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Analysis

Energy poor need more energy, but do they need more carbon? Evaluation of people's basic carbon needs

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ABSTRACT

In the era of low-carbon energy transitions, both climate and energy justice studies have raised concerns about the deterioration of energy poverty triggered by carbon mitigation policies. Nevertheless, no in-depth analysis has thus far examined the relationship between people suffering energy poverty and their carbon dioxide emissions. This study addresses the issue by presenting a novel approach to measuring people's basic carbon needs (BCN), which are defined as the amount of carbon emissions needed to achieve (socially and materially) adequate levels of domestic energy services. The results, using Japan as a case study, reveal the differences in people's BCN based on climatic, socio-demographic, and dwelling factors, showing that people in energy poverty need greater carbon emissions to fulfil their basic energy needs than the affluent population. In upcoming low-carbon energy transitions, people's BCN must be reduced while satisfying their basic energy needs. However, this study shows that the carbon intensity of domestic energy services for energy poverty households is high, leading carbon mitigation policies such as carbon pricing to adversely affect them without suitable countermeasures. Hence, ensuring access to low-carbon energy for all, including the energy poor, is essential to engender an inclusive low-carbon energy transition.

1. Introduction

"People are burning fossil fuels to obtain energy, and energy is a necessity for any remotely modern form of life" (Shue, 2014, p. 3). Many argue that energy services are essential means to satisfy human needs (Brand-Correa and Steinberger, 2017; Gough, 2017). However, energy poverty (EP) has now become a major concern for both developing countries and countries in the global north.[1] EP is defined as "the inability to attain a socially and materially necessitated level of domestic energy services" (Bouzarovski and Petrova, 2015, p. 31). The number of people who suffer EP has recently been increasing in various developed countries due to rising energy costs as well as aging and stagnant economies. Studies have focused mostly on European countries such as Austria (Brunner et al., 2012), Belgium (Meyer et al., 2018), France (Legendre and Ricci, 2015; Fizaine and Kahouli, 2019), Germany (Heindl, 2015; März, 2018), Greece (Papada and Kaliampakos, 2016, 2018), Italy (Fabbri, 2015; Besagni and Borgarello, 2019), and Spain (Aristondo and Onaindia, 2018; Castaño-Rosa et al., 2020) as well as the United Kingdom, a forerunner in the field (Boardman, 2010; Hills, 2012). However, EP studies have recently increased from non-European countries such as Australia (Poruschi and Ambrey, 2018; Liu and Judd, 2019; Awaworyi Churchill and Smyth, 2020), Canada (Tardy and Lee, 2019), China (Robinson et al., 2018; Lin and Wang, 2020), Hong Kong (Fuller et al., 2019), South Korea (Lee and Shepley, 2020), the United States (Mohr, 2018; Bednar and Reames, 2020), and Japan (Okushima, 2016, 2017, 2019).

Related to this issue, one important challenge, namely, the nexus between EP and carbon mitigation, has attracted much attention recently (e.g., Galvin and Sunikka-Blank, 2018; Kerr et al., 2019; Galvin, 2020a). As the people who suffer EP are the people who lack sufficient energy for a healthy and decent life, they inevitably need more energy to exit from such a miserable situation. However, for any reason, more energy consumption leads to more carbon emissions unless their additional energy uses are covered by non-carbon energy (e.g., solar or biomass) or perfectly offset by emissions reductions by the non-energy poor (Gough, 2017; Galvin, 2020a). In general, people in EP cannot afford to adopt low-carbon technology such as solar PV panels on their own (Chapman and Okushima, 2019; Sovacool et al., 2019a, 2019b;

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[1] This study addresses the issue of EP in developed countries. In regard to EP in developing countries, see IEA (2010), González-Eguino (2015), and Samarakoon (2019). Following Bouzarovski and Petrova (2015) and Bouzarovski (2018), the term "energy poverty" is used synonymously with "fuel poverty."

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Carley and Konisky, 2020); hence, EP eradication efforts are more likely to raise carbon emissions without suitable countermeasures.

Such a trade-off has been a concern in the EP literature (e.g., Ürge-Vorsatz and Tirado Herrero, 2012; Bouzarovski, 2018). In addition, from an interdisciplinary viewpoint, moral or political philosophers have discussed such a dilemma under the topic of "climate justice," which demands fair and equitable burden sharing of climate change and its resolution (Kanbur and Shue, 2019). According to Henry Shue, a representative scholar in this field, we must tackle (at least) two justice-related constraints when restricting our carbon emissions: (i) guaranteeing the poor (the currently vulnerable) the minimum necessary emissions (or energy) for a decent life and (ii) avoiding hazardous climate change for the future vulnerable (Shue, 2014). He mentions that the (current) poor should have an "inalienable right to produce carbon emissions as long as the only affordable energy is carbon-based energy" and worries that increasing fossil fuel prices by "putting a price on carbon" would plunge the poor into deeper poverty: "Climate change is only half the story. The other half is that more than two billion human beings suffer from energy poverty right now" (Shue, 2014, p. 333).[2]

While studies in various disciplines examine the dilemmatic relationship between EP and carbon emissions, few studies provide a detailed quantitative analysis of it. In this context, the most important question is what carbon emissions are needed for households or individuals to meet their basic energy needs (BEN). Furthermore, how does this carbon requirement differ between people, especially between those who suffer EP and others? To answer these questions, this study develops a novel approach to measuring the basic carbon needs (BCN)—a new operational concept we present—of each household or person. Using this method, we empirically investigate the relationship between people in EP and their carbon emissions to offer a viable solution for the trade-off issue as well as contribute to interdisciplinary scholarship in the field of climate justice.

The remainder of this paper is organized as follows. Section 2 reconsiders the nexus between EP and carbon mitigation by reviewing existing scholarship of EP, or more broadly, energy justice, and that of climate justice. Section 3 presents the new measurement approach developed in this study, providing new and practical definitions of EP, BEN, and BCN. Section 4 provides the results and discusses the findings. The final section presents concluding remarks and the policy implications derived from the results. This study analyzes Japan as a case study, since decarbonization with alleviating EP is an urgent issue in the country (Chapman and Okushima, 2019; Castaño-Rosa and Okushima, 2021), although the methodology and implications of this research are applicable to other countries as well.

2. People in energy poverty: their energy needs and derived carbon emissions

People who suffer energy poverty (EP), by definition, cannot achieve "a socially and materially necessitated level of domestic energy services" (Bouzarovski and Petrova, 2015, p. 31) or "domestic energy services required to live a decent and healthy life" (Middlemiss and Gillard, 2015, p. 147). Theoretically, such *a threshold level* of the needed energy services can be considered to be equivalent to people's *basic energy needs* (BEN). The exact specification of BEN is highly contested; however, many scholars, not only EP researchers but also moral or political philosophers (e.g., Caney, 2011; Shue, 2014), agree that the poor should be guaranteed a certain level of energy services use for a healthy and decent life.

Indeed, we can consider the people in EP to be those who cannot obtain the BEN level of domestic energy services. However, it is notable that the amount of BEN should not take the same value for households or individuals; rather, it should vary depending on their *circumstances* such as the climate in which they live, family composition, and dwelling characteristics (Okushima, 2019). From an ethical viewpoint, as Caney (2012) describes, "People have unequal needs. For example, some have a greater need for fuel to keep them warm" (p. 264). Sen (2010) also stresses the same idea that people's heterogeneities such as age or disability and differences in the environment in which they live such as climate make their needs diverse (pp. 254–255).

More complicatedly, even if we assume an equal amount of BEN for some people in similar *circumstances*, this would not mean they need the same amount of carbon emissions to fulfil their BEN. Carbon emissions at the individual level generally depend on households' energy mix, which relates to their availability of low(er)-carbon energy (e.g., solar energy). Hence, if we consider the carbon emissions corresponding to their BEN, we can define their *basic carbon needs* (BCN) as the carbon emissions required when the household consumes the exact amount of their BEN, given the present carbon intensity of their domestic energy services use. As shown below, this concept of BCN is useful as an operational and numerically measurable figure.

In the climate justice literature, a similar idea to BCN, namely *subsistence emissions*, has been argued since the seminal work by Shue (1993). This scholarship discusses that the carbon emissions necessary for our subsistence are deemed morally essential and can be morally excusable even though they might harm future generations through climate change (e.g., Gardiner, 2010). Although determining what counts as our subsistence is difficult and debatable, many scholars in this field agree that this concept can be extended to the necessary emissions for achieving "a decent life" more than purely the "survival level" (Traxler, 2002; Vanderheiden, 2008; Rao and Baer, 2012; Gough, 2017).[3]

Noteworthily, BCN must be considered to be "derivative needs" (Dean, 2010) or an "avoidable necessity" (Shue, 2014). People have rights to the basic necessities for a decent life, but carbon emissions are not inherently such necessities (Hayward, 2007; Caney, 2011). It is not the carbon itself that people need; it is energy services such as heating. However, as long as we live in fossil fuel-dependent economies, we can survive "only through activities that generate carbon" (Shue, 2014, p. 98). Therefore, the carbon emissions that we need to attain a decent life depend on the prevailing social, economic, and technological conditions.

It would be useful to measure the BCN of households or individuals; nevertheless, there is no established method for this (Shue, 2014). While most studies only address this idea conceptually, a few studies estimate a variant of *subsistence emissions* empirically. For instance, Druckman and Jackson (2010) estimate the greenhouse gas emissions required to attain the basket of expenditure considered to be necessary for a decent life in the United Kingdom; the basket was defined by the Joseph Rowntree Foundation (Bradshaw et al., 2008). They show *subsistence emissions* of 17 t-CO_2 per household (including indirect emissions), 37% lower than the actual consumption-based emissions in the United Kingdom. In addition, Qu et al. (2013) survey 123 peasant and herdsmen households in less developed regions in China and show that their *subsistence emissions* are 5.58 t-CO_2. Both studies use a bottom-up approach in which the consumption items related to basic needs are summed and converted into derived carbon emissions (the direct and indirect emissions attributable to the consumption of necessary goods and services) using input–output tables.

Meanwhile, although they do not provide specific estimates, Rao and Baer (2012) develop a conceptual framework for estimating the greenhouse gas emissions required to achieve "decent living standards" in the context of sustainable development. Their concept of "decent living" emissions is broader than that used in this study; their concept includes the indirect emissions for all goods and services as well as those for building out the infrastructure necessary to meet such standards. In this

[2] Broadly speaking, such a problem belongs to the issues regarding a fair distribution of carbon emissions between people, including present and future generations, which has been debated since the last century (Shue, 1993; Banuri et al., 1996).

[3] Despite such scholars bearing the poor in developing countries in mind, the ideas are mostly applicable to EP in developed countries (Caney, 2011; Gough, 2017).

Table 1
Energy use for domestic energy services by household *type*.

	Detached house		Apartment	
	Vulnerable type	Others	Vulnerable type	Others
1. Hokkaido	*Type 1* 46.1 (43.6)	*Type 2* 39.3 (37.1)	*Type 3* 27.7 (25.6)	*Type 4* 24.3 (22.8)
2. Tohoku Hokuriku	*Type 5* 34.0 (31.8)	*Type 6* 27.9 (26.1)	*Type 7* 20.9 (19.5)	*Type 8* 18.1 (16.9)
3. Kanto Tokai Kinki Chugoku Shikoku Kyushu	*Type 9* 23.9 (22.4)	*Type 10* 20.4 (19.2)	*Type 11* 16.8 (15.9)	*Type 12* 15.7 (14.8)
4. Okinawa	*Type 13* 15.8 (14.7)	*Type 14* 13.7 (12.9)	*Type 15* 12.3 (12.0)	*Type 16* 10.7 (10.4)

Means and medians (within parentheses) of energy use for domestic energy services (in GJ) by household *type*. The numbers of energy use are presented for a household with one person as a benchmark (see also footnote 13 for more details on this point). "Vulnerable type" means households that include elderly (65 years old or over) member(s). For details of the regions, see Fig. A.1.

research stream, Zhu and Pan (2007) estimate the energy requirements for satisfying decent living standards in China and Rao et al. (2019) calculate the energy requirements for such standards in Brazil, India and South Africa using a bottom-up approach.[4]

In contrast to such existing studies, this research presents a new type of estimation methodology for measuring the BCN. Our method focuses on the carbon emissions corresponding to domestic energy services use in the context of EP, rather than the emissions related to all kinds of goods and services consumption. Furthermore, as shown in the next section, we employ the relative poverty concept, in which poverty is defined by the relative position within a society (e.g., Eskelinen, 2011). With this concept, we present a pragmatic approach to evaluating the BCN.

3. Methods and data

This section describes a new approach to measuring people's basic energy needs (BEN) and basic carbon needs (BCN). It also details how we define energy poverty (EP) in this study using the BEN concept.

3.1. Basic energy needs (BEN)

To estimate the BCN of household i (BCN_i), the first step is defining the BEN of household i (BEN_i) in measurable units. In this regard, this study adopts the direct measurement approach developed by Okushima (2019), under which the EP threshold (poverty line) for each household can be provided via calorific values (joule).[5] This study regards this threshold as the BEN for each household.

As discussed in Section 2, BEN *should differ* between households corresponding to energy vulnerability factors such as climate, family composition, and dwelling characteristics (Sen, 2010; Caney, 2011; Okushima, 2019; Robinson et al., 2019; Castaño-Rosa and Okushima, 2021). To address such diversities of energy vulnerability factors, the direct measurement approach introduces a concept of *type*. Each *type* consists of households living under similar *circumstances* related to domestic energy services use.[6] Notably, the more *types* are stratified, the more correctly the difference in household energy needs is identified, although finer partitioning leads to fewer observations in each *type*; hence, what resolution level is appropriate depends on the dataset and research purpose.

In this context, this study stratifies the whole population into 16 *types* ($t = 1, \cdots, 16$) following Okushima (2019). This stratification can capture the difference in energy needs with a reasonable level of accuracy in the Japanese context as well as secure a sufficient number of observations for each *type* for the estimation. Here, the *circumstances* are specified in line with the three energy vulnerability factors: four climate types (four climate zones), two socio-demographic types (having elderly [65 years of age or over] member(s) or not), and two dwelling types (living in a detached house or apartment),[7] as shown in Table 1.

Table 1 shows the differences in mean and median energy use for domestic energy services between these 16 *types*. For the specific data used, see Section 3.4. In this study, energy services use is described in calorific values (gigajoule), including all domestic energy services use such as space heating and cooling, water heating, lighting, cooking, and appliance usage, but excluding mobility, as is usual in EP scholarship. The energy use of each household is equivalized using the square root scale to correct for economies of scale for household size:

$$E_i^{Eq} = E_i \Big/ \sqrt{HS_i}, \tag{1}$$

where E_i is the energy use for the domestic energy services of household i, HS_i is the number of household members of household i, and E_i^{Eq} is the energy use for the domestic energy services of household i which is equivalized with the square root of household size.[8] As this equation indicates, in terms of household size, household energy use is normalized on the basis of a household with one person to make households with different sizes comparable. Hereafter, E_i^{Eq} is used for household energy use for domestic energy services unless otherwise noted.

The results in Table 1 indicate that the typology is appropriate for our research purpose, providing reasonable outputs in line with the theory. As in studies such as Okushima (2019), energy use for domestic energy services is higher in households living in colder climates, living in detached houses, and including elderly members than their respective counterparts.

Next, the BEN of each household can be defined. Here, BEN are determined as 60% of the median energy use for domestic energy services among *type-t* households. That is, $BEN_{t(i)}$, namely, the BEN of the *type* to which household i belongs, are 60% of the median of E_i^{Eq} among *type-t* households. This procedure follows the direct measurement approach proposed by Okushima (2019), which defines 60% of the

[4] As another research stream, there is a vast literature on human needs, which statistically (top-down) investigates the relationship of energy consumption (or carbon emissions) with human development indicators such as the human development index (HDI) and life expectancy using cross-country data (e.g., Steinberger and Roberts, 2010; Steinberger et al., 2012; Arto et al., 2016; Vita et al., 2019).

[5] Okushima (2019) analyzes EP in Japan using an older dataset of 2014–2015, but does not perform a carbon-related analysis.

[6] The terms "*type*" and "*circumstance*" are attributed to Roemer (1993, 1998).

[7] As in Okushima (2019), this study does not consider the difference in the energy efficiency of dwellings (e.g., insulation level) or that of home appliances (e.g., air conditioners) because of data limitations. Indeed, detailed statistics on the quality of existing housing stock in Japan are lacking; however, studies suggest that the insulation level of existing houses in Japan is generally poor (about 40% of existing houses are uninsulated) and that households in EP are more likely to live in such low-quality houses (Okushima, 2016, 2017; Castaño-Rosa and Okushima, 2021; Yagita and Iwafune, 2021).

[8] For more details, see Okushima (2019) and "What are equivalence scales?" by the OECD (www.oecd.org/eco/growth/OECD-Note-EquivalenceScales.pdf).

median energy use (after adjusting for the differences by *type*) as the energy poverty lines. The concept of relative poverty rather than absolute poverty lies behind this 60% median threshold, since EP in developed countries has traditionally been understood as a relative poverty concept (Townsend, 1979; Bradshaw et al., 2008; Liddell et al., 2012). Moreover, in the context of EP, the 60% median threshold is more reasonable than 50% of the median because energy is a necessity and energy use for domestic energy services increases at a slower pace than income (Okushima, 2019). Section 4 provides the estimation results of BEN.

3.2. Basic carbon needs (BCN)

With the BEN of each *type* obtained, the BCN of each household (BCN_i) become measurable. BCN_i are defined by multiplying $BEN_{t(i)}$(i.e., the BEN of the *type* to which household i belongs) by CI_i (i.e., the carbon intensity of household i (t-CO_2/GJ)):

$$BCN_i = BEN_{t(i)} \times CI_i. \tag{2}$$

CI_i is given by

$$CI_i = C_i / E_i, \tag{3}$$

where E_i is the energy use for the domestic energy services of household i and C_i is the carbon dioxide emissions of household i derived from their domestic energy services use.[9]

CI_i varies by household, reflecting energy sources (i.e., electricity, city gas, LPG, and kerosene) and use for domestic energy services. In addition, CI_i depends on how the electricity household i use was generated (i.e., from coal, oil, natural gas, nuclear, or renewables in power plants or from their own solar PV). In other words, CI_i depends on the availability and affordability of low(er)-carbon energy and technology (e.g., on- or off-gas grid or deploying solar or not) for household i. Access to low(er)-carbon energy is highly correlated with the area in which a household lives, more than just affordability in Japan (Chapman and Okushima, 2019; Castaño-Rosa and Okushima, 2021).

Fig. 1 describes the relationships among BEN, CI, and BCN. BCN are derivative needs which are derived from BEN, rather than inherent needs themselves, and the size of BCN depends on the carbon intensity of each household. Therefore, BCN can be reduced by lowering carbon intensity while maintaining BEN, which is desirable and should be promoted to engender an inclusive low-carbon energy transition.

3.3. Energy poverty (EP)

Finally, in line with the above concepts, this study defines EP by employing a multidimensional EP measurement approach (Okushima, 2017, 2019). This method is an application of multidimensional poverty measurement (Atkinson, 2003; Bourguignon and Chakravarty, 2003; Alkire and Foster, 2011; Alkire et al., 2015). There are two dimensions (attributes) which characterize EP: domestic energy services use (E_i^{Eq}) and income (y_i). E_i^{Eq} represents the fulfillment of the energy services needs of households, whereas y_i does general affordability.[10] The income dimension also serves to avoid the misidentification (false positive) of wealthy households as being in EP (Okushima, 2017, 2019).[11] Given the thresholds of the first (energy) dimension z_1 and second (income) dimension z_2, this study defines (multidimensional) EP as their intersection of these two dimensional-poverty:

$$\text{Household } i \text{ is in energy poverty} \Leftrightarrow E_i^{Eq} < z_1 \,\&\, y_i < z_2. \tag{4}$$

The threshold in dimension 1 (poverty line regarding energy services use), z_1, equals $BEN_{t(i)}$ in this study. $BEN_{t(i)}$ are determined as 60% of the median energy services use among *type-t* households.

Regarding z_2, this study defines households in the lowest 30% income group as (income-dimensionally) poor following Boardman (1991, 2010) and Okushima (2017, 2019). The 30th percentile of (before-tax) annual household income in Japan is 3.04 million yen according to the 2014 National Survey of Family Income and Expenditure, a representative governmental survey of more than 50,000 respondents. As seen below, our dataset includes only range-type information on (before-tax) annual income; therefore, to avoid false negatives, this study defines z_2 as 5 million yen (a cut-off point, about USD 47,000), leading to income ranges 1 and 2 of our data being income-dimensionally poor (Table 2).

The above procedure enables us to fully identify whether household i is in EP. This study uses the headcount ratio to assess the prevalence of EP in the regions:

$$H = \frac{q}{n}, \tag{5}$$

where n is the total number of households in the region, q is the number of households who suffer EP in the region, and H is the headcount ratio, that is, the ratio of EP households to all households in the region.

3.4. Data

This new approach is applied to the Japanese case using the unique microdata on households' energy use and CO_2 emissions. The dataset for this study was created using anonymized information from the 2018 Survey on the Actual Conditions of Carbon Dioxide Emissions from Residential Sector, provided for this research by the Ministry of the Environment (MOE), the government of Japan.[12] This survey describes energy consumption, CO_2 emissions, energy expenditure, and other characteristics (e.g., income, dwelling type, living area, and energy-saving behavior) for each household, with a sample of 9,996 households across Japan. All the information needed to evaluate BEN, BCN, and EP in the above procedure, i.e. energy use (energy consumption) for domestic energy services E_i, carbon emissions derived from their domestic energy services use C_i, number of household members (household size) HS_i, and annual income (only range-type information) y_i for each household, is obtained from this dataset as described in Table 2. For additional information for the readers, Fig. B.1 illustrates the distribution of (equivalized) energy use for domestic energy services, Fig. B.2 shows that by energy type, and Fig. B.3 does that by use purpose, in 10 Japanese regions.

The dataset includes information on domestic energy consumption and carbon emissions at the household level, measured in *quantity* terms. This feature can avoid the limitations of previous studies that have used household *expenditure* data to calculate CO_2 emissions (Gough et al., 2011; Büchs and Schnepf, 2013; Chancel, 2014). For example, *expenditure* data cannot distinguish between the different energy consumption levels of households who pay a lower or higher price per unit energy. Okushima (2019) also uses these survey data, but an older wave, 2014–2015, only using energy-related data. This study uses the new 2018 information, focusing more on households' carbon emissions.

4. Results and discussion

Using this new approach and unique dataset, this study is the first to

[9] In this equation, E_i and C_i need not be equivalized because equivalization relates to both energy use and carbon emissions.

[10] As shown below, income y_i is not equivalized in this analysis because it is provided only by range-type information and is simply used as a cut-off point.

[11] For example, some people might choose the low use of energy services because of their strong "eco-friendly" preferences, even if they can afford to use more (Sen, 1992; Okushima, 2019). In addition, we can avoid the misidentification of wealthy households who live in super-insulated homes and thus consume less energy as being in EP.

[12] The details of this survey are provided by the MOE (http://www.env.go.jp/earth/ondanka/ghg/kateiCO2tokei.html).

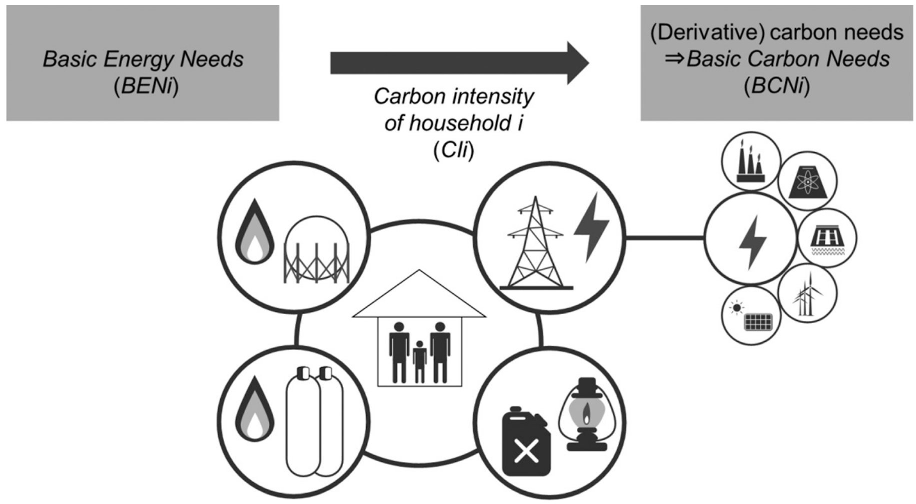

Fig. 1. Conceptual diagram of basic carbon needs (BCN).

Table 2
Descriptive statistics of our dataset.

	N	Median	Mean	SD	Max	Min
Household energy use (E_i) (in GJ)	9996	27.7	31.5	19.5	174.4	1.5
Household carbon emissions (C_i) (in t-CO_2)	9996	2.50	2.90	1.88	20.08	0.19
Number of household members (HS_i)	9996	2	2.35	1.35	12	1
Annual household income (y_i) (Japanese yen)						
1. ~ 2,500,000	2307	–	–	–	–	–
2. 2,500,000– 5,000,000	3361	–	–	–	–	–
3. 5,000,000– 7,500,000	1961	–	–	–	–	–
4. 7,500,000– 10,000,000	1288	–	–	–	–	–
5. 10,000,000– 15,000,000	777	–	–	–	–	–
6. 15,000,000– 20,000,000	133	–	–	–	–	–
7. 20,000,000~	79	–	–	–	–	–
8. Unknown	90	–	–	–	–	–

The numbers are original (not equivalized) annual data. Sampling weights were used in all calculations. Information on income is only categorically provided.

Table 3
BEN by household *type*.

	Detached house		Apartment	
	Vulnerable type	Others	Vulnerable type	Others
1. Hokkaido	*Type 1* 26.1	*Type 2* 22.3	*Type 3* 15.3	*Type 4* 13.7
2. Tohoku Hokuriku	*Type 5* 19.1	*Type 6* 15.6	*Type 7* 11.7	*Type 8* 10.1
3. Kanto Tokai Kinki Chugoku Shikoku Kyushu	*Type 9* 13.4	*Type 10* 11.5	*Type 11* 9.5	*Type 12* 8.9
4. Okinawa	*Type 13* 8.8	*Type 14* 7.8	*Type 15* 7.2	*Type 16* 6.2

The numbers are BEN (in GJ) by household *type*, presented for a household with one person as a benchmark (see also footnote 13 for more details on this point). By definition, the value of the BEN is equivalent under the same *type*. "Vulnerable type" means households that include elderly (65 years old or over) member(s). For details of the regions, see Fig. A.1.

estimate the basic energy needs (BEN) and basic carbon needs (BCN) of Japanese households as well as analyze their characteristics in detail. Tables 3 and 4 show the averages of BEN and BCN by household *type*, respectively.[13] There are large differences in both BEN and BCN between these *types*, which are reasonably explained in line with theory and practice. As expected, households with elderly members or those living in detached houses have more BEN and BCN in all regions, whereas regional differences are prominent mainly due to climatic differences (colder in the north and warmer in the south; see Fig. A.1).[14] Households living in the north (regions 1 and 2) have much more BEN and BCN because of the higher need for winter heating (see also Fig. B.3). As Fig. A.1 illustrates, there exists a variety of climates in Japan, from subarctic to subtropical climate zones: therefore, winter heating needs differ

[13] As explained in Section 3, both BEN and BCN are provided on the basis of a household with one person through the equivalization process. Therefore, we need these values multiplied by the square root of household size (e.g., about 1.414 for two-person households) if we want to know the BEN and BCN for households with multiple members.

[14] See Fig. A.1 for details on Japanese regions and climatic differences. Figs. B.1–3 show the distribution of domestic energy services use, domestic energy services use by energy source, and domestic energy services use by purpose for each region.

Table 4
BCN by household *type*.

	Detached house		Apartment	
	Vulnerable type	Others	Vulnerable type	Others
1. Hokkaido	*Type 1* 2.49	*Type 2* 2.41	*Type 3* 1.59	*Type 4* 1.38
2. Tohoku Hokuriku	*Type 5* 1.93	*Type 6* 1.68	*Type 7* 1.12	*Type 8* 1.00
3. Kanto Tokai Kinki Chugoku Shikoku Kyushu	*Type 9* 1.25	*Type 10* 1.08	*Type 11* 0.84	*Type 12* 0.80
4. Okinawa	*Type 13* 1.52	*Type 14* 1.37	*Type 15* 1.16	*Type 16* 1.01

The numbers are the means of BCN (in t-CO_2) by household *type*, presented for a household with one person as a benchmark (see also footnote 13 for more details on this point). By definition, the BCN of each household have a different value, although the value of BEN is equivalent under the same *type*. "Vulnerable type" means households that include elderly (65 years old or over) member(s). For details of the regions, see Fig. A.1.

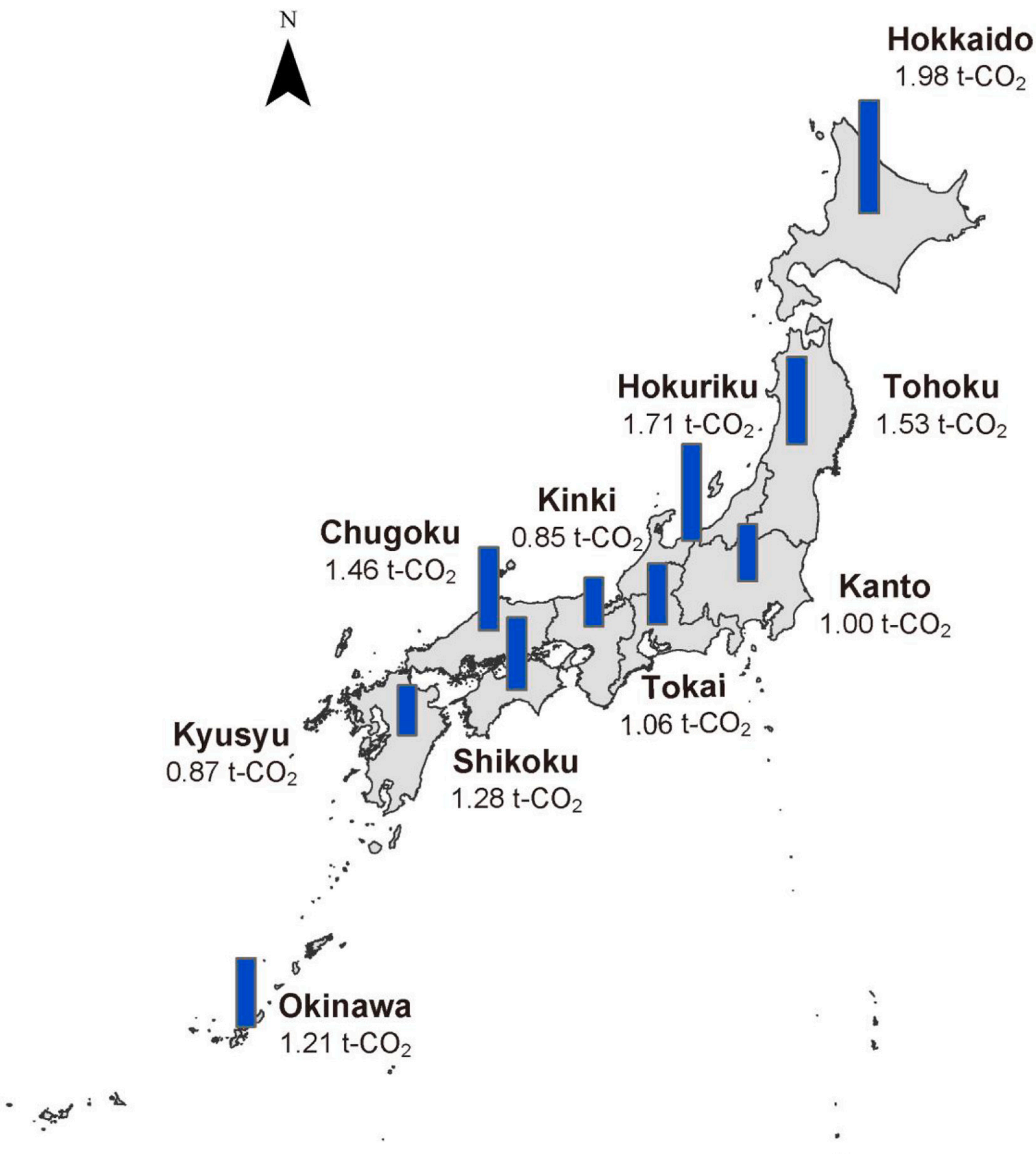

Fig. 2. BCN in 10 Japanese regions.
The numbers are the means of the BCN of households in 10 Japanese regions, presented for a household with one person as a benchmark (see also footnote 13 for more details on this point). The mean of the BCN of households in the entire Japan is 1.11 t-CO_2.

largely between regions (see Okushima (2019) for more details). Given these differences, as also shown in Table 1, it is unreasonable to consider BEN without accounting for such regional or climatic differences. The results in Table 3 confirm this point.

In terms of carbon emissions, living in the north inevitably leads to larger BCN, reflecting households' higher heating needs. For example,

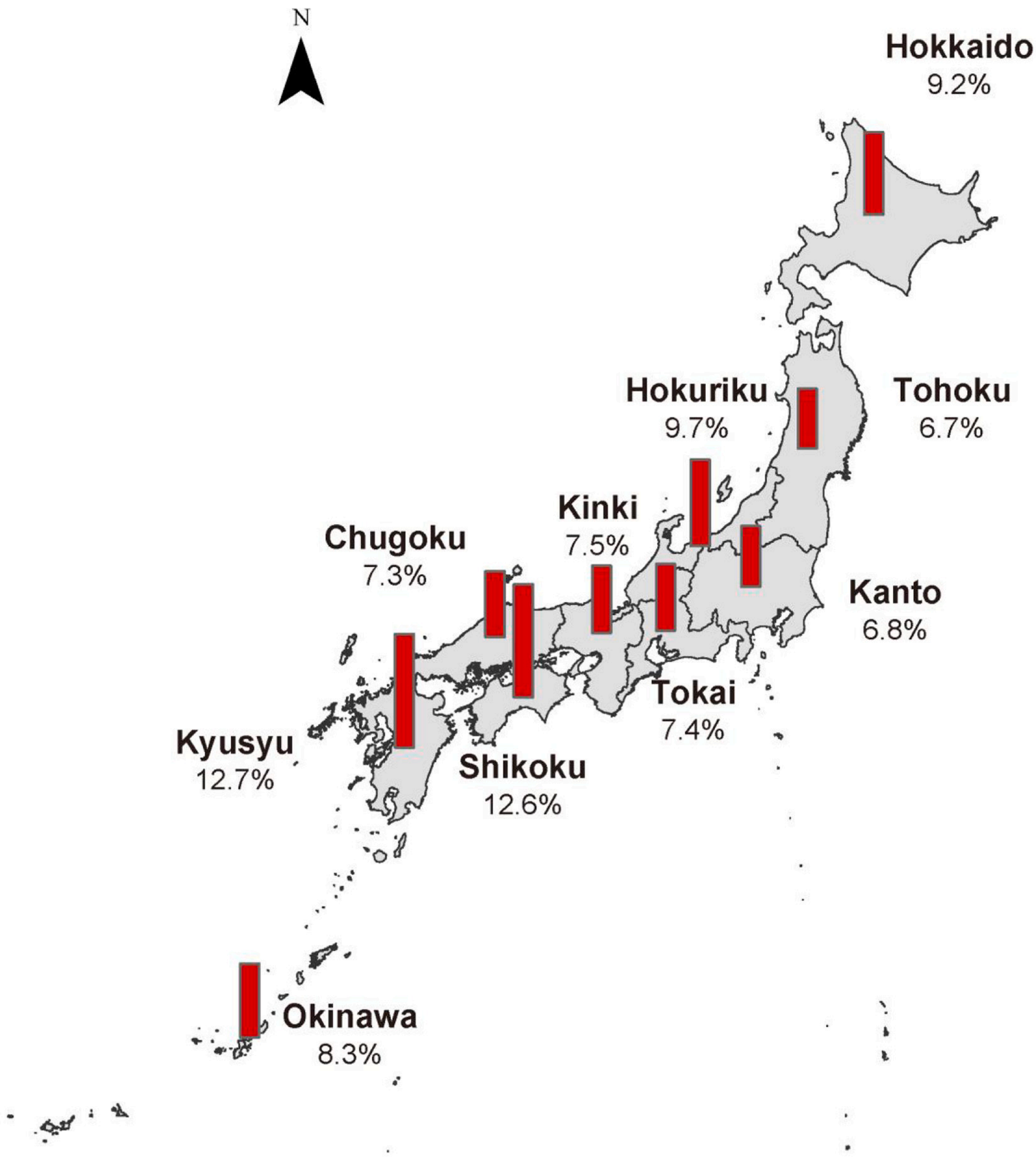

Fig. 3. EP prevalence in Japan.
The EP rates are measured by the headcount ratio, that is, the ratio of EP households to all households in the region. The EP rate in the entire Japan is 8.0%.

the regional averages of the BCN of households (a household with one person basis) are 1.98, 1.53, and 1.71 t-CO_2 in Hokkaido, Tohoku, and Hokuriku, respectively (Fig. 2). Fig. 2 also shows that western and southern regions such as Chugoku, Shikoku, and Okinawa have larger BCN than other regions in contrast to the BEN distribution (Table 3). This can be attributed to regional differences in access to low(er)-carbon energy across Japan. We discuss this issue later.

As explained in Section 3, this study defines households who use energy for domestic energy services less than the BEN level (and whose income is below the income threshold) as energy poor. Fig. 3 describes the prevalence of EP using the ratio of EP households to all households (headcount ratio) in each region. At the national level, 8.0% of households are living in EP. The result is similar to previous estimates such as Okushima (2016, 2017) using affordability types of EP measures and Okushima (2019) using the same method for 2014–2015 data. The prevalence of EP is relatively high in the northern regions of Hokkaido and Hokuriku as well as in the western and southern regions of Shikoku, Kyushu, and Okinawa. In those regions, a large number of households have not reached an adequate level of domestic energy services, reflecting their low incomes and existing disadvantages such as lack of access to natural gas due to the wide off-gas grid area in those regions (Castaño-Rosa and Okushima, 2021).

By definition, people in EP need more energy to achieve an adequate energy services level (BEN). Then, to satisfy their BEN level, do EP households need to generate more carbon emissions than non-EP ones (i.e., the more affluent population)? Studies express concerns that efforts to eradicate EP risk adversely affecting low-carbon transitions by means of the induced carbon emissions from the households in EP, usually energy-inefficient ones (e.g., Ürge-Vorsatz and Tirado Herrero, 2012).

Notably, Fig. 4 shows the disparity of BCN between the people who suffer EP and others, indicating the greater BCN of EP households than the rest of the population in any region. This might clarify the pessimistic result that people in EP need more carbon than the wealthy population to fulfil their BEN, although they cannot satisfy their BEN level at present. In addition, it means that carbon mitigation policies such as higher carbon pricing inevitably damage them to a larger extent than the more affluent population due to their greater carbon needs in absolute terms. This fact is doubly important in the context of climate

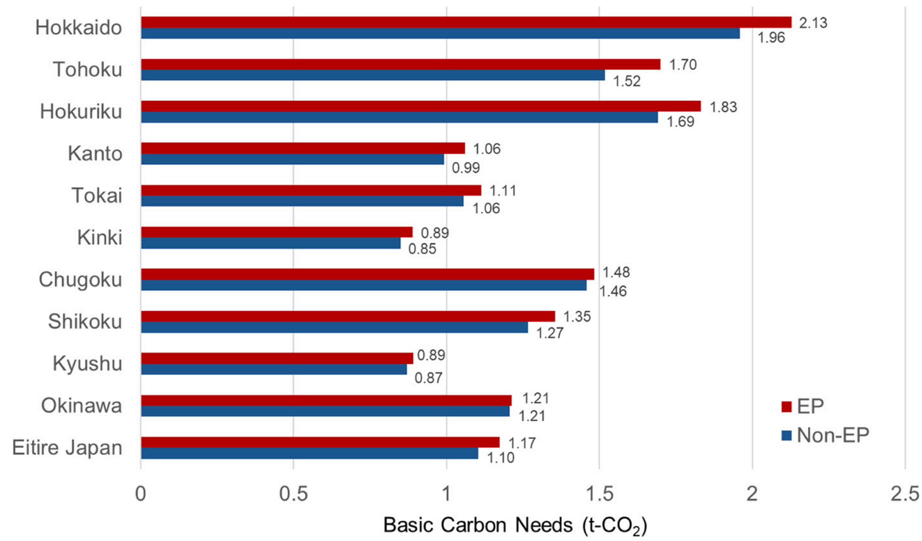

Fig. 4. BCN gap between EP households and others (non-EP).
"EP" means households in EP and "non-EP" means those not living in EP. The numbers represent the means of the BCN of EP and non-EP households in 10 Japanese regions, presented for a household with one person as a benchmark (see also footnote 13 for more details on this point).

and energy justice because the people who now already suffer from EP would suffer more from carbon mitigation policies in the (near) future.

Fig. 4 also shows that people in EP living in northern regions have greater BCN because of their heating needs, implying that they need to generate more carbon emissions to satisfy an adequate level of domestic energy services than those living in warmer areas. As discussed in the climate justice literature such as Caney (2011), caring for greater BCN because of the climate in which they live would be morally justified since they have no responsibility for the colder climate itself.[15]

Moreover, even in warmer areas, EP households in Chugoku, Shikoku, and Okinawa have larger BCN than those in other central and western regions because of the low availability of natural gas (city gas, see Fig. B.2) and since a large share of the electricity used in those areas comes from coal-fired power generation.[16] In the context of climate justice, people are not morally responsible for such regional differences in the quality of the energy infrastructure (Caney, 2011; Gough, 2017). These results show that the proposed method provides a quantitative approach to tackling the climate justice issues discussed by moral or political philosophers since the classical work by Shue (1993).

Hence, what drives the difference in BCN between the people in EP and others? The answer is presented in Fig. 5. By definition, the BEN level depends on the *type* of household; households of the same *type*, irrespective of whether they suffer EP, have the same BEN level theoretically (see also Table 3). Nevertheless, Fig. 4 shows that the BCN of EP households are larger in all regions than those of non-EP. This is because EP households have higher carbon intensity of their domestic energy services use than the wealthy population (Fig. 5). While this fact was suggested in the recent studies such as Galvin and Sunikka-Blank (2018) and Galvin (2020a), or could even be inferred from the research that showed higher emissions per *pound of income* in the lower-income decile in the United Kingdom (Gough et al., 2011; Gough, 2017), to the best of our knowledge, the present study is the first to show detailed quantitative evidence of it.

Fig. 5 depicts the higher carbon intensity of domestic energy services use for EP households than non-EP households in any region, resulting in the greater carbon needs of EP households. As explained in Section 3, the difference in carbon intensity comes from households' energy mix (electricity, natural gas, LPG, and kerosene) for their domestic energy services use as well as how the electricity they use was really generated. The higher carbon intensity of EP households in Fig. 5 demonstrates that they generally use energy sources with higher carbon emissions for their domestic energy services than the wealthy population in any region because of their lower income (e.g., they cannot deploy solar panels) and lower availability of low(er)-carbon energy (e.g., no access to natural gas). Access to low(er)-carbon energy is a vital but previously overlooked issue in developed countries such as Japan (Chapman and Okushima, 2019; Sovacool et al., 2019a, 2019b; Carley and Konisky, 2020; Castaño-Rosa and Okushima, 2021).

Fig. 5 shows the higher carbon intensity in Chugoku, Shikoku, and Okinawa because much of the electricity sold in those regions comes from coal-fired power generation, which also results in higher BCN in those regions (Fig. 4). Japan liberalized the electricity retail market in 2016, although the 10 major incumbent electricity companies still have dominant shares in each region. Therefore, the energy mix of the power generation of each regionally dominant electricity company significantly affects people's BCN in each region.

Okinawa is a typical case. In Okinawa, people have little heating needs because of the local subtropical climate (Fig. B.3), leading to the lowest energy services use (Fig. B.1) and lowest BEN (Table 3). Nonetheless, in terms of carbon emissions, the position is reversed: people have relatively high carbon needs due to their high carbon intensity. This stems from the high carbon intensity of the electricity sold by Okinawa's incumbent power company, from which most households in the region buy their electricity. Almost two-thirds (64%) of its electricity was generated by coal-fired power in 2018, the largest proportion among the 10 major incumbent electricity companies in Japan.[17]

On the contrary, households in Kinki and Kyushu regions have lower carbon intensity than other regions. This also relates to the "access to low-carbon energy" issue. Households living in those regions use

[15] Sen (2010, p. 255) also mentions that contingencies such as "environmental conditions, including climatic circumstances, such as temperature ranges" are given for individuals in converting their incomes and personal resources into functionings and quality of life.

[16] Another factor is the lower urban populations (Castaño-Rosa and Okushima, 2021). Household CO_2 emissions are closely related to urbanization level in Japan as well as elsewhere such as the United Kingdom (Druckman and Jackson, 2009; Büchs and Schnepf, 2013).

[17] Okinawa Electric Power Company (https://www.okiden.co.jp/company/guide/demand/).

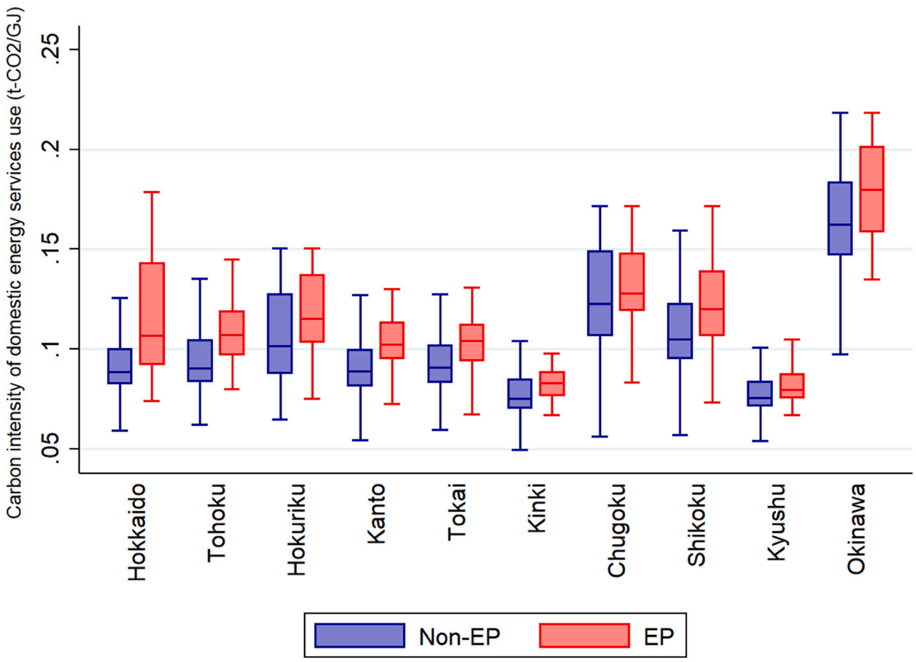

Fig. 5. Carbon intensity of the domestic energy services use of EP households and others (non-EP).
This figure shows the distribution of the carbon intensity of the domestic energy services use of households, that is, the distribution of CI_i in Eq. 3. Here, "EP" means households in EP and "non-EP" means those not living in EP. 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.

electricity generated by nuclear power: the major incumbent power companies in Kinki and Kyushu regions had generated electricity by nuclear power, 22% and 34%, respectively in 2018.[18] By contrast, people living in other regions use less or no nuclear-generated electricity because of the nuclear power plant shutdown after the Great East Japan Earthquake and Fukushima nuclear accident in 2011 (Okushima, 2016). The above results empirically show that differences in access to low(er)-carbon energy among households have a significant impact on the distribution of people's carbon needs. Such advantages and disadvantages, attributable to the historically embedded energy systems and infrastructure where she/he lives, bring up a major issue related to energy justice and spatial justice (Sovacool et al., 2016; Bouzarovski and Simcock, 2017; Carley and Konisky, 2020).

To summarize, people who suffer EP have higher carbon intensity, leading to their greater carbon needs than the affluent population. The result indicates a trade-off between EP alleviation and carbon mitigation. Moreover, their higher carbon intensity inevitably leads to a vulnerability to the ongoing low-carbon energy transition because of the potential for higher carbon pricing (Ürge-Vorsatz and Tirado Herrero, 2012; Büchs and Schnepf, 2013; Balint et al., 2017; Gough, 2017).[19]

As we have shown, differences in the opportunity to use low(er)-carbon energy or renewables exist even in developed countries, which relates to morally relevant issues that have been debated in the climate justice literature (Caney, 2011; Shue, 2014; Gough, 2017) and the energy justice literature (Jones et al., 2015; Jenkins et al., 2016; Sovacool et al., 2016). These factors are considered to be beyond one's control or responsibility, such as greater energy needs due to a colder climate. Heavier burden is morally unfair for those with greater carbon needs because of "the kinds of environment they live in" or "the lack of access to other (lower-carbon) energy sources," which are not attributable to the persons (Caney, 2011, pp. 95–96).

This point has become a significant issue for sharing the benefits and burdens of carbon mitigation in the post-Paris Agreement era. Lowering the carbon intensity of people in EP with guaranteeing their BEN becomes a big challenge to engender an inclusive or just low-carbon transition for developed countries. In the Japanese context, promoting access to solar power for EP households through the provision of low-cost solar panels or even low-cost electricity generated by publicly- or community-owned solar firms is essential for tackling the trade-off (Chapman and Okushima, 2019; Castaño-Rosa and Okushima, 2021). Promoting the use of biomass energy for people in EP is also a promising option for some suitable areas in Japan.[20] The above findings show that sharing the benefits of low-carbon energy or technology to all, including the people in EP, benefits both EP alleviation and carbon mitigation and allows low-carbon transitions to be inclusive or just (Granqvist and Grover, 2016; Carley and Konisky, 2020).

5. Limitations of the study

Further investigations are required, especially in the following areas. First, the definition of basic energy needs (BEN) or basic carbon needs (BCN) is debatable. This study uses the relative poverty concept to define the BEN level from an operational or practical viewpoint; however, alternative definitions are available. For example, studies such as Druckman and Jackson (2010) and Qu et al. (2013) calculate a kind of *subsistence emissions* using a bottom-up approach in which they count necessary goods and services consumption and convert these into emissions using input–output tables. The question of what constitutes basic human needs, which has long been debated among philosophical scholars, relates to "the deep questions about how we should live and what kinds of societies we ought to have" (Gardiner, 2010, p. 17). In this study, the poverty thresholds are set in line with the relative poverty measure, although using a bottom-up approach that well accounts for

[18] Kansai Electric Power (https://kepco.jp/ryokin/power_supply/). Kyushu Electric Power (http://www.kyuden.co.jp/rate_adj_power_composition_co2.html).

[19] Another vulnerability for people in EP is the energy poverty premium (Okushima, 2019). This means that people in EP buy domestic energy services at a higher unit price than the wealthy population. The energy poverty premium and their higher carbon intensity might form serious double bottlenecks in the future low-carbon energy transition in Japan.

[20] In our context, the use of heat from renewable energy is especially important to deal with winter heating needs, especially in colder-climate areas. As an example in Japan, Shimokawa town in Hokkaido produces super-insulated public housing for elderly people, equipped with district heat supply systems that use locally produced woody biomass (see https://www.town.shimokawa.hokkaido.jp/section/2018/05/sustainable-forest-future-community-ichinohashi-bio-village-of-shimokawa-town.html).

regional or cultural differences could be more promising in some cases (Walker et al., 2016; Rao and Min, 2018; Rao et al., 2019).

Relatedly, this study concentrates on the new concept of BCN and does not fully examine BEN. In the strict sense, energy is also just a means to ensure the "fulfillment of subsistence rights" (Shue, 2014) or "intermediate needs" (Gough, 2017). In other words, what people really need is a variety of "functionings" such as keeping warm itself, as expressed by the term of capability approach (Sen, 1985, 2010; Nussbaum, 2000; Day et al., 2016). In this context, while this study does not explicitly consider the differences in the energy efficiency of dwellings and appliances, a policy such as improving the energy efficiency of dwellings and heating appliances is important, which could help people keep warm with less energy consumption and thereby decouple the satisfaction of "human needs" from energy use (Doyal and Gough, 1991; Brand-Correa and Steinberger, 2017; Gough, 2017).[21] From this viewpoint, reducing people's energy needs as well as carbon intensity is vital for low-carbon transitions.

Furthermore, the discussion in this study is based on existing social, economic, and technological systems. In addition, as for carbon mitigation policies, we assume economic instruments such as carbon pricing; therefore, a more radical type of policy such as direct regulation or fossil fuel phase-out is outside the scope of this study. Normative discussions on issues such as what kinds of socio-technical provisioning systems are desirable for supporting people's BEN or BCN and how current systems can be shifted to more ideal ones are also future research avenues (e.g. Brand-Correa and Steinberger, 2017; Lamb and Steinberger, 2017).

Finally, it could be criticized that this study does not present a single, clear ethical (justice) framework to be followed. Basically, developing the BCN concept in this study was highly motivated by the pioneering study of subsistence emissions by Shue (1993). His so-called guaranteed-minimum approach derives from the concept of human rights, in which moral thresholds below which people should not fall are guaranteed for all persons (Shue, 1980; Caney, 2010) — in the context of distributive justice theory, this is analogous to sufficientarianism (Frankfurt, 1987; Crisp, 2003; Shields, 2020). Meanwhile, our ethical position may appear to be a kind of luck egalitarianism (Roemer, 1993; Dworkin, 2000; Knight, 2013), which is also called responsibility-sensitive egalitarianism, in some arguments on energy or spatial injustice with regard to energy infrastructure disparity. In this sense, this study seems to eclectically or arbitrarily choose some justice theory useful for each case without defining the solid ethical framework. Galvin (2019) points to this kind of eclectic use of justice theories as a problematic feature of the energy justice literature, indicating that the philosophical basis of energy justice research is underdeveloped and that this may hamper our ability to persuade policymakers and the public.[22] While such philosophical inquiries are beyond the scope of this study, a more in-depth discussion on the ethical framework should be a subject for future work.

6. Conclusions

This study develops a novel approach to measuring people's basic carbon needs (BCN) and investigates the trade-off relationship between energy poverty (EP) alleviation and carbon mitigation using the Japanese case. The results show the greater carbon needs of the energy poor due to the higher carbon intensity of their domestic energy services use than the more affluent population. This means that the energy poor need to generate more carbon emissions to attain their basic energy needs (BEN) than the wealthy population in Japan. It also implies that decarbonization policy such as higher carbon pricing, which may be introduced in the near future, will place a severe burden on people in EP. Carbon pricing would exacerbate EP. Indeed, without alleviation measures, it may drive the poor into deeper poverty, as climate justice philosophers such as Shue (2014) state. Our results support the validity of this statement—even for developed nations such as Japan.

This study also confirms the disparity of BCN between people, even if their BEN level is equivalent, because of differences in the energy systems or infrastructure they can use (Brand-Correa and Steinberger, 2017; Lamb and Steinberger, 2017; Gough, 2017). Additional carbon emissions owing to their greater BCN (e.g., due to no access to renewables or natural gas) as well as from their greater BEN (e.g., due to living in a colder climate) could be morally justified because they are not responsible for the additional emissions related to such energy vulnerabilities (Caney, 2011). Unfortunately, carbon mitigation policy such as carbon pricing would increase the burden on disadvantaged people such as those in EP with greater carbon needs, which brings up distributional issues regarding climate or energy justice (Sovacool et al., 2016; McCauley and Heffron, 2018; Kanbur and Shue, 2019).

With the utmost care, the Japanese low-carbon energy transition would be inclusive, allowing one-10th of people (i.e., those suffering EP) to participate. In terms of EP alleviation, traditionally, the "triad" policy is suggested, i.e. social tariffs, income support, and retrofits for EP households (Bouzarovski, 2018). These traditional types of policies are urgently needed since there is no measure targeting the EP, historically and currently, in Japan (Okushima, 2016, 2017). Moreover, as policy implications from the results, this study stresses the need to make renewable energy accessible to people in EP or promote their access to low-carbon technology to make them less vulnerable to future decarbonization policies (Shue, 2014; Sovacool et al., 2019a, 2019b; Carley and Konisky, 2020). Chapman and Okushima (2019) show that low-income and EP households have much lower access to low(er)-carbon energy such as solar in Japan, leading to their higher carbon intensity, as shown in the present study. To engender an inclusive low-carbon transition, policies for people in EP to access low(er)-carbon energy, especially solar, are necessary. In the Japanese context, studies propose measures such as providing EP households with low-cost or fully subsidized solar panels or procuring solar energy generated by publicly- or community-owned solar facilities (Chapman and Okushima, 2019; Castaño-Rosa and Okushima, 2021).

In addition to ensuring access to low(er)-carbon energy for people in EP, it is important to abate carbon emissions by the non-energy poor, which can offset the (possible) additional emissions by the poor. Oswald et al. (2020) indicate that the energy consumption of high-income people, especially in relation to transport, is vital for the reduction of CO_2 emissions in society. Also, studies such as Galvin (2020a) suggest that redistributing income from wealthy people to the poor would lower total CO_2 emissions in society. The non-energy poor, specifically high-income people, emit significantly more CO_2 than their BCN; therefore, addressing their overuse of energy or CO_2 should also be essential.

Finally, BCN are not inherent needs themselves, rather just derivative needs. The thing is satisfying BEN. Households' carbon intensity depends on the current socio-economic-technological situation of each country, region, household, and individual; hence we can work toward lower or even zero BCN in the future with fully satisfying people's BEN by popularizing low(er)-carbon energy and technology regardless of their income bracket and residential location. In addition, tackling a more complex and normative question such as what kinds of socio-economic-technological systems are desirable for fulfilling people's BEN remains to be addressed in future work.[23]

[21] Okushima (2016, 2017) examines the energy efficiency of housing in the context of Japanese EP. Furthermore, studies suggest that a thermal retrofit policy is effective for reducing energy consumption even if prebound and rebound effects related to occupant behavior are taken into account (e.g., Sunikka-Blank and Galvin, 2012; Guerra Santin, 2013; Harputlugil and de Wilde, 2021).

[22] In addition, Galvin (2020b) reexamines the "justice" notion in the environmental, climate, and energy justice literature from its historical roots in the civil rights movement. For the latest development on energy justice research, see also Jenkins et al. (2020) and Pellegrini-Masini et al. (2020).

[23] For a discussion on this issue, see e.g. Brand-Correa and Steinberger (2017) and Lamb and Steinberger (2017).

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Declaration of Competing Interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Climate and regions of Japan

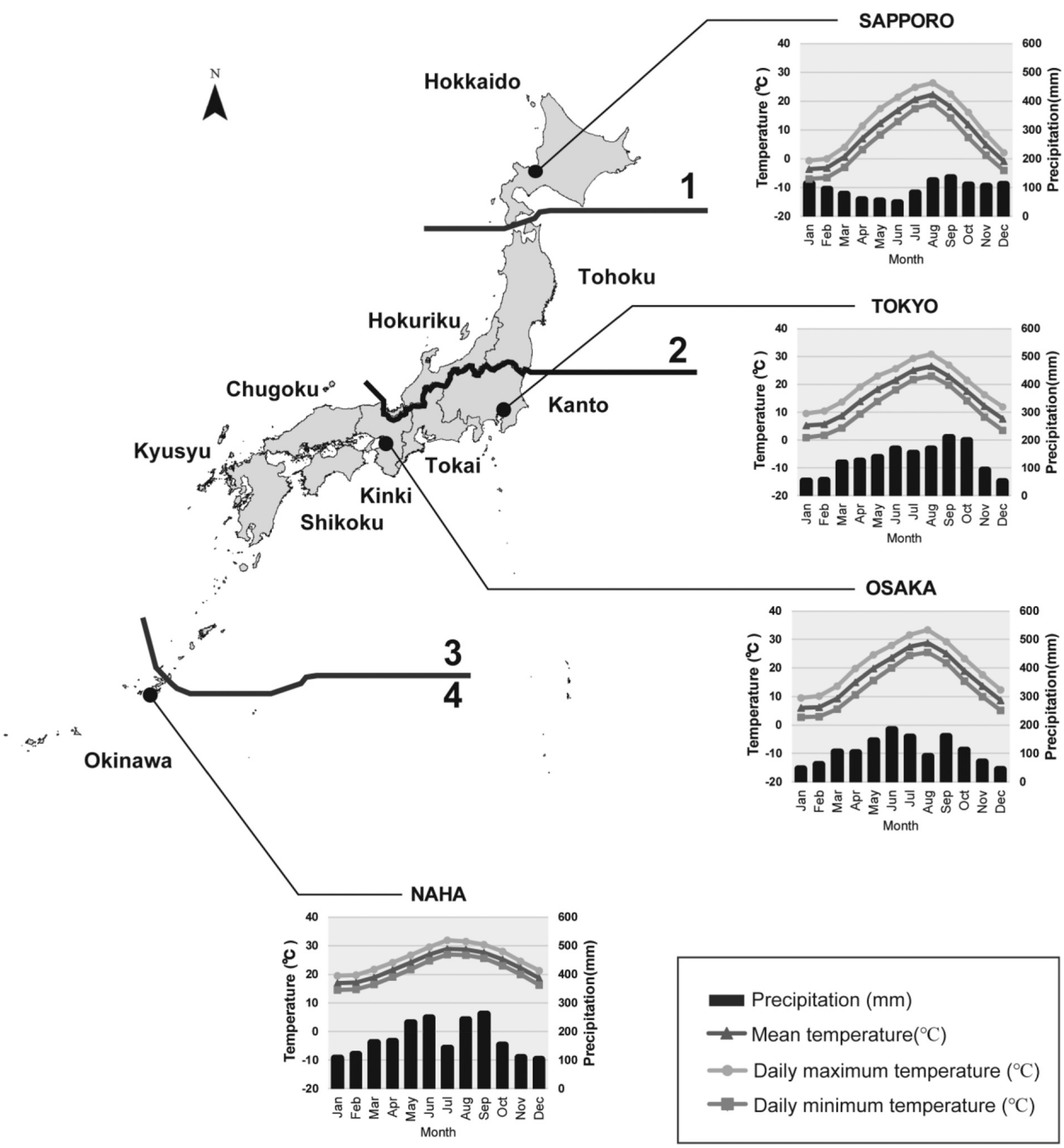

Fig. A.1. Climate and regions of Japan.
Precipitation is the amount of monthly precipitation. Temperatures are the monthly averages of the daily mean, maximum, and minimum temperatures.
Source: Tables of climatological normals (1981–2010), Japan Meteorological Agency. http://www.data.jma.go.jp/obd/stats/data/en/index.html

Appendix B. Energy use for domestic energy services in Japan

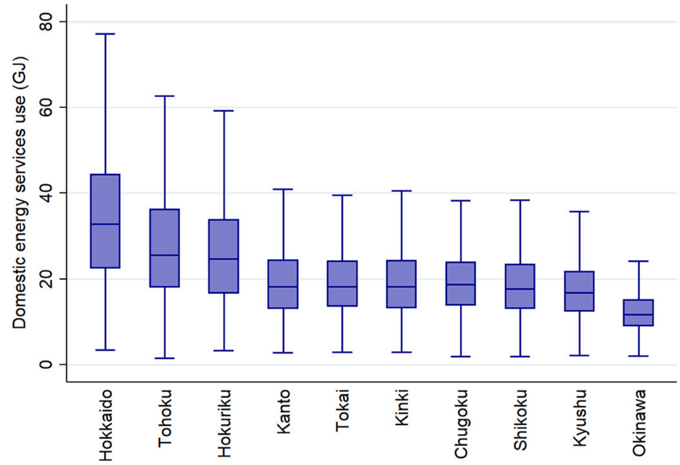

Fig. B.1. Distribution of domestic energy services use in 10 Japanese regions.
Domestic energy services use is measured by the energy use for domestic energy services (GJ). The horizontal line in each box is the median, the top and bottom of the box are the upper and lower quartiles, and both ends of the whiskers are the upper and lower adjacent values.

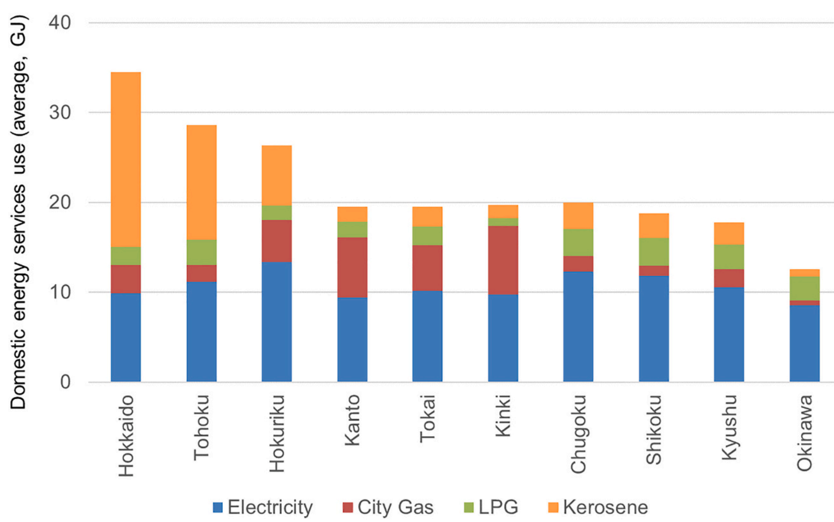

Fig. B.2. Domestic energy services use by source in 10 Japanese regions.
Domestic energy services use is measured by the energy use for domestic energy services (GJ).

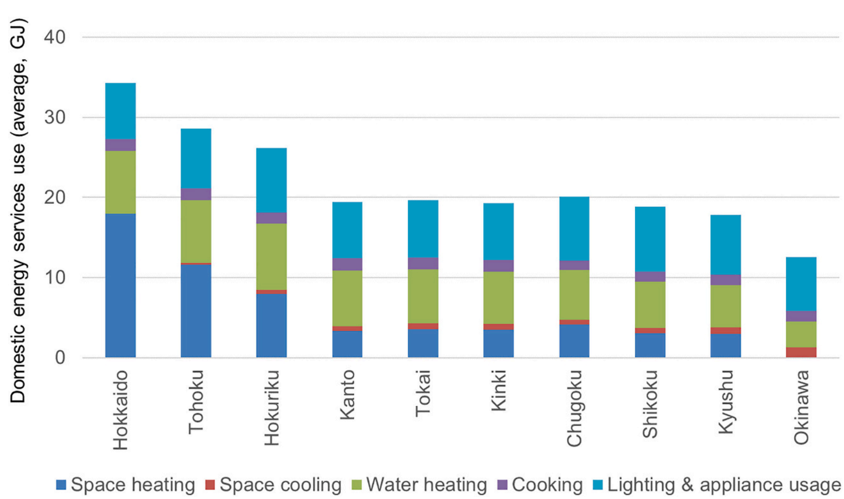

Fig. B.3. Domestic energy services use by purpose in 10 Japanese regions.
Domestic energy services use is measured by the energy use for domestic energy services (GJ). This figure is derived from the data estimated by the MOE (http://www.env.go.jp/earth/ondanka/ghg/kateiCO2tokei.html). The values do not exactly correspond with those in other figures and tables.

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