poverty in developed countries such as the UK, although this study uses this measure to only gauge dimensional-poverty for energy, one of the attributes of multidimensional energy poverty. This means that the threshold for "energy," z_1, is given by 0.1 (ten percent).

[Please insert Figure 4 here]

Figure 4 shows the rates of dimensional-poverty for energy (energy deprivation rates) in the base year of 2004 by income decile. The income is equivalized with the square root scale; in other words, the household income is divided by the square root of household size. This indicates that the rates in the lower income decile groups are high. On the other side, the rates in the higher income groups are negligible, especially above the fourth decile. As explained, the threshold of the dimension of income, z_2, is given by the boundary income between the third and fourth income deciles shown by the dotted line in Figure 4. The choice of income threshold is also based on the argument of Boardman [1], who categorizes

30% of households with the lowest incomes as "low-income households." Consequently, the result confirms the validity of this threshold.

Subsequently, Figure 5 shows the housing conditions of the households derived from the dataset. Due to data limitations, it can only be checked whether they own or rent their houses and the age of their houses if owned. After the oil shocks of the 1970s, the Japanese government first established the energy conservation standards for housing in 1980.[10] In other words, there was no energy efficiency regulation in Japan for housing before 1979. Therefore, the threshold in the dimension of energy efficiency of housing (the third attribute) is z_3; the households living in their own houses built before 1979 or in rented houses are categorized as in "dimensional-poverty for energy efficiency of housing" in this analysis.[11,12] Figure 5 indicates higher proportions of households living in the built-before-1979 houses for lower income deciles and vice-versa. Additionally, it is noteworthy that the rate of households living in rented houses is high in the lower deciles, with more than 40% in the lowest decile group.

---

[10] Thermal insulation improves by 30% before and after the 1980 standard [45]. Many studies indicate that enhancing energy efficiency of buildings still has great potential for tackling energy related problems [25][46].

[11] It is said that the lifetime of housing in Japan is approximately 27 years [47].

[12] There is the difficulty of how to consider the case of rented houses. Owing to data limitations, housing age can only be checked if the houses are owned. Hence, this study defines households living in rented houses as in dimensional-poverty for energy efficiency of housing due to their incapability of energy-saving investments, following the argument such as Boardman [2].

[Please insert Figure 5 here]

Figure 6 synthesizes these results in a three-dimensional diagram. This figure illustrates multidimensional energy poverty in the base year 2004. As explained (see Figure 3), the MEPI has three dimensions; “energy, ” “income,” and “energy efficiency of housing.” Moreover, the threshold for energy is set as $z_1 = 0.1$; the threshold for income, z_2, is the boundary income between the third and the fourth deciles; the threshold for energy efficiency of housing, z_3, is whether they live in their own houses built after 1980 or not. It identifies households as (multidimensional) energy-poor only if they are poor or deprived in all three dimensions.

[Please insert Figure 6 here]

Three hatched bars in Figure 6 correspond to the parts featuring multidimensional energy poverty in this analysis. Remarkably, the rates of dimensional-poverty for energy, measured by the traditional 10% measure, differ substantially between households that are in dimensional-poverty for housing (P for housing) or households that are not (NP for housing). Energy efficiency of housing is an essential factor, from the viewpoint of receiving “adequate energy services” [1][2][3]. The above results in Figure 4-6 clearly show the necessity of energy poverty evaluation from a multidimensional perspective.

This study then gauges multidimensional energy poverty in Japan after the 2000s using the MEPI, with the results presented in Table 1. It calculates the energy poverty rates in the two cases: the annual case where the energy costs for y_{i1} are calculated on an annual-average basis, and the winter case where energy costs are calculated on the winter-average basis. Table 1 shows, in the annual case, that the energy poverty rates gradually increase: 3.2% in 2004, 4.1% in 2007, 4.5% in 2010, and 5.3% in 2013; in the winter case, 5.5 % in 2004, 6.8% in 2007, 7.4% in 2010, and 8.4% in 2013. It is clear that the energy poverty rates in winter are much higher than the annual ones, while in both cases there is a gradual increase in the 2000s and a more significant one after 2011, reflecting the escalation of energy costs after the Fukushima accident.

[Please insert Table 1 here]

This study also identifies household types that are vulnerable or at high risk of energy poverty. Table 2 illustrates the proportion of energy-poor households by household type. In the results, mother-child and single-elderly households are characterized as vulnerable. Even in 2004, before the "great surge" in international energy prices, more than one-tenth of households, specifically 11.9% of mother-child and 11.3% of single-elderly households, are in energy poverty in the annual case. After the Fukushima accident, in 2013, the share of mother-child households rises to 18.2%, and that of single-elderly to 16.4%. When evaluated in winter, the energy poverty rates become worsening. The result shows that approximately a quarter of mother-child and single-elderly households are energy-poor in 2013.

[Please insert Table 2 here]

Table 2 also indicates the surge of energy poverty rates before and after 2011. Even in 2010, before the earthquake, 15.8% of mother-child and 14.3% of single-elderly households are energy-poor in the annual case. After the accident, in 2013, the share of mother-child households increases to 18.2%, and that of single-elderly to 16.4%. The results indicate the severe and worsening situation on these vulnerable households especially after the GEJE.

Moreover, this study analyzes the situation of energy poverty in Japan from another important perspective: individual type. Table 3 describes the result of energy poverty rates, estimated at the individual base and not the household base, as in Table 2. As in the previous results, the energy poverty rates gradually increase and rise after the Fukushima accident. Notably, the elderly are more vulnerable than adults or children. No less than 12.5% of the elderly are energy poor in the winter case after the earthquake in 2013, more than twice the other categories. This result is well accounted for, as the elderly are mostly individuals in dimensional-poverty for housing. 53% of the elderly live in energy-inefficient houses built before 1979 in the dataset. This is quite high in comparison to 26% of adults or 15% of children. Although child (income) poverty is an emerging issue in Japan [29][48], this result suggests that more focus is necessary in the context of energy poverty on the elderly.

[Please insert Table 3 here]

The results prove that the rise in energy prices and lowering incomes in the 2000s stifled the livelihood of households in Japan. Especially, energy price hikes after 2011 have further aggravated the situation of energy poverty in Japan. In 2013, roughly one-fourth of vulnerable households (mother-child and single-elderly) were energy-poor in the winter estimate; stated in a different fashion, 12.5% of elderly people fell into energy poverty at that time.

6. Conclusion

The question is of gauging energy poverty in developed countries from a multidimensional perspective. As a classical study on multidimensional poverty, Atkinson and Bourguignon [49] emphasize that there are many cases in poverty measurement when a single dimensional index cannot represent the situation comprehensively. Therefore, this study suggests a new measure to evaluate energy poverty in developed countries from a multidimensional angle, the MEPI, which is composed of three attributes (dimensions) of energy poverty in developed countries: energy costs, income, and energy efficiency of housing. The MEPI is a practical alternative to traditional energy poverty measures, and is applicable in numerous cases.

The study applies the measure to gauge energy poverty in Japan throughout the period under analysis, including before and after the Great East Japan Earthquake and the Fukushima nuclear accident, which is an invaluable case in point. The empirical results, which are based on unique microdata, show that energy poverty has been aggravated since the 2000s. Examining the situation by household type, mother-child and single-elderly households, in particular, are vulnerable to energy poverty. As individuals, the elderly are in a more severe situation. Additionally, the results show the serious impact of energy price escalation after the Fukushima accident on energy poverty aggravation, especially for vulnerable households or the elderly.

Recently, international energy prices are at relatively a low level, which might ease the situation of energy poverty in Japan to a certain extent. It might also alleviate the difficulties of vulnerable households and individuals to a certain degree. However, the unique characteristics of Japan, such as a persistently sluggish economy, nuclear plant shutdowns, rising FIT charges, need for higher carbon pricing, etc., reduce the positive effects.[13] In this context, the government might consider some countermeasures to redress energy poverty, such as social tariffs and income supports, from the poverty and distributive perspectives. Moreover, it is essential to introduce effective measures to promote energy-saving investments that specifically target low-income and vulnerable households [2].[14]

Future research is necessary, especially on the definition of energy poverty. For multidimensional poverty indices, selecting the dimensions of poverty

---

[13] See also [28] for the latest situation.

[14] When considering countermeasures, viewpoints other than these three dimensions are also important and it is essential to focus on the local or individual context [3][4][17]. One example is to promote effective use of firewood for heating in mountainous areas.

is of utmost importance. As such, Kakwani and Silber [50] emphasize that researchers must decide, “what matters” in the target problems for themselves, and Boardman [2] claims that the choice of definition should be pragmatic. This study develops a multidimensional energy poverty index focusing on three dimensions: energy costs, income, and energy efficiency of housing, which reflects the traditions in this research field since Boardman [1], and is reasonable as a multidimensional measure of energy poverty in developed countries. Nevertheless, there could be another type of multidimensional energy poverty index, for example, including a dimension of wealth or subjective judgment.

Another area of future research, although it lies outside the scope of this study, is the possible application of the MEPI in other countries. For example, if applying it to a developing nation, some refinements will be necessary, especially in the dimensions of poverty. As said, most existing studies focus on energy access issues in the context of energy poverty in developing countries [5][6]; however, Nussbaumer et al. [38] evaluate energy poverty in developing countries (African countries) using a multidimensional approach.[15] These studies accentuate the multidimensional nature of energy poverty in developing countries, as well as the large income disparity and the limited access to modern types of energy services,

---

[15] Nussbaumer et al. [38] develop the multidimensional energy poverty index (MEPI), which also derives from the Alkire and Foster’s [33] approach, although they define the dimensions of energy poverty in the African context, using categorical data, such as “type of cooking fuel” and “has access to electricity or not.” Hence, their index is different and incomparable with the MEPI of this study.

which are peculiar to developing countries. To apply the MEPI, it is essential to consider the features of energy poverty in each country in various contexts [3][17].

Finally, the author believes that the new measure, MEPI, and its findings, will have important implications for future practices of tackling energy poverty in Japan and in other developed or developing countries.

Acknowledgments

The author would like to thank his colleagues, students, and the staff of the National Statistics Center for their assistance with this research. Furthermore, the author wishes to thank the editor and anonymous referees of this journal. This research was supported by the Grant from Nippon Life Insurance Foundation and the Grant for Environmental Research Projects from the Sumitomo Foundation.

References

[1] Boardman B. Fuel poverty: from cold homes to affordable warmth. London: Belhaven Press; 1991.

[2] Boardman B. Fixing fuel poverty: challenges and solutions. London: Earthscan; 2010.

[3] Bouzarovski S, Petrova SA. Global perspective on domestic energy deprivation: overcoming the energy poverty-fuel poverty binary. Energy Res Soc Sci 2015;10: 31–40.

[4] Middlemiss L, Gillard R. Fuel poverty from the bottom-up: characterising household energy vulnerability through the lived experience of the fuel poor. Energy Res Soc Sci 2015; 6:146–54.

[5] González-Eguino M. Energy poverty: an overview, Renew Sustain Energy Revs 2015;47:377–85.

[6] IEA (International Energy Agency). Energy poverty: how to make modern energy access universal? Paris: OECD/IEA; 2010.

[7] Fischer W, Hake J.-Fr, Kuckshinrichs W, Schröder T, Venghaus S. German energy policy and the way to sustainability: five controversial issues in the debate on the “Energiewende.” Energy 2016; 115:1580–91.

[8] Hake J.-Fr, Fischer W, Venghaus S, Weckenbrock C. The German Energiewende – history and status quo. Energy 2015; 92:532–46.

[9] Schuessler R. Energy poverty indicators: conceptual issues: Part I: the ten-percent-rule and double median/mean indicators. ZEW Discussion Paper 2014; 14-037.

[10] Hills J. Getting the measure of fuel poverty. London: Department of Energy and Climate Change, Government of UK; 2012.

[11] Bouzarovski S, Petrova S, Sarlamanov R. Energy poverty policies in the EU: a critical perspective. Energy Pol 2012;49:76–82.

[12] Brunner K.-M, Spitzer M, Christanell A. Experiencing fuel poverty: coping strategies of low-income households in Vienna/Austria. Energy Pol 2012;49:53–9.

[13] METI (Ministry of Economy, Trade and Industry). Strategic energy plan. Tokyo: Ministry of Economy, Trade and Industry, Government of Japan; 2014a.

[14] METI (Ministry of Economy, Trade and Industry). Energy white paper 2014. Tokyo: Ministry of Economy, Trade and Industry, Government of Japan; 2014b.

[15] METI (Ministry of Economy, Trade and Industry). Energy white paper 2015. Tokyo: Ministry of Economy, Trade and Industry, Government of Japan; 2015.

[16] METI (Ministry of Economy, Trade and Industry). Energy white paper 2016. Tokyo: Ministry of Economy, Trade and Industry, Government of Japan; 2016.

[17] Day R, Walker G, Simcock N. Conceptualizing energy use and energy poverty using a capabilities framework. Energy Pol 2016;93:255–64.

[18] Chawla M, Pollitt MG. Energy-efficiency and environmental policies and income supplements in the UK: evolution and distributional impacts on domestic energy bills. Econ Energy Environ Pol 2013;2:21–40.

[19] Hills J. Fuel poverty: the problem and its measurement. London: Department of Energy and Climate Change, Government of UK; 2011.

[20] Moore R. Definitions of fuel poverty: implications for policy. Energy Pol 2012;49:19–26.

[21] Sovacool BK. Fuel poverty, affordability, and energy justice in England: policy insights from the warm front program, Energy 2015;93:361–71.

[22] Waddams Price C, Brazier K, Wang W. Objective and subjective measures of fuel poverty. Energy Pol 2012;49:33–9.

[23] Dubois U. From targeting to implementation: the role of identification of fuel poor households. Energy Pol 2012;49:107–15.

[24] Heindl P, Schuessler R. Dynamic properties of energy affordability measures. Energy Pol 2015;86:123–32.

[25] Fabbri K. Building and fuel poverty, an index to measure fuel poverty: an Italian case study. Energy 2015;89:244–58.

[26] Phimister E, Vera-Toscano E., Roberts D. The dynamics of energy poverty: evidence from Spain. Econ Energy Environ Pol 2015;4:153–66.

[27] Thomson H, Snell C. Quantifying the prevalence of fuel poverty across the European Union. Energy Pol 2013;52:563–72.

[28] Okushima S. Measuring energy poverty in Japan, 2004–2013. Energy Pol 2016;98:557–64.

[29] MHLW (Ministry of Health, Labour and Welfare). White paper on annual health, labour and welfare 2012. Tokyo: Ministry of Health, Labour and Welfare, Government of Japan; 2012a.

[30] MHLW (Ministry of Health, Labour and Welfare). White paper on labour and economy 2012. Tokyo: Ministry of Health, Labour and Welfare, Government of Japan; 2012b.

[31] Atkinson AB. Multidimensional deprivation: contrasting social welfare and counting approaches. J Econ Inequal 2003;1:51–65.

[32] Bourguignon F, Chakravarty, SR. The measurement of multidimensional poverty. J Econ Inequal 2003;1:25–49.

[33] Alkire S, Foster J. Counting and multidimensional poverty measurement. J Pub Econ 2011;95:476–87.

[34] Duclos J, Sahn DE, Younger SD. Robust multidimensional poverty comparisons. Econ J 2006;116:943–68.

[35] McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS. Climate change 2001: impacts, adaptation, and vulnerability: contribution of working croup II to

the third assessment report of the intergovernmental panel on climate change. Cambridge, UK: Cambridge University Press; 2001.

[36] Pachauri S, Mueller A, Kemmler A, Spreng D. On measuring energy poverty in Indian households. World Dev 2004;32:2083–104.

[37] Alkire S, Foster J, Seth S, Santos ME, Roche JM, Ballón P. Multidimensional poverty measurement and analysis. Oxford: Oxford University Press; 2015.

[38] Nussbaumer P, Bazilian M, Modi V. Measuring energy poverty: focusing on what matters. Renew Sustain Energy Rev 2012;16:231–43.

[39] Peichl A, Pestel N. Multidimensional affluence: theory and applications to Germany and the US. Appl Econ 2013a;45:4591–601.

[40] Peichl A, Pestel N. Multidimensional well-being at the top: evidence for Germany. Fisc Stud 2013b;34:355–71.

[41] Foster J, Greer J, Thorbecke E. A class of decomposable poverty measures. Econometrica 1984;52:761–6.

[42] Foster J, Greer J, Thorbecke E. The Foster-Greer-Thorbecke (FGT) poverty measures: 25 years later. J Econ Inequal 2010;8:491–524.

[43] Sen A. On economic inequality: enlarged edition. Oxford: Clarendon Press; 1997.

[44] Haughton J, Khandker SR. Handbook on poverty and inequality. Washington, DC: World Bank; 2009.

[45] METI (Ministry of Economy, Trade and Industry). Energy conservation policies of Japan. Tokyo: Ministry of Economy, Trade and Industry, Government of Japan; 2011.

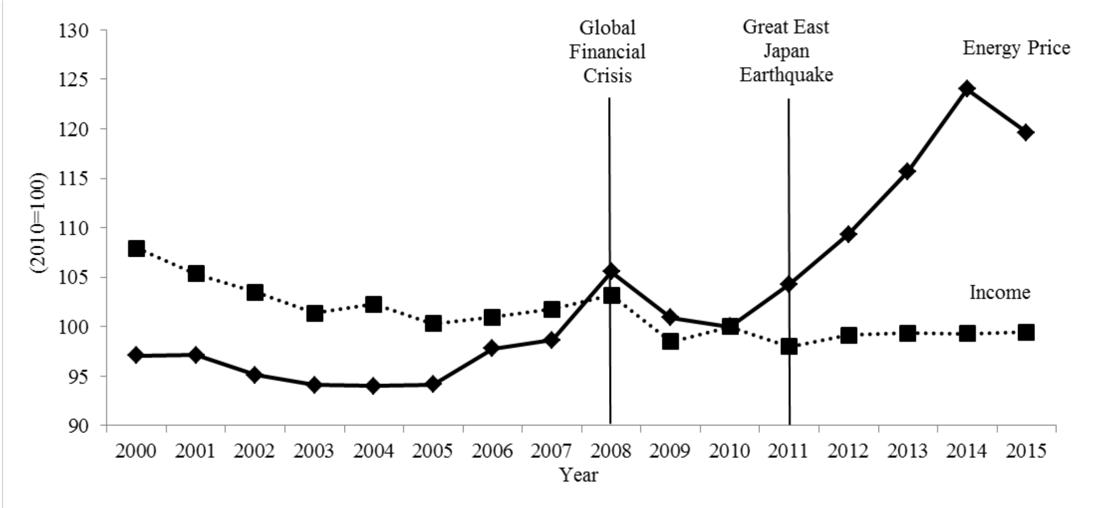
[46] Markovska N, Duić N, Mathiesen BV, Guzović Z, Piacentino A, Schlör H, Lund H. Addressing the main challenges of energy security in the twenty-first century – contributions of the conferences on sustainable development of energy, water and environment systems. Energy 2016;115:1504–12.

[47] Ministry of the Environment. Annual report on the environment, the sound material-cycle society, and biodiversity in Japan 2014. Tokyo: Ministry of the Environment, Government of Japan; 2014.

[48] Cabinet Office. White paper on children and young people 2014. Tokyo: Cabinet Office, Government of Japan; 2014.

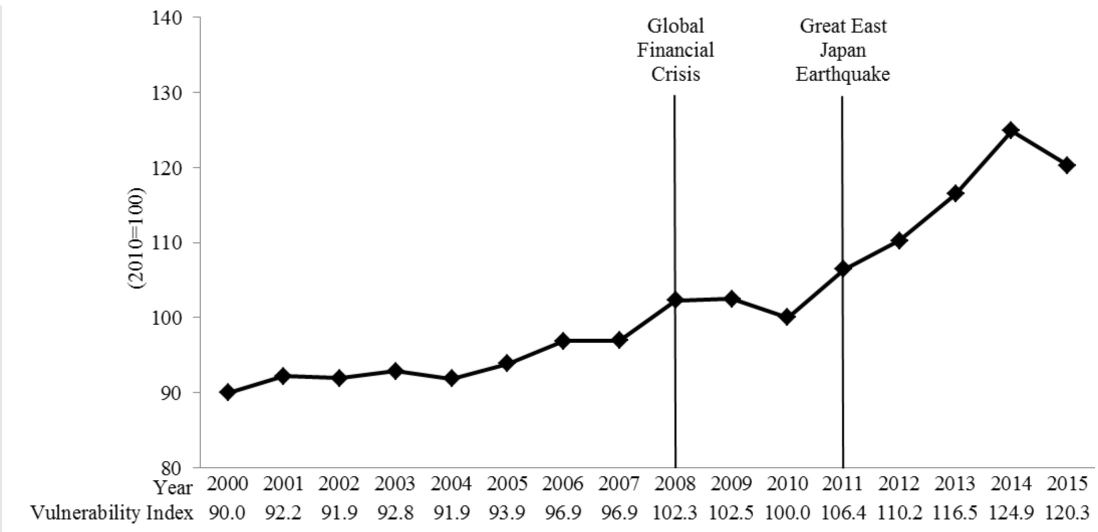
[49] Atkinson AB, Bourguignon F. The comparison of multi-dimensional distribution of economic status. Rev Econ Stud 1982;49:183–201.

[50] Kakwani N, Silber J. (Eds.). The many dimensions of poverty. New York: Palgrave Macmillan; 2007.



Note: "Energy price" is a composite index of CPIs for electricity, gas, and other fuels with the 2010 weights. "Income" is the annual average income of all workers' households derived from the Family Income and Expenditure Survey, Statistics Bureau, Ministry of Internal Affairs and Communications, Japan.

Figure 1. Trends in domestic energy prices and household income after 2000



Note: "Vulnerability index" is the ratio of "Energy price" to "Income" in Figure 1. As in Figure 1, "Energy price" is a composite index of CPIs for electricity, gas, and other fuels with the 2010 weights. "Income" is the annual average income of all workers' households derived from the Family Income and Expenditure Survey, Statistics Bureau, Ministry of Internal Affairs and Communications, Japan.

Figure 2. Trends in vulnerability index for energy poverty after 2000

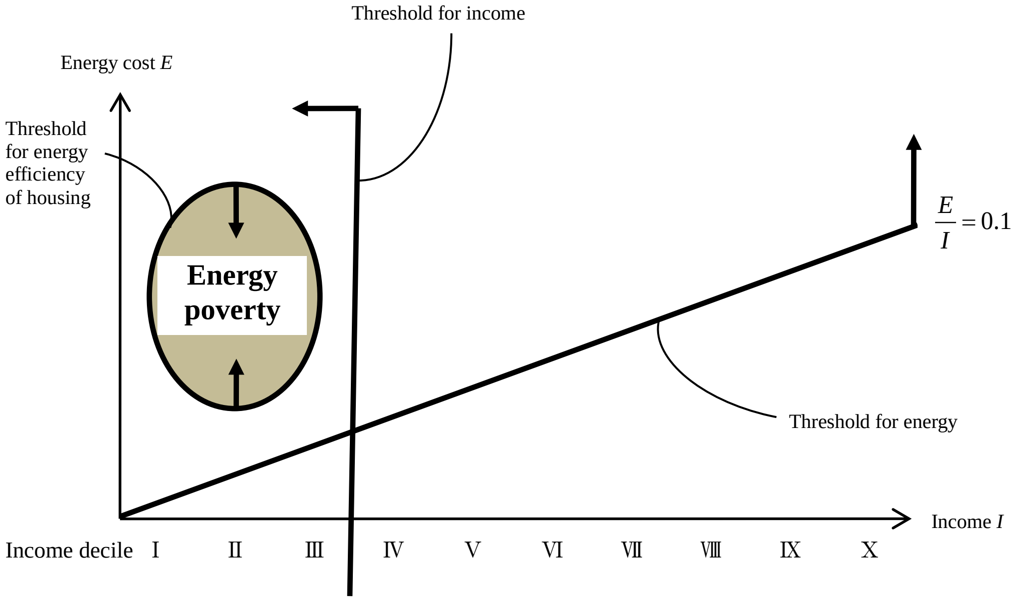


Figure 3. Concept of multidimensional energy poverty

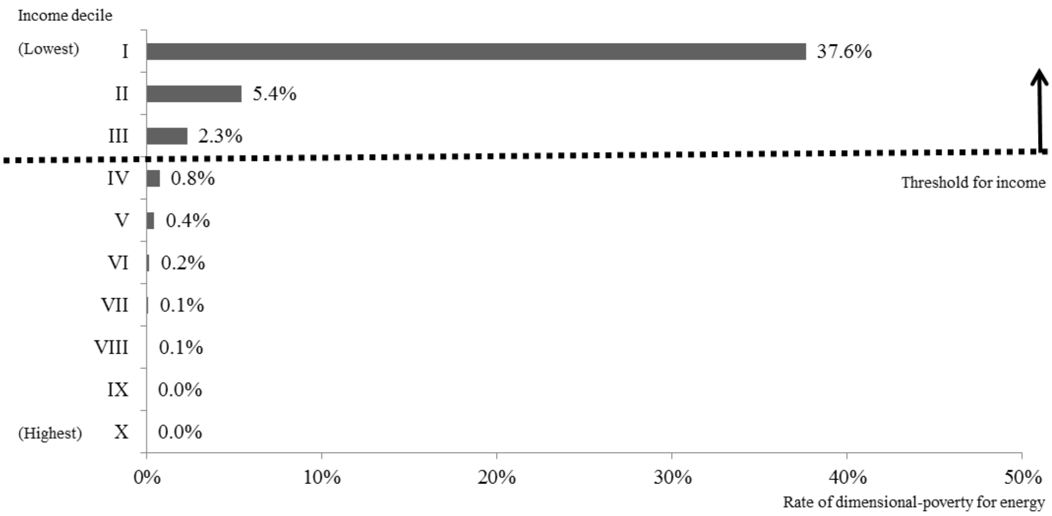


Figure 4. Rate of dimensional-poverty for energy by income decile group

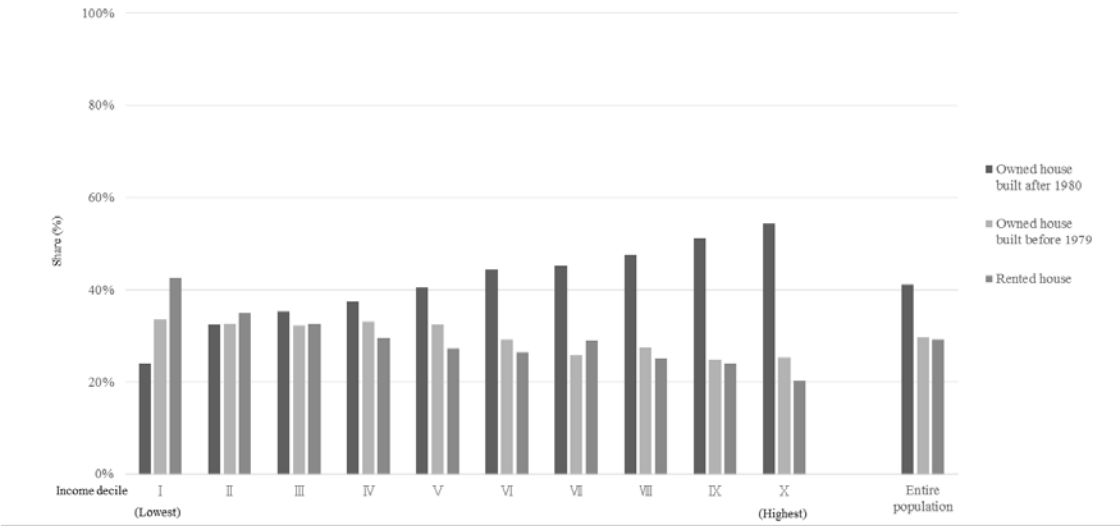
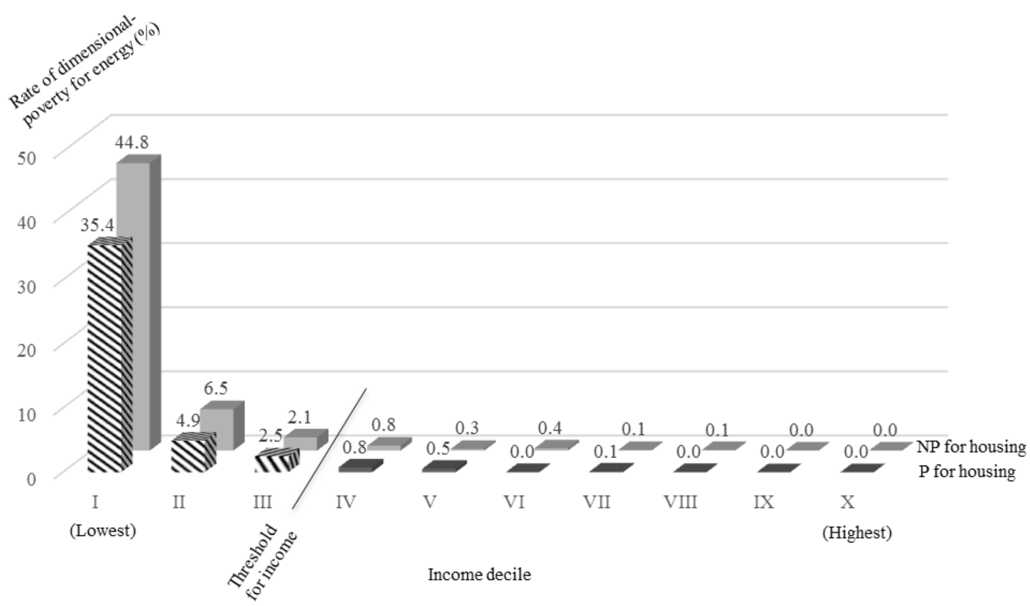


Figure 5. Housing conditions by income decile group



Note: "P for housing" means the dimensional-poverty for energy efficiency of housing and "NP for housing" vice versa. Three hatched bars are the parts corresponding to the multidimensional energy poverty in this analysis.

Figure 6. Three-dimensional diagram of multidimensional energy poverty

Table 1. Energy poverty rates in Japan

	Annual base				Winter base			
	2004	2007	2010	2013	2004	2007	2010	2013
Energy poverty rate	3.2%	4.1%	4.5%	5.3%	5.5%	6.8%	7.4%	8.4%

Table 2. Energy poverty rates by household type

	Annual base				Winter base			
	2004	2007	2010	2013	2004	2007	2010	2013
Mother-child	11.9%	14.5%	15.8%	18.2%	19.0%	22.2%	23.6%	25.8%
Single-elderly	11.3%	13.7%	14.3%	16.4%	17.1%	20.8%	22.0%	24.5%
Elderly	3.7%	4.9%	5.6%	6.9%	7.2%	9.2%	10.3%	11.7%
Single-person	3.2%	4.0%	4.2%	4.8%	5.5%	6.5%	6.9%	7.6%
Other	1.6%	2.2%	2.5%	3.1%	3.1%	4.0%	4.5%	5.2%

Note: Mother-child households are composed of a single female parent and an unmarried child (or children). Single-elderly households consist of one person 65 years old or over. Elderly households are households with two or more persons 65 years old or over. Single-person households consist of a single person less than 65 years of age.

Table 3. Energy poverty rates by individual type

	Annual base				Winter base			
	2004	2007	2010	2013	2004	2007	2010	2013
Elderly	4.6%	6.0%	6.6%	7.9%	8.1%	10.1%	11.1%	12.5%
Adult	1.7%	2.2%	2.6%	3.1%	3.2%	4.1%	4.5%	5.2%
Child	1.4%	1.9%	2.2%	2.6%	2.7%	3.5%	3.8%	4.5%

Note: "Elderly" are 65 years of age or over. "Adult" is 18-64 years of age. "Child" is less than 18 years old.