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How to evaluate energy sufficiency: A direct measurement 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

ABSTRACT

This study presents a novel approach to measuring energy sufficiency, which can identify whether people really satisfy an adequate level of domestic energy services, considering their diverse energy needs. The result, applying the method to the case of Japan, clarifies the characteristics of people in energy sufficiency, and those of the energy poor and energy extravagant. The study also demonstrates that reducing inequalities in access to low-carbon energy or technology is a major challenge in engendering an inclusive low-carbon energy transition.

Keywords: energy sufficiency, energy poverty, energy extravagance, climate justice, energy justice, energy transition

NONMENCLATURE

Abbreviations	
DES	Domestic Energy Service(s)
EE	Energy Extravagance / Energy Extravagant
EP	Energy Poverty / Energy Poor
ES	Energy Sufficiency / Energy Sufficient
GJ	Gigajoules
JPY	Japanese Yen

1. INTRODUCTION

Recently, the concept of ES has been widely discussed in the field of energy research [1-4]. Energy services, such as heating or cooking, are essential for people's normal daily functioning. A certain amount of energy use can be morally justified, for example, from the perspective of guaranteeing human rights [5]. On the other hand, excessive energy use can be morally impermissible, particularly from the perspective of climate change, energy-associated pollutants, external costs associated with the extraction of energy resources, and so on [6].

Conceptually, a sufficiency level of energy services use (or energy consumption) can be described as in Fig. 1 (here, the level is defined at the household level, not at the aggregated society level). This definition of ES is characterized by dual thresholds: the lower threshold mentioning basic energy needs or a subsistence level, and the upper threshold indicating environmental sustainability or relative overconsumption (energy extravagance). Using the terminology of distributive justice theory, the lower threshold is related to the sufficientarian threshold [7,8][1] and the upper threshold to the limitarian threshold [9,10].[2] The idea of a consumption corridor [11], which is a similar concept, is not limited to energy; however, if applied to energy, it can be renamed an energy consumption corridor, which is analogous to the energy sufficiency concept of this study.

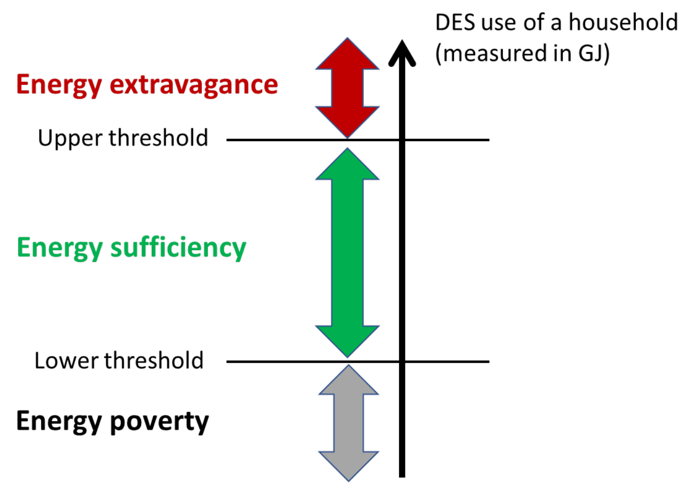


Fig. 1 Concept of energy sufficiency

ES has been discussed conceptually, although few studies have empirically considered this concept. The most important but difficult task is to determine both the upper and lower thresholds in a theoretically appropriate and empirically measurable manner. Against this background, this study proposes a novel approach for empirically evaluating ES. Our direct measurement approach—to define the lower and upper

[1] Sufficientarianism says that "whether individuals have secured enough of some goods is a question that is central to determining whether a society is just" (Shields [7], p. 1).
[2] Limitarianism is "the idea that in the world as it is, no one should have more than a certain upper limit of valuable goods" (Robeyns [10], p. 1).

thresholds for specifying ES levels—was applied in this study. This study examined Japan as a case study; however, the method and implications of this study are transferable to other countries.

2. MATERIAL AND METHODS

In this study, the state of ES was defined as fulfilling an adequate level of DES use and was measured at the individual household level (Fig. 1). In other words, ES is a state of being neither in EP nor EE for each person or household. As shown in Fig. 1, an adequate level indicates the range between the lower and upper thresholds. The lower thresholds separated an adequate (sufficient) level from an EP level, whereas the upper thresholds distinguished an adequate level from an EE level. As mentioned earlier, the study focused on DES use, that is, heating, cooling, water heating, cooking, and appliance usage, excluding transport, in line with the EP measurement literature [12,13].

As shown in previous literature, determining an adequate level of DES use requires considering the difference in people's energy needs [14,15]. Taking Japan as an example, Fig. 2 illustrates DES use per household (in GJ, equivalized) between 10 Japanese regions: People living in Hokkaido (in a subarctic climate) have higher energy needs, mainly for winter heating, while heating needs are almost non-existent in Okinawa (in a subtropical climate). To gauge ES at the household level, an approach that considers people's diverse energy needs is necessary.

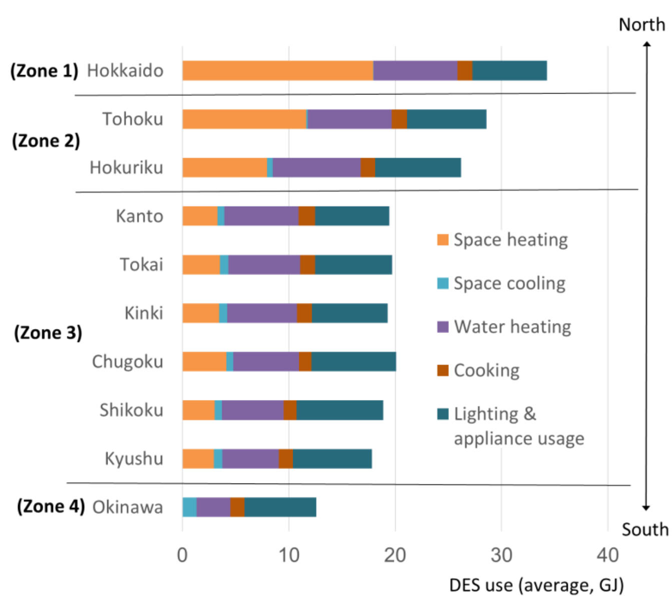


Fig. 2 DES use by purpose in 10 Japanese regions

The study then applied the direct measurement approach, originally developed for gauging EP by Okushima [16,17], to measure the ES. In the direct measurement approach, households are divided into different *types*, in which households of the same *type* are those living in similar *circumstances* regarding DES usage patterns. The approach divided households into 16 *types* according to three circumstantial factors—climatic, dwelling, and socio-demographic factors, following previous studies [16,17], as shown in Table 1.

Table 1 Household type in this study

	Detached house		Apartments	
	Vulnerable type	Others	Vulnerable type	Others
(Zone 1) Hokkaido	*Type 1*	*Type 2*	*Type 3*	*Type 4*
(Zone 2) Tohoku, Hokuriku	*Type 5*	*Type 6*	*Type 7*	*Type 8*
(Zone 3) Kanto, Tokai, Kinki, Chugoku, Shikoku, Kyushu	*Type 9*	*Type 10*	*Type 11*	*Type 12*
(Zone 4) Okinawa	*Type 13*	*Type 14*	*Type 15*	*Type 16*

Note: "Vulnerable type" refers to the households that include older adults (65 years old or over) member(s). For details on the regions, see Fig. 2.

Table 2 presents the median DES use for each household *type*. Here, DES use is measured by energy consumption for domestic energy services use (in GJ) and equivalized with the square root of household size to correct for economies of scale [16,17]. To define the range meaning the ES level, the study set the lower threshold of each *type* as 60% of the median of DES use (in GJ), following EP studies [15-17], and set the upper threshold of each *type* as twice the median [18,19].[3][4]

Table 2 Lower and upper thresholds of each household type

	Median of DES use (GJ)	Lower threshold (GJ)	Upper threshold (GJ)
Type 1	43.6	26.1	87.1
Type 2	37.1	22.3	74.3
Type 3	25.6	15.3	51.1
Type 4	22.8	13.7	45.6
Type 5	31.8	19.1	63.6
Type 6	26.1	15.6	52.1
Type 7	19.5	11.7	39.0
Type 8	16.9	10.1	33.7
Type 9	22.4	13.4	44.8
Type 10	19.2	11.5	38.4
Type 11	15.9	9.5	31.8
Type 12	14.8	8.9	29.6
Type 13	14.7	8.8	29.3
Type 14	12.9	7.8	25.9
Type 15	12.0	7.2	24.0
Type 16	10.4	6.2	20.7

[3] There is considerable debate on how such thresholds must be set, but here, it has not been discussed due to space limitations (see e.g. [15,20]).

[4] Notably, for identifying people in EP, this study adds an income threshold to avoid the possibility of false positives; then, EP is multidimensionally identified with the thresholds of both DES use and income dimensions. For more information, see [13,15].

Regarding the dataset, this study used unique microdata on Japanese households' energy use and CO_2 emissions in 2018. The dataset was created using anonymized information, provided for this study, from the 2018 Survey on the Actual Conditions of Carbon Dioxide Emissions from Residential Sector.[5]

3. RESULTS AND DISCUSSION

Fig. 3 shows the ES rate, the share of households in ES, and showing the rates of EP and EE in Japan. As the results show, most people living in Japan, as in the case of people in the global north, have been satisfying an adequate level of DES, though about one-tenth of households are energy poor and another one-twentieth live in a state of excessive DES use.[6]

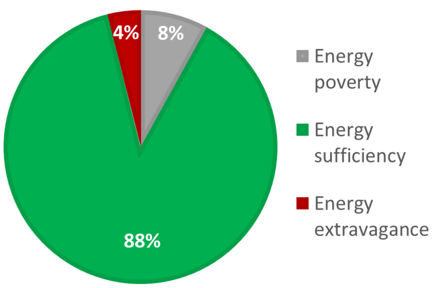
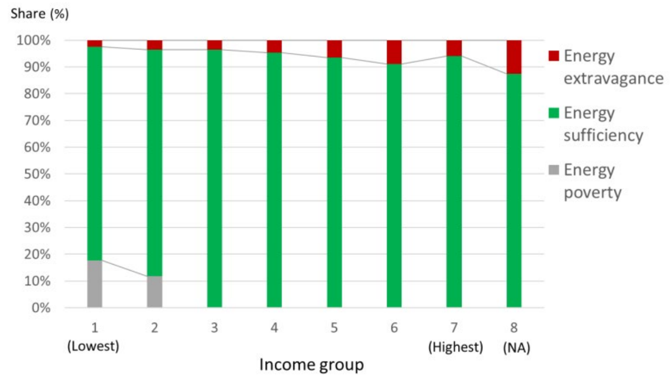


Fig. 3 ES, EP and EE share in Japan

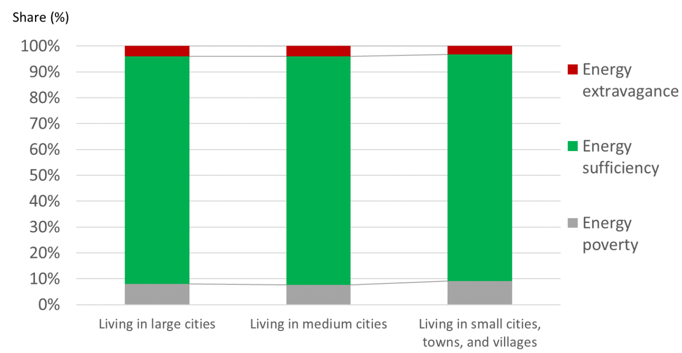
Fig. 4 depicts the shares of ES, EP, and EE households by income group. As expected, living in ES requires a sufficient income level; consequently, 10–20% of households in the bottom two income groups suffer EP. On the other hand, as the income level rises, the proportion of households in EE also rises. Notably, more than 10% of the households with no answer on their income level overconsume DES. This result is fairly reasonable given the generally low response rate on income from rich people.



Note: Income group 1—means their annual income is less than 2.5 million JPY; 2—between 2.5 and 5 million; 3—between 5 and 7.5 million; 4—between 7.5 and 10 million; 5—between 10 and 15 million; 6—between 15 and 20 million; 7—more than 20 million; and 8—unknown (no answer on their income level).

Fig.4 ES, EP and EE share by income group

Fig. 5 illustrates the shares of ES, EP, and EE households by city size, showing that the ES rates are not significantly different in terms of city size. EE is a slightly more prevalent in large cities, with many high-income residents, while less populated areas have a larger share of EP, who cannot meet an adequate DES level [14].



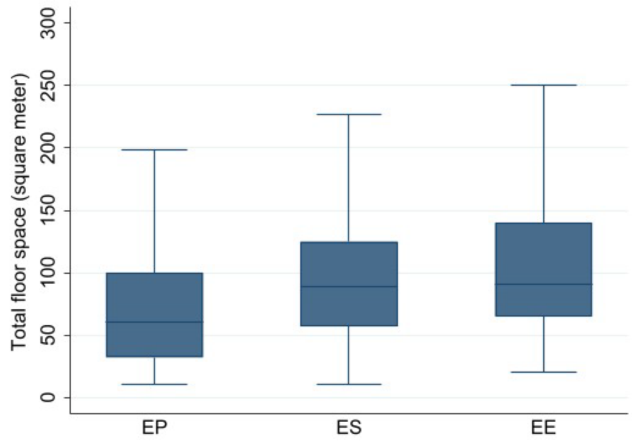
Note: Large cities include Tokyo (23 wards), government ordinance-designated cities, and prefectural capitals: Medium cities are cities with a population of more than 50 thousand: Small cities, towns, and villages are cities, towns, and villages with a population of less than 50 thousand.

Fig.5 ES, EP and EE share by city size

When considering an adequate level of DES use, houses' size would be considered an essential factor. Previous studies have shown that house size is the dominant factor affecting domestic energy consumption [21,22]. Supporting these studies, Fig. 6 shows that EE households often live in larger houses with many rooms, clarifying the strong relationship between house size and excessive DES use. This result is consistent with the findings of qualitative Japanese studies [23].

[5] The details of this survey are given by the Ministry of the Environment, Japan (http://www.env.go.jp/earth/ondanka/ghg/kateiCO2tokei.html, last accessed June 27th, 2022).

[6] Note that this study considers ES from the aspect of how much energy is used, but not from the other aspects like "Timing" or "Flexibility" (when energy is used) [1]. Such issues are left for future work.



Note: The horizontal line in each box is the median; the top and bottom of the box are the upper and lower quartiles, and both ends of the whiskers are the upper and lower adjacent values.

Fig. 6 Distribution of house size by ES, EP, and EE

Fig. 7 shows the ES, EP, and EE shares in the total domestic energy consumption and the total CO_2 emissions from DES use in Japan. As expected, ES constituted the majority of each category. However, it is notable that EE people account for 8.1% of the total domestic energy consumption and 7.3% of the total CO_2 emissions, despite EE's minor population sharing of 3.9%.

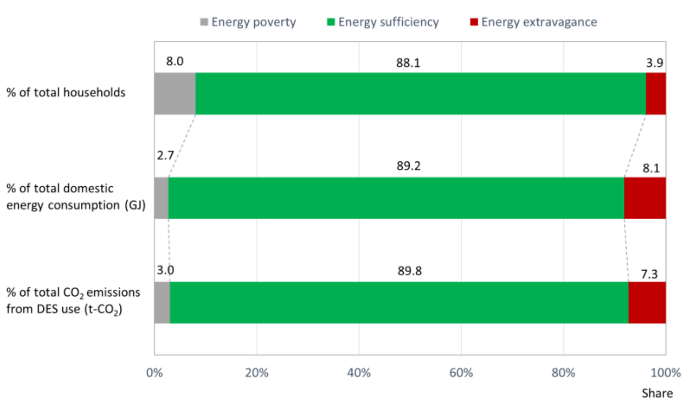
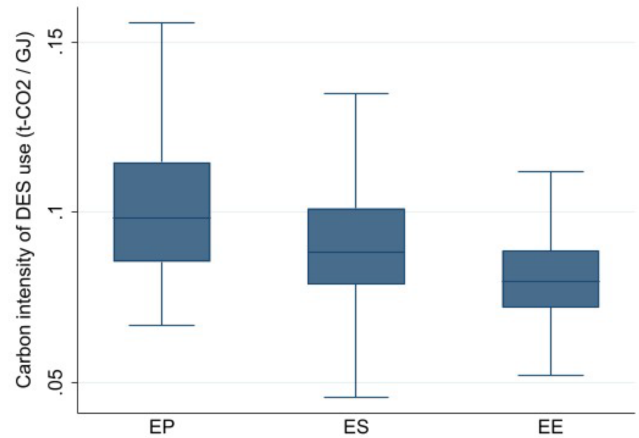


Fig. 7 ES, EP, and EE share in total domestic energy consumption and CO_2 emissions

Fig. 7 also shows that EE people account for a smaller share of CO_2 emissions than energy consumption regarding DES use. This indicates the existing inequality of low-carbon energy access in Japan, i.e., the "access to low-carbon energy" issue [14,15]. Fig. 8 shows the results more directly, comparing the distribution of carbon intensity of DES use of ES, EP, and EE. The figure clarifies that EE people generally have much lower carbon intensity of their (huge) DES use than ES and EP. This implies that inequality in access to low-carbon energy or technology exists, possibly leading to present and future regressive impacts on society (double injustice) [11,24]. Such inequality must be alleviated as soon as possible to ensure an inclusive low-carbon energy transition.



Note: The horizontal line in each box is the median; the top and bottom of the box are the upper and lower quartiles, and both ends of the whiskers are the upper and lower adjacent values.

Fig. 8 Distribution of carbon intensity of DES use by ES, EP, and EE

4. CONCLUSIONS

This study proposes a novel and practical approach to evaluating ES, that is, a method to identify whether people really fulfill an adequate level of DES use—with a full account of their diverse energy needs. The findings of this study can be used to identify the characteristics of ES people, as well as to elucidate the realities of people both in EP and EE; in particular, the reality of EE people has not yet been well explored but is in urgent need of clarification [25,26].

Furthermore, the results can be used to examine a fair burden-sharing scheme regarding the huge costs of ongoing low-carbon energy transitions. A few studies [10,27-29] have suggested that more progressive wealth and carbon taxes should be introduced to ensure fair energy transitions. In this context, the results of this study suggest that EP people should be exempted from such taxation, while EE people should bear a heavier (more than proportional) carbon tax burden if strengthening the carbon pricing policy for deep carbon mitigation. Such progressive carbon pricing policy is, needless to say, not efficient in an economics sense; however, it may be ethically plausible and acceptable to the general public. These arguments are only an example of application of this study, but are considered to be future research avenues.

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REFERENCE

[1] Darby S, Fawcett T. Energy sufficiency: an introduction. European Council for Energy Efficient Economy; 2018.

[2] Thomas S, Thema J, Brischke LA, Leuser L, Kopatz M, Spitzner M. Energy sufficiency policy for residential electricity use and per-capita dwelling size. Energy Efficiency 2019;12:1123–49.

[3] Sorrell S, Gatersleben B, Druckman A. The limits of energy sufficiency: A review of the evidence for rebound effects and negative spillovers from behavioural change. Energy Research & Social Science 2020; 64: 101439.

[4] Wiedmann T, Lenzen, M, Keyßer LT, Steinberger JK. Scientists' warning on affluence. Nature Communications 2020; 11: 3107.

[5] Shue H. Subsistence protection and mitigation ambition: Necessities, economic and climatic. The British Journal of Politics and International Relations 2019; 21(2): 251-62.

[6] Sovacool BK, Kim J, Yang M. The hidden costs of energy and mobility: A global meta-analysis and research synthesis of electricity and transport externalities. Energy Research & Social Science 2021; 72: 101885.

[7] Shields L. Sufficientarianism. Philosophy Compass 2020; 15: e12704.

[8] Huseby R. The limits of Limitarianism. Journal of Political Philosophy 2022; 30: 230-48.

[9] Timmer D. Limitarianism: Pattern, Principle, or Presumption? Journal of Applied Philosophy 2021;38: 760-73.

[10] Robeyns I. Why Limitarianism? Journal of Political Philosophy 2022; 30: 249-70.

[11] Gough I. Defining floors and ceilings: the contribution of human needs theory. Sustainability: Science, Practice and Policy 2020; 16:1: 208-19.

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

[13] Okushima S. Gauging energy poverty: a multidimensional approach. Energy 2017; 137: 1159–66.

[14] Castaño-Rosa R, Okushima S. Prevalence of energy poverty in Japan: a comprehensive analysis of energy poverty vulnerabilities. Renewable and Sustainable Energy Reviews 2021; 145: 111006.

[15] Okushima S. Energy poor need more energy, but do they need more carbon?: Evaluation of people's basic carbon needs. Ecological Economics 2021; 187: 107081.

[16] Okushima S. Understanding regional energy poverty in Japan: a direct measurement approach. Energy and Buildings 2019; 193: 174–84.

[17] Kahouli S, Okushima S. Regional energy poverty reevaluated: a direct measurement approach applied to France and Japan. Energy Economics 2021; 102: 105491.

[18] Drewnowski J. The affluence line. Social Indicators Research 1978; 5: 263-78.

[19] Concialdi P. What does it mean to be rich? Some conceptual and empirical issues. European Journal of Social Security 2018; 20(1): 3-20.

[20] Timmer D. Thresholds in Distributive Justice. Utilitas 2021; 33(4): 422-41.

[21] Huebner GM, Shipworth D. All about size? – The potential of downsizing in reducing energy demand. Applied Energy 2017; 186 (2): 226-233.

[22] Ellsworth-Krebs K. Implications of declining household sizes and expectations of home comfort for domestic energy demand. Nature Energy 2020; 5: 20–5.

[23] Yagita Y, Iwafune Y. Residential energy use and energy-saving of older adults: A case from Japan, the fastest-aging country. Energy Research & Social Science 2021; 75: 102022.

[24] Sovacool BK, Newell P, Carley S, Fanzo J. Equity, technological innovation and sustainable behavior in a low-carbon future. Nature Human Behaviour 2022; 6: 326-37.

[25] Oswald Y, Owen A, Steinberger JK. Large inequality in international and intranational energy footprints between income groups and across consumption categories. Nature Energy 2020; 5: 231–9.

[26] Castano Garcia A, Ambrose A, Hawkins A, Parkes S. High consumption, an unsustainable habit that needs more attention. Energy Research & Social Science 2021; 80: 102241.

[27] Benoit P. A Luxury Carbon Tax to Address Climate Change and Inequality: Not All Carbon Is Created Equal. Ethics & International Affairs 2020 (Online exclusive) https://www.ethicsandinternationalaffairs.org/2020/a-luxury-carbon-tax-to-address-climate-change-and-inequality-not-all-carbon-is-created-equal/#author (last accessed June 27th, 2022).

[28] Chancel L, Piketty T. Carbon and inequality: from Kyoto to Paris. Paris School of Economics; 2015.

[29] Chancel L. Climate change and the global inequality of carbon emissions, 1990-2020. Paris School of Economics; 2021.