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Research Article

Double energy vulnerability in Japan

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A R T I C L E I N F O

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A B S T R A C T

This paper presents initial insights into the intersection of domestic energy poverty and transport poverty in Japan, emphasising the vulnerable populations and geographic areas where these dual challenges are most pronounced. We use microdata derived from a governmental household budget survey to calculate the cost burdens arising from expenditure on domestic energy, and public and private transportation. The findings suggest that risk of experiencing high domestic energy burdens is strongly differentiated by income and age, being more prevalent in low-income households and where the lead householder is over 65. Transport cost burdens display a weaker association with demographic variables, and instead are strongly geographical with high-cost burdens most prevalent in rural and peri-urban areas. Low-income and older people who are also living in a spatially peripheral locality are at greatest risk of double-energy vulnerability. Japan's climatic diversity poses an additional challenge, with households in the northern regions of the country facing increased vulnerability due to colder winters and higher heating costs. We propose several policy recommendations arising from these findings, emphasising the need for nuanced strategies that are tailored to geographical context.

1. Introduction

The concept of double energy vulnerability (DEV) captures the situation of people who are at increased risk of experiencing domestic energy and transport poverty simultaneously (Robinson and Mattioli, 2020). Whilst many specific indicators of energy poverty exist, broadly it encapsulates a situation in which people are unable to (affordably) attain a necessary level of domestic energy services, leaving them unable to meet their social and material needs (Bouzarovski and Petrova, 2015; Day et al., 2016). Similarly, transport poverty can be understood as circumstances in which people cannot access or afford the transport services necessary for their basic needs (Simcock et al., 2021). Both energy and transport poverty are individually harmful to a person's wellbeing, and the simultaneous experience of both problems is likely to exacerbate and compound these harms (Simcock et al., 2021). Therefore, research about DEV is of ethical, political, and practical importance.

Empirical studies on DEV have taken place in England (Robinson and Mattioli, 2020), and more recently in Mexico, Northern Ireland, Ireland and the United Arab Emirates (J Furszyfer Del Rio et al., 2023; Lowans et al., 2023; Sovacool and Furszyfer Del Rio, 2022), indicating that DEV can be found across different national and sub-national contexts. Research also identifies the groups most likely to be doubly energy vulnerable, suggesting that a combination of spatial peripheralization and social marginalization heighten the risk of simultaneously experiencing energy and transport deprivation (DD Furszyfer Del Rio et al., 2023; Robinson and Mattioli, 2020; Simcock et al., 2021). However, research into DEV is still in its relative infancy. There is a need for further empirical studies to investigate the presence, extent and socio-spatial patterning of DEV in new geographical settings.

In this research paper, our aim is to provide a first assessment of the presence of DEV in Japan and the people and places who are most vulnerable. In doing so, we contribute to the emerging literature on DEV and examine whether existing findings around the socio-spatial patterning of vulnerability are applicable in a different geographical context. To the best of our knowledge, this is the first investigation of DEV in Japan specifically and east Asia more broadly. Furthermore, our findings provide an initial step in developing effective public policies to alleviate DEV in the Japanese context.

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2. Method and data

Data for this study comes from anonymized information from the 2019 Family Income and Expenditure Survey (FIES) conducted by the Statistics Bureau, Ministry of Internal Affairs and Communications, Japan.[1] We calculate original figures using this dataset, provided for this study by the Statistics Bureau. The dataset provides details on household expenditure, annual income, household size, household characteristics, home location, dwelling characteristics, and so on. The FIES is a reliable dataset, as it is conducted by the government in accordance with the Statistics Act and has a sample size of around 8000 households allowing a high degree of representativeness. It is the only governmental statistical source in Japan that includes household expenditure data on both domestic energy and transport energy services for each month, and for each region of Japan.

To measure vulnerability to energy and transport poverty our study adopts the 'cost burden' approach (Hernández and Bird, 2010), which involves calculating the percentages of gross household income spent on domestic energy ('DE_burden'), private transport energy ('PriTE_burden') and public transport ('PubT_burden'), respectively. This approach is common in relation to energy poverty, with a household expenditure on domestic energy of more than 10% of income often taken as an indicator of an inability to access affordable energy services (Mattioli et al., 2017). Although some studies have adopted the 10% threshold for transport poverty (e.g., RAC Foundation, 2012), doing so has significant flaws such as greatly overestimating the incidence of transport poverty among high-income groups (for a full explanation, see Mattioli et al., 2017; see also Alonso-Epelde et al., 2023). Even in relation to energy poverty, energy burden approaches have been criticized for, *inter alia*, not recognising households experiencing 'hidden' energy poverty (Tirado Herrero, 2017), not fully distinguishing between energy poverty and income poverty (Hills, 2012; Legendre and Ricci, 2015), and failing to account for the key role of energy efficiency and housing stock condition in causing energy poverty (Hills, 2012; Mulder et al., 2023; Siksnelyte-Butkiene et al., 2021). Furthermore, even when using the cost burden approach, simply transposing the 10% threshold from one context to another can be problematic (Tirado Herrero, 2017) and often deviates from its original meaning as defined by Boardman (1991).

Despite these weaknesses, it is typically acknowledged that cost burden approaches can still provide useful insights into the prevalence and patterning of vulnerability to energy and transport poverty – for example, it continues to be used, alongside other indicators, by the European Union's Energy Poverty Advisory Hub (Gouveia et al., 2022, 2023). To mitigate against some of the approach's weaknesses, in this study we do not define a fixed percentage threshold as firmly indicating either energy or transport poverty, respectively. Instead, we use the approach to identify *relative* differences in the proportion of gross income spent on energy and transport between different socio-demographic groups and spatial settings – with higher relative burdens reasonably indicating a greater *vulnerability* to energy and transport poverty. This does mean we are unable to give firm figures on the estimated number of people experiencing energy or transport poverty, a point we further reflect on in Section 5.

In this study, monthly household income is derived by dividing each household's gross annual income by twelve. For classifying households into income quintiles (from the lowest income group 'Inc1' to the highest 'Inc5'), their income is divided by the square root of their household size to normalize for the size of household (Kahouli and Okushima, 2021; Okushima, 2019, 2021).[2] Domestic energy costs are calculated as household expenditure of each household for their domestic energy use (electricity, city gas, propane gas, and kerosene). Transport costs are calculated as household expenditure for (i) private motor fuel (gasoline and/or diesel costs) and (ii) public transport fares. Following Alonso-Epelde et al. (2023), the category of public transport includes buses, trains and taxis. We exclude air travel as our focus is on short- and medium-length journeys. We analyse private transport fuel costs and public transport costs separately to enable a more detailed and transparent analysis. For example, by separating them, we can examine the relationship between private car use and age, or between public transport use and population density, and illuminate the relative impact of public and private transport costs on household expenditure.

The FIES contains geographical data on the municipality in which each household lives. We use the population density of each municipality, given by the 2020 Population Census,[3] as a proxy variable for the degree of rurality-urbanity and to classify households into quartiles according to the population density. Hence, we define four categories of population density, ranging from 'PD1' (lowest population density, therefore most rural) to 'PD4' (highest population density, therefore most urban). To provide context to our analysis, Fig. 1 maps the location of these population density categories.

This study does have some limitations. We were unable to include expenditure on electric vehicle usage, as this data is not separately collected in the FIES. However, only a very small percentage of households in Japan use an electric car (IEA, 2023) so inclusion of this data would not change the core picture of the results. A further limitation is that FIES only includes households with two or more members, and so excludes single-person households which may be vulnerable to energy and transport poverty. Third, since no detailed nationwide statistics on the quality of existing housing stock exist in Japan, we could not consider differences in the energy efficiency of housing in relation to domestic energy burdens. Indeed, the level of insulation in housing is generally poor in Japan compared to many European countries (Castaño-Rosa and Okushima, 2021; Okushima, 2021). According to the recent government estimates,[4] about 30% of the existing housing stock is uninsulated, and 60% have low insulation levels.[5] Finally, the survey sample changes every month and so longitudinal analysis of the same households is not possible. Against this background, the study uses the month of February (February 2019), since domestic energy expenditure in February is highest in the whole year (Kahouli and Okushima, 2021).

3. Results

3.1. Energy and transport burdens by income and locality

Fig. 2 shows domestic energy burdens (domestic energy cost divided by income) and transport burdens for both private transport (motor fuel costs divided by income) and public transport (public transport costs divided by income), by degree of rurality-urbanity. The result indicates

[1] The Statistics Bureau, Ministry of Internal Affairs and Communications, Japan (https://www.stat.go.jp/english/data/kakei/index.html, accessed 12 November 2023).

[2] This equivalisation (normalisation) process is only used for grouping households into income quintiles. To perform the 'cost burden' approach, income, domestic energy costs and transport costs need not be equivalised because equivalisation relates to both numerators (e.g. domestic energy costs) and denominators (i.e. income) (Okushima, 2016).

[3] The Statistics Bureau, Ministry of Internal Affairs and Communications, Japan (https://www.stat.go.jp/english/data/kokusei/2020/summary.html, accessed 12 November 2023).

[4] The document by MLIT (Ministry of Land, Infrastructure, Transport and Tourism). Available at https://www.mlit.go.jp/report/press/content/001487807.pdf (accessed 1 May 2024).

[5] Historically, people in Japan have tended to prioritise the seismic resistance of their homes over home insulation (Yagita and Iwafune, 2021).

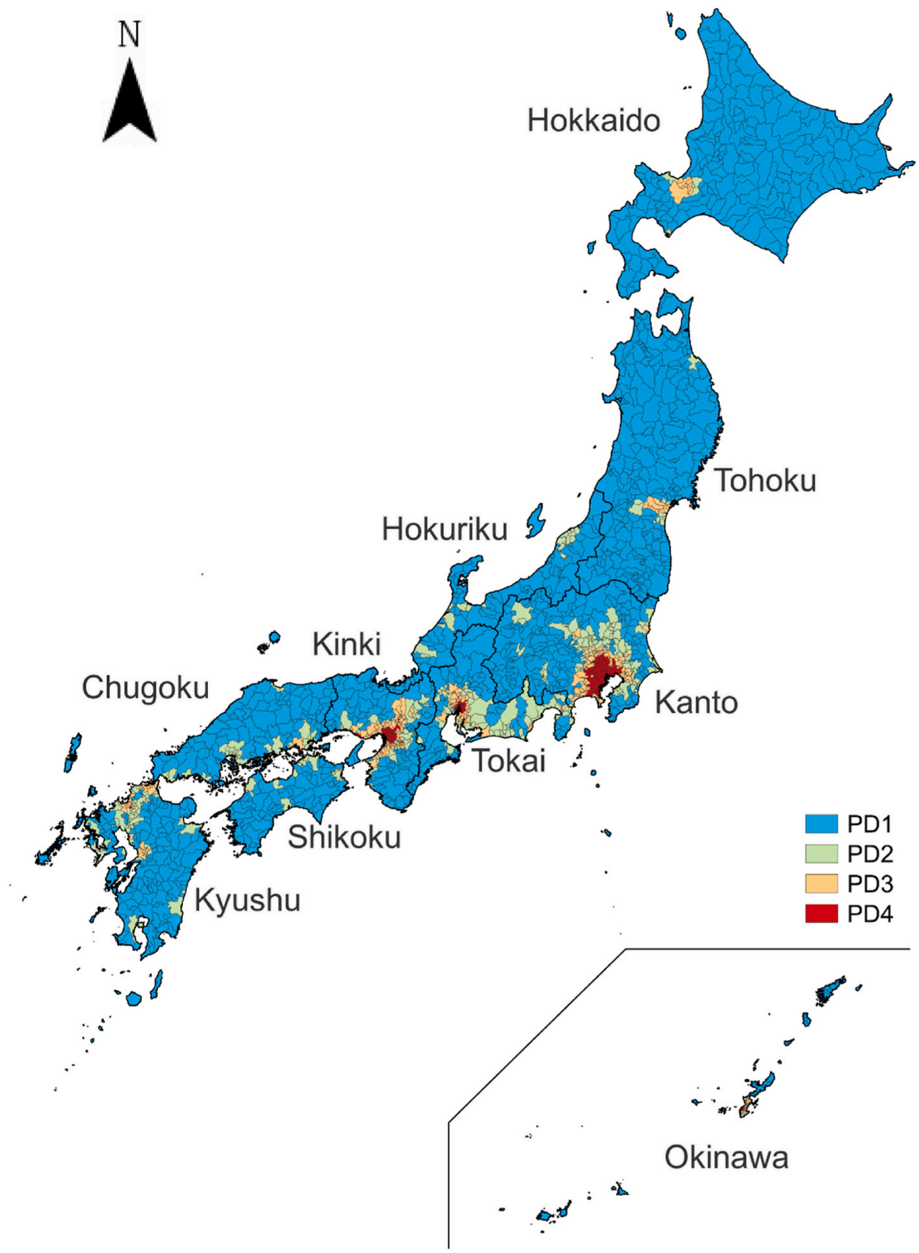

Fig. 1. Location of the population density categories used in data analysis
Note: For the population density, it is shown from the lowest, most rural ('PD1') to the highest, most urbanized ('PD4').

that both domestic energy burdens and private transport burdens are higher in more rural areas. The difference is particularly large for private transport, where expenditure in the most urbanized areas is relatively minimal. Indeed, two-thirds of households living in the most urbanized areas ('PD4') have no private transport expenditure, suggesting that car and motorbike use in these areas is low. This trend is reversed for public transport as the cost burden is higher in urban areas. If public and private transport costs were considered together, this would *partially* equalize the difference in rural-urban transport burdens, although rural areas would still have a higher transport burden on average.

Next, Fig. 3 shows domestic energy and transport burdens by income quintiles ('Inc1': lowest, 'Inc5': highest). Domestic energy burdens show a clear income-related trend, being substantially higher for those on low-incomes in comparison to the highest income households. This trend is much stronger than the urban-rural differences for domestic energy burdens shown in Fig. 2. The transport expenditure burdens shown in Fig. 3 are more nuanced. As with domestic energy burdens, private transport burdens are generally higher for those with lower incomes. However, 51% of households in the lowest income group ('Inc1') have zero private transport expenditure. Meanwhile, expenditure on public transport is greatest among the highest income quintile and least in the lowest income group.

Fig. 4 examines the domestic energy and transport burdens in more detail, considering the degree of rurality-urbanity whilst also controlling for income levels. In terms of domestic energy burdens, the relationship shown in Fig. 2 – which suggested energy burdens tended to be slightly higher in more rural areas – becomes less clear. Rather, there is a strongly negative relationship between income and energy burden. For each income quintile the level of energy burden is broadly similar across the spatial categories, with only slightly higher burdens for those living in more rural localities. This suggests that the relationship shown in Fig. 2 is primarily driven by a larger proportion of low-income people living in more rural areas, rather than, for example, rural households requiring greater levels of energy consumption.

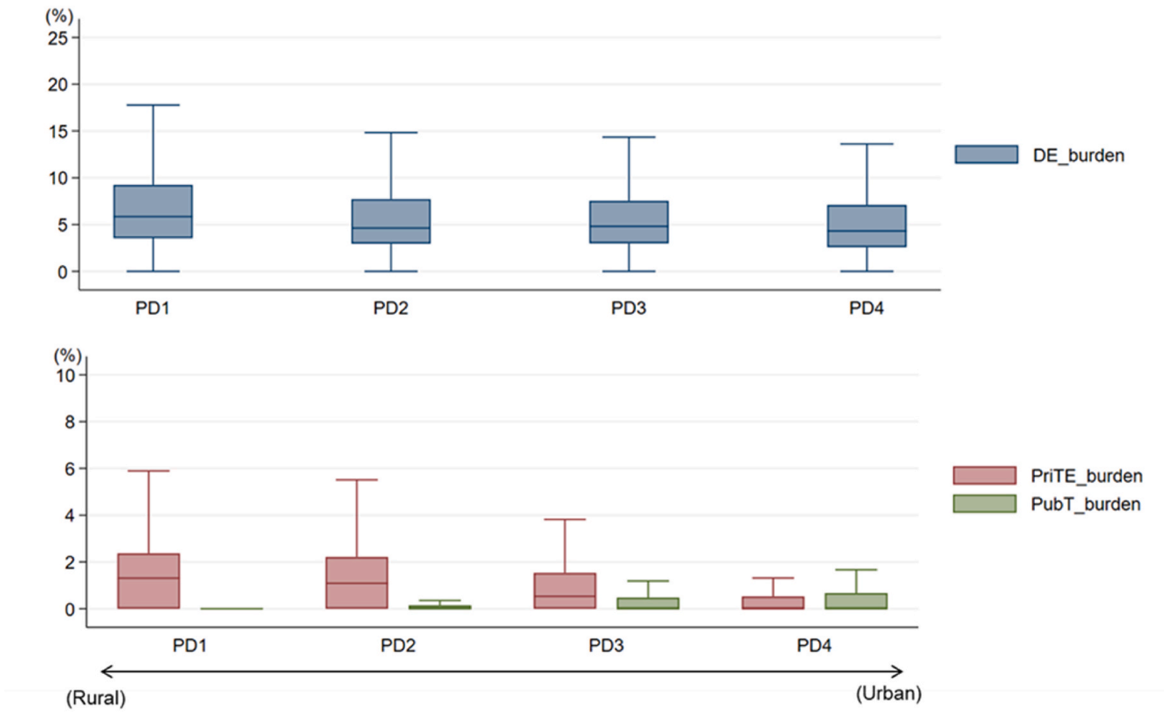

Fig. 2. Energy and transport burdens by degree of rurality-urbanity
Note: The horizontal line in each box is the median, the top and bottom of the box are the upper and lower quartiles, and both ends of the whiskers are the upper and lower adjacent values. 'DE_burden' means domestic energy burden, 'PriTE_burden' means private transport energy burden, and 'PubT_burden' means public transport burden. For the population density, it is shown from the lowest, most rural ('PD1') to the highest, most urbanized ('PD4').

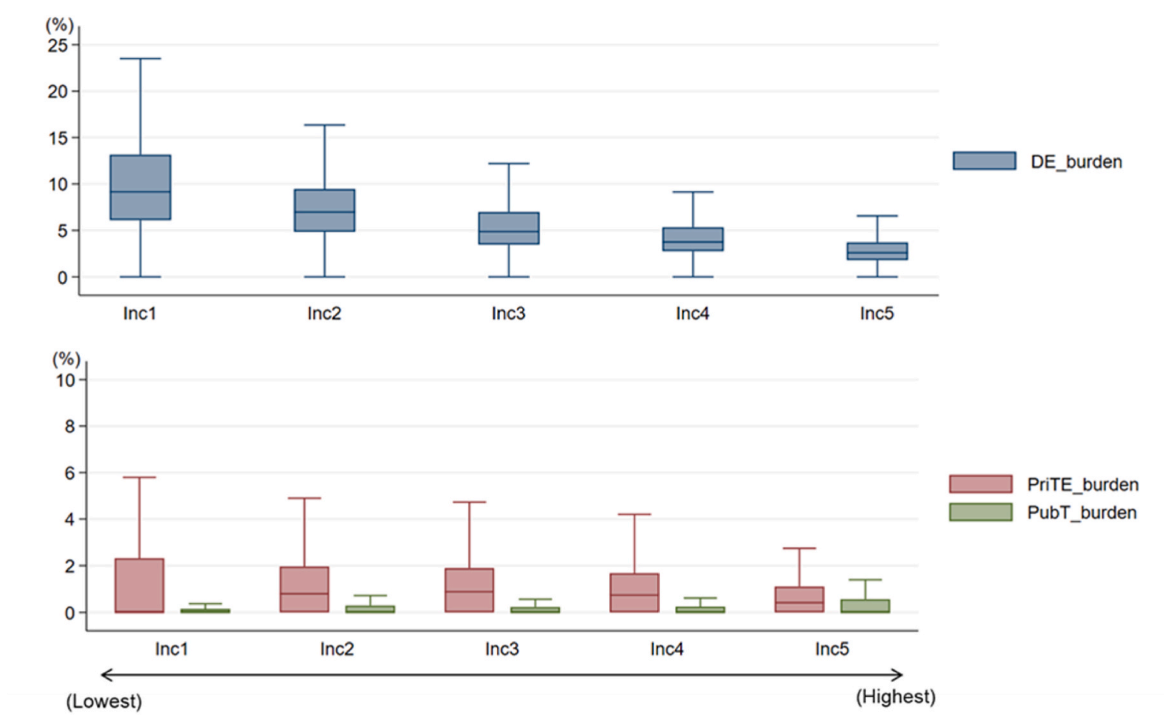

Fig. 3. Energy and transport burdens by income quintile
Note: The horizontal line in each box is the median, the top and bottom of the box are the upper and lower quartiles, and both ends of the whiskers are the upper and lower adjacent values. 'DE_burden' means domestic energy burden, 'PriTE_burden' means private transport energy burden, and 'PubT_burden' means public transport burden. For the income quintile, it is shown from the lowest income group ('Inc1') to the highest ('Inc5').

In comparison, transport burdens are spread relatively equally across the income spectrum but display a much stronger geographical trend. In the most urban areas ('PD4'), the lowest income group has the smallest private transport burden. Private transport burdens are greater for all income groups in more rural areas, especially the lower-income groups, whilst public transport burdens shrink.

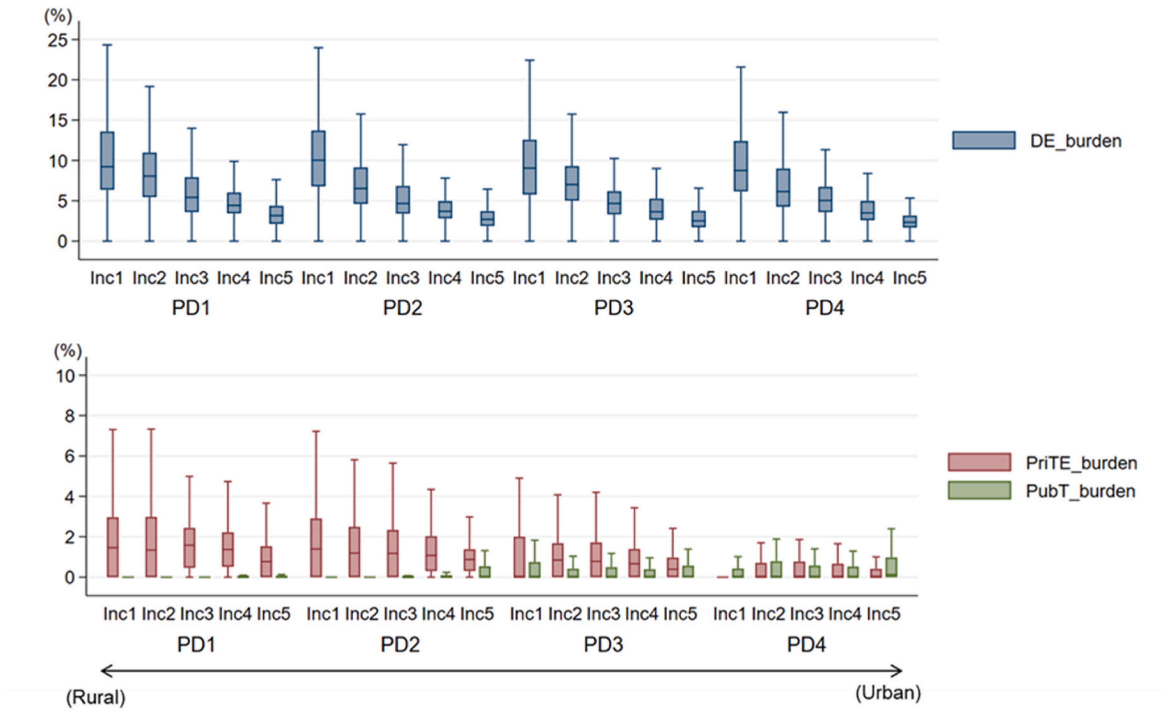

Fig. 4. Energy and transport burdens across income quintiles, by degree of rurality-urbanity
Note: The horizontal line in each box is the median, the top and bottom of the box are the upper and lower quartiles, and both ends of the whiskers are the upper and lower adjacent values. 'DE_burden' means domestic energy burden, 'PriTE_burden' means private transport energy burden, and 'PubT_burden' means public transport burden. For the income quintile, it is shown from the lowest income group ('Inc1') to the highest ('Inc5'). For the population density, it is shown from the lowest, most rural ('PD1') to the highest, most urbanized ('PD4').

3.2. *Energy and transport burdens among older people*

In Japan, which has one of the most ageing populations globally, households with older people (over 65 years old) are considered particularly vulnerable to unaffordable energy costs (Okushima, 2016, 2017; Yagita and Iwafune, 2021), and so we focus on them here.

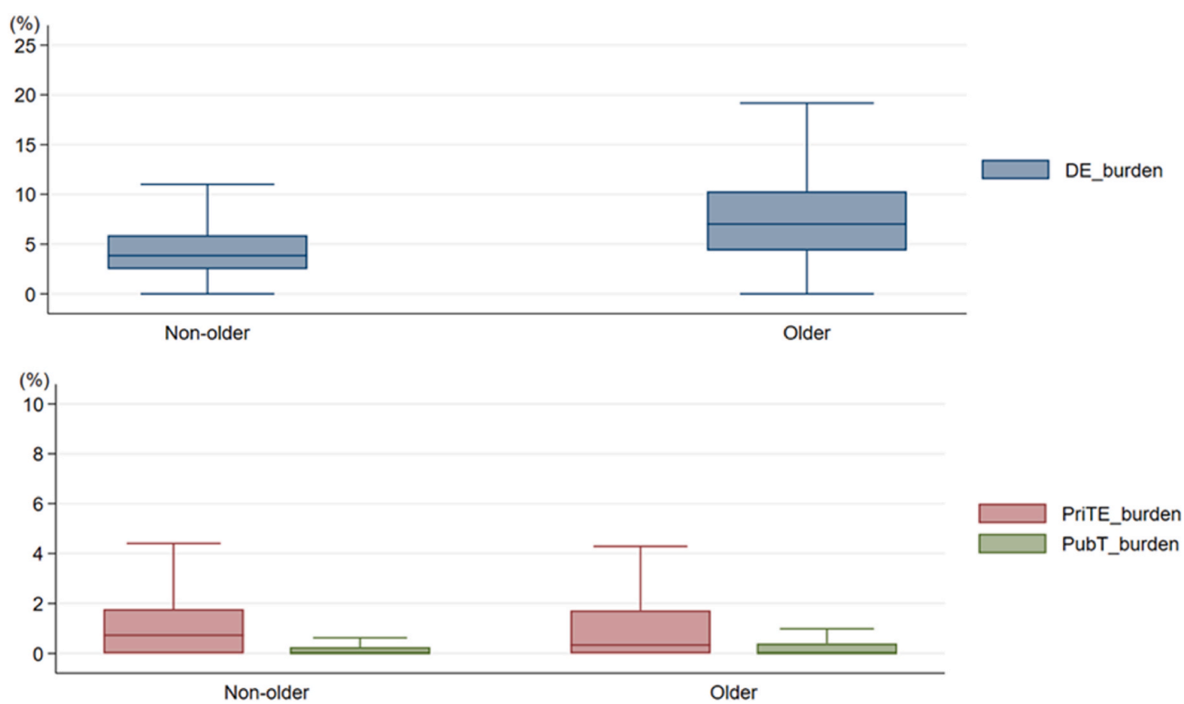

Fig. 5. Energy and transport burdens between older and non-older households
Note: The horizontal line in each box is the median, the top and bottom of the box are the upper and lower quartiles, and both ends of the whiskers are the upper and lower adjacent values. 'DE_burden' means domestic energy burden, 'PriTE_burden' means private transport energy burden, and 'PubT_burden' means public transport burden. 'Older' means the households in which a householder is 65 years old or over, and 'Non-older' means the other households.

Fig. 5 shows that older households typically have higher domestic energy burdens in comparison to younger households. In contrast, the median (as well as the mean) private transport burden is lower for older people in comparison to younger people, due to older people's higher percentage of no private motor use. Meanwhile, the public transport burden is slightly greater for older people, indicating some private to public transport replacement as people age.

Fig. 6 shows the domestic energy and transport burdens between older and non-older households, whilst controlling for degree of rurality-urbanity. For domestic energy, the same trend as Fig. 5 can be observed – older households have consistently higher energy burdens than non-older households across all the spatial categories.

For transport, Fig. 6 shows that older households living in more rural areas (PD1 and PD2) have notably higher private transport burdens than the aggregate measures. This suggests that in rural areas older people continue to drive due to a lack of other transport options – as indicated by the minimal spending on public transport in the most rural areas. Conversely, Fig. 6 also indicates that older households in more urban areas (especially PD4) mostly do not use private cars, and although their public transport costs are slightly higher these are still less than the private transport costs of households in rural localities.

3.3. Energy and transport burdens in different climatic zones

Japan has very different climates inside the country from north to south. Previous literature on energy poverty measurement points to the need for assessments to take full account of such climatic difference between regions (Kahouli and Okushima, 2021; Okushima, 2019, 2021). Fig. 7 shows the domestic energy and transport burdens for each of Japan's ten regions. As existing studies on energy poverty suggest, domestic energy burdens are greater in northern regions such as Hokkaido and Tohoku, reflecting large heating needs in winter due to a colder climate, and lower in southern regions with a subtropical climate such as Okinawa.[6]

Transport burdens do not display any correlation with climatic differences. This is to be expected, as there is not a strong reason why transport expenditure would alter depending on climatic conditions. The smallest private transport burdens are found in the Kanto and Kinki regions, which are partly counteracted by higher public transport burdens. The Kanto and Kinki regions include Japan's two largest cities - Tokyo and Osaka - and many households living in such mega cities can rely on public transport and do not need to use private car services. Meanwhile, Okinawa, Kyushu and Shikoku have relatively high private transport burdens and little spending on public transport. This indicates that although households living in these regions may have a lower risk of energy poverty due to their warm climate, they may be at greater risk of experiencing transport poverty. The northern regions of Hokkaido and Tohoku experience relatively high cost burdens for both transport and domestic energy. Therefore, people living in these regions may face double energy vulnerability – a heightened risk of experiencing energy and transport poverty simultaneously.

To identify climate impacts from a different angle, Fig. 8 compares the domestic energy and transport burdens between winter (Feb 2019, the same as other results in this paper) and summer (Aug 2019). As existing studies point out (e.g., Castaño-Rosa and Okushima, 2021), in Japan energy consumption in summer is significantly lower than in winter – as such, domestic energy burdens are also much lower in summer. For transport, however, there is no strong indication of seasonality. This paper does not include the results of seasonality by income group or age, but the same conclusions can be drawn as Fig. 8.

[6] In Japan, heating in winter is typically provided by individual heating appliances, such as kerosene or gas stoves and air conditioners (heat pumps). Central heating systems (whole house heating) are rare except in Hokkaido (MOE, 2024; Yagita and Iwafune, 2021).

4. Discussion

4.1. Domestic energy burdens

Domestic energy burdens have a strong negative correlation with income level, with energy burdens increasing as income decreases. This suggests, as studies in other contexts have found (Hernández and Bird, 2010; Walker et al., 2014), that in Japan income is an important determinant of energy vulnerability and that people on low incomes are at greater risk of experiencing energy poverty.

Older households (over 65 years old) also have consistently higher energy burdens, validating previous research in Japan that suggests this group is more vulnerable to energy poverty (Okushima, 2016, 2017; Yagita and Iwafune, 2021). Research in multiple other geographical contexts has also found that older people are often more vulnerable to domestic energy poverty (Simcock et al., 2021). This vulnerability is typically attributed to a combination of lower incomes (Okushima, 2016; O'Neill et al., 2006), and greater levels of energy consumption due to longer hours at home during retirement and a physiological need for higher indoor temperatures (Chard and Walker, 2016; Yagita and Iwafune, 2021).

In terms of rural-urban spatial differences, Fig. 2 suggests that households in the most rural localities generally have slightly higher energy burdens. However, disaggregating by income (Figs. 3 and 4) suggests that this relationship is relatively more influenced by income-related factors (namely, a higher proportion of low-income people living in rural areas), rather than other aspects of rural life such as a reliance on more expensive fuels or more inefficient housing. In this regard, our findings slightly differ from studies of rural energy poverty in other countries (Isaacs et al., 2010; Mould and Baker, 2017; Papada and Kaliampakos, 2016; Walker et al., 2015). However, they are consistent with the result of Okushima (2024), which found that energy poverty prevalence is only weakly associated with the degree of rurality-urbanity, especially when climatic factors are controlled for. There is a need for further research to explore in-depth the factors influencing energy vulnerability in rural Japan.

Regional climate plays a role in the spatial patterning of energy burdens, with domestic energy burdens greater in northern regions such as Hokkaido. This reflects large heating needs in winter due to a colder climate, and lower heating needs in southern regions with a subtropical climate such as Okinawa. This is again consistent with previous research (Kahouli and Okushima, 2021; Okushima, 2019, 2021).

4.2. Transport burdens

The relationship between income and transport burdens (shown in Fig. 3) is more nuanced than for domestic energy burdens. Public transport burdens are on average slightly greater for high-income households. For private transport, meanwhile, there is a weak negative correlation with low-income households having, in general, higher cost burdens. Yet more than half of households in the lowest income category have no expenditure at all on private transport, indicating low levels of car ownership among this group. This echoes research in other geographical contexts, such as the USA and UK (Klein et al., 2023; The Health Foundation, 2023), which finds that the lowest-income households are less likely to own or use a car due to affordability reasons. This can be problematic if there are a lack of alternative transport options available, because it places people at risk of being socially excluded and unable to access key services (Lucas, 2012; MLIT, 2023a).

In comparison to domestic energy burdens, transport burdens are more strongly differentiated geographically. Figs. 2 and 4 show that the highest transport costs are found in more rural localities ('PD1' and 'PD2') due to consistently higher private transport burdens. This is the case even for low-income groups living in rural areas, who also spend minimal amounts on public transport in these localities. This suggests such households are unable to access necessary services through either

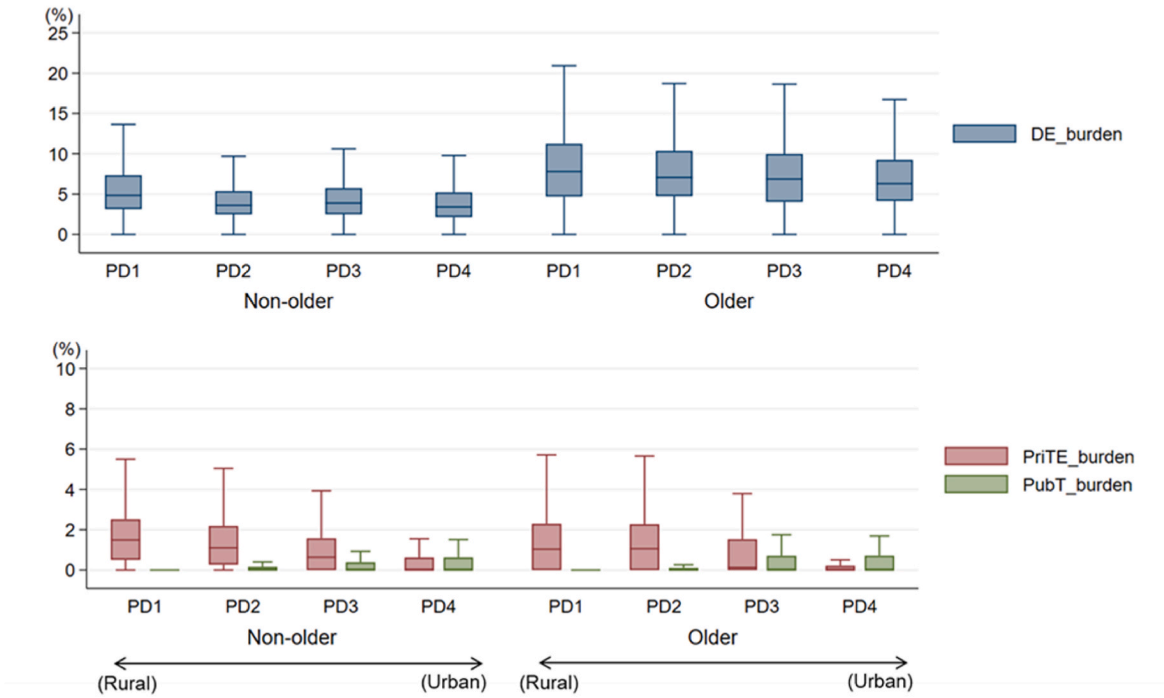

Fig. 6. Energy and transport burdens between older and non-older households, by degree of rurality-urbanity
Note: The horizontal line in each box is the median, the top and bottom of the box are the upper and lower quartiles, and both ends of the whiskers are the upper and lower adjacent values. 'DE_burden' means domestic energy burden, 'PriTE_burden' means private transport energy burden, and 'PubT_burden' means public transport burden. 'Older' means the households in which a householder is 65 years old or over, and 'Non-older' means the other households. For the population density, it is shown from the lowest, most rural ('PD1') to the highest, most urbanized ('PD4').

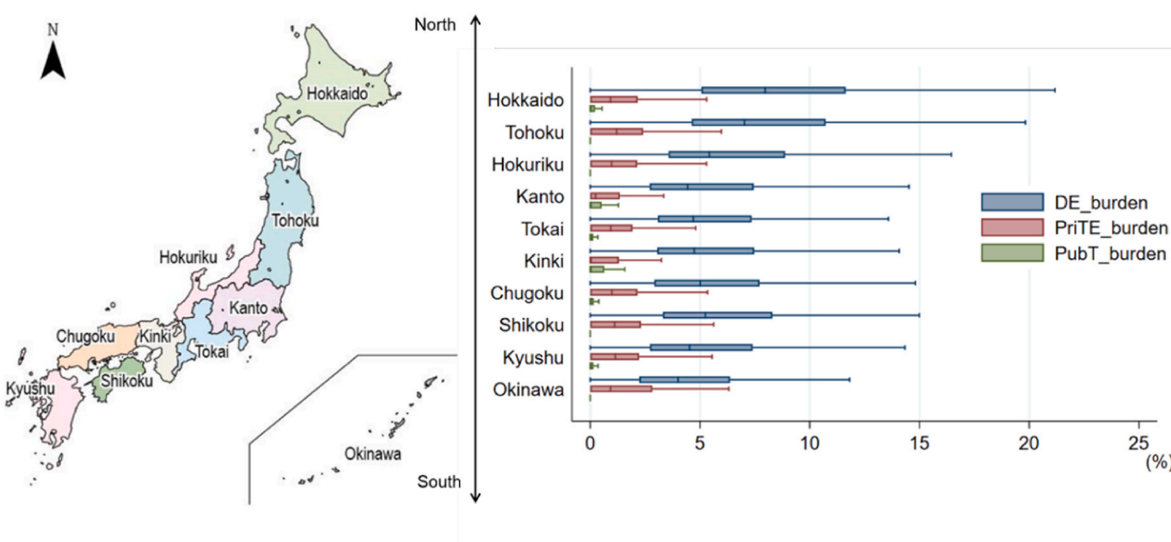

Fig. 7. Energy and transport burdens between the Japanese regions
Note: The vertical line in each box is the median, the right and left ends of the box are the upper and lower quartiles, and both ends of the whiskers are the upper and lower adjacent values. 'DE_burden' means domestic energy burden, 'PriTE_burden' means private transport energy burden, and 'PubT_burden' means public transport burden.

public transport or active travel (e.g., walking or cycling), and so are inevitably reliant on car ownership. As car ownership and use carries substantial financial costs, this 'forced car ownership' (Mattioli, 2017) increases transport burdens and the risk of experiencing transport poverty among lower income groups living in more rural localities.

Conversely, across all income categories households living in urban areas (especially, 'PD4') spend relatively little on private transport. Although public transport burdens are greater in these areas, they are still much lower than the private transport burdens found in more rural areas. This indicates that in urbanized localities a strong public transport system enables people to largely forego car use, and that urban public transport remains relatively affordable in Japan. The fact that the lowest income households living in the most urban areas have the smallest private and public transport burdens also indicates that a proportion of this group have very limited mobility and/or primarily access daily services through active travel such as walking. Whilst this means that

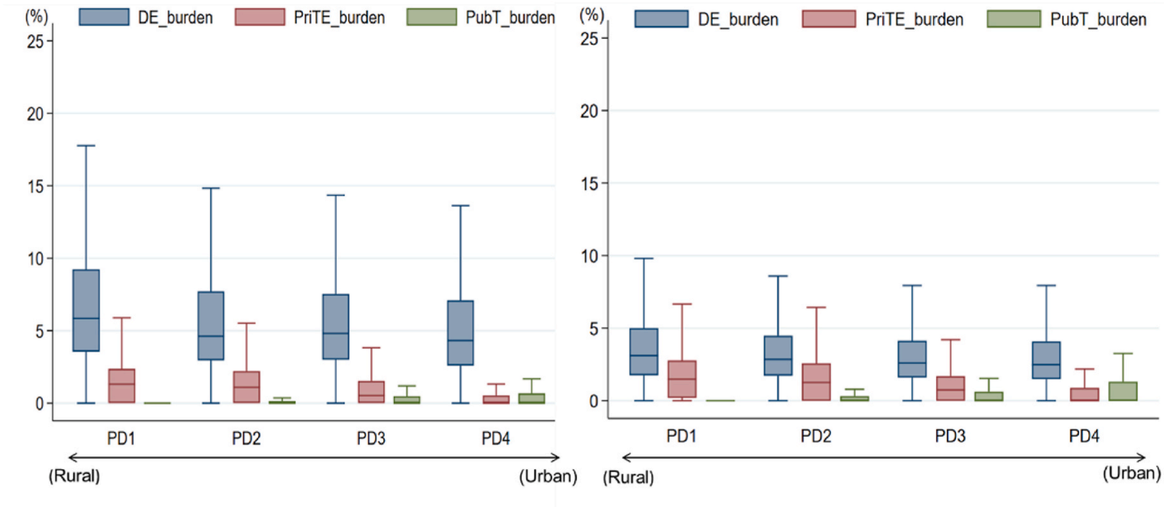

Fig. 8. Energy and transport burdens by degree of rurality-urbanity, in winter (left chart) and summer (right chart)
Note: The horizontal line in each box is the median, the top and bottom of the box are the upper and lower quartiles, and both ends of the whiskers are the upper and lower adjacent values. 'DE_burden' means domestic energy burden, 'PriTE_burden' means private transport energy burden, and 'PubT_burden' means public transport burden. For the population density, it is shown from the lowest, most rural ('PD1') to the highest, most urbanized ('PD4').

their transport cost burdens are limited, qualitative research in the UK by Martiskainen et al. (2023) suggests that such 'forced walking' can sometimes be problematic from a health and social inclusion perspective.

Private transport burdens are slightly lower, and public transport burdens are slightly greater, among older people – particularly those living in urban areas. In Japan, people tend to stop driving as they get older. Furthermore, in recent years the Japanese government strongly encourages older drivers to voluntarily return their drivers licenses – ostensibly to reduce the risk of traffic accidents (Cabinet Office, Government of Japan, 2020; MLIT, 2020); hence 48.5% of older households in our data have zero private transport burden, indicating no use of a car.

4.3. Double energy vulnerability

In this section, we consider differences and overlaps in the people and places vulnerable to both high energy and transport burdens – and so at increased risk of double energy vulnerability.

Our results would suggest that vulnerability to domestic energy poverty is most strongly influenced by socio-demographic factors (namely, income and age), alongside climate. In contrast, transport poverty is more strongly associated with geographic differences, with higher transport burdens consistently found in rural areas. Spatial peripheralization is likely to be key in explaining this trend (Golubchikov and O'Sullivan, 2020), with many rural areas having marginal access to key services and public transport networks; as such, their residents are reliant on more expensive car travel for relatively long journeys. Private car use appears to often be a 'basic need' in rural Japan (MLIT, 2020).

Our findings therefore identify that low-income people living in spatially peripheral (often rural, but potentially also peri-urban) localities are most likely to encounter double energy vulnerability. This echoes the pattern suggested in previous conceptual (Simcock et al., 2021) and empirical research from other contexts – including England (Robinson and Mattioli, 2020), Mexico (DD Furszyfer Del Rio et al., 2023), and Northern Ireland (J Furszyfer Del Rio et al., 2023). The situation in Japan therefore seems to be broadly similar, adding further evidence that this patterning cuts across multiple and diverse national contexts. One way to explain this commonality is through critical political-economy theory, which would suggest that spatial inequalities, and the relative disadvantages faced by rural areas, are the result of the fundamental dynamics of capitalism in producing 'cores' and 'peripheries' in the pursuit of profit maximization (Golubchikov and O'Sullivan, 2020).

Age and climate factors add further layers of complexity to the urban-rural spatial pattern. In Japan, our data suggests that older people face a greater risk of energy poverty but a slightly lower risk of transport-related economic stress. Meanwhile, living in a colder climate increases vulnerability to energy poverty but appears to have little relationship to transport burdens. These additional variables can therefore (partially) counteract, mediate or reinforce the vulnerability induced by income and spatial location. Fig. 9 attempts to visualize some of these complexities by positioning households with different characteristics based on their approximate and relative vulnerability to energy and transport poverty.

5. Conclusion and policy implications

In this paper, we have provided some initial, preliminary insights into the people and places in Japan vulnerable to domestic energy poverty and transport poverty, and at heightened risk of experiencing both simultaneously. Several policy implications arise from these findings.

Given that our results indicate that levels of double energy vulnerability have a broad geographical patterning, policies to address this issue can also be spatially tailored. In Japanese urban areas, our findings suggest that domestic energy poverty is the most common energy-related inequality; therefore, this should be the core focus of policy action in this spatial sphere. At the same time, it is important that cheap, reliable and convenient public transport remains in widespread in Japan's cities to ensure that transport poverty risks remain minimized in these areas. Understanding and addressing the additional domestic energy poverty risks experienced by people who are older, on a low-income, or living in colder climates is also important – for example, by ensuring these groups are prioritized and supported in the implementation of energy efficiency measures such as retrofits. Since energy poverty is not yet on the policy agenda in Japan, such measures have only been introduced at a very limited level compared to European countries (Castaño-Rosa and Okushima, 2021; Chapman and Okushima, 2019).

In rural areas, there needs to be a greater focus on addressing transport poverty and double energy vulnerability, especially among

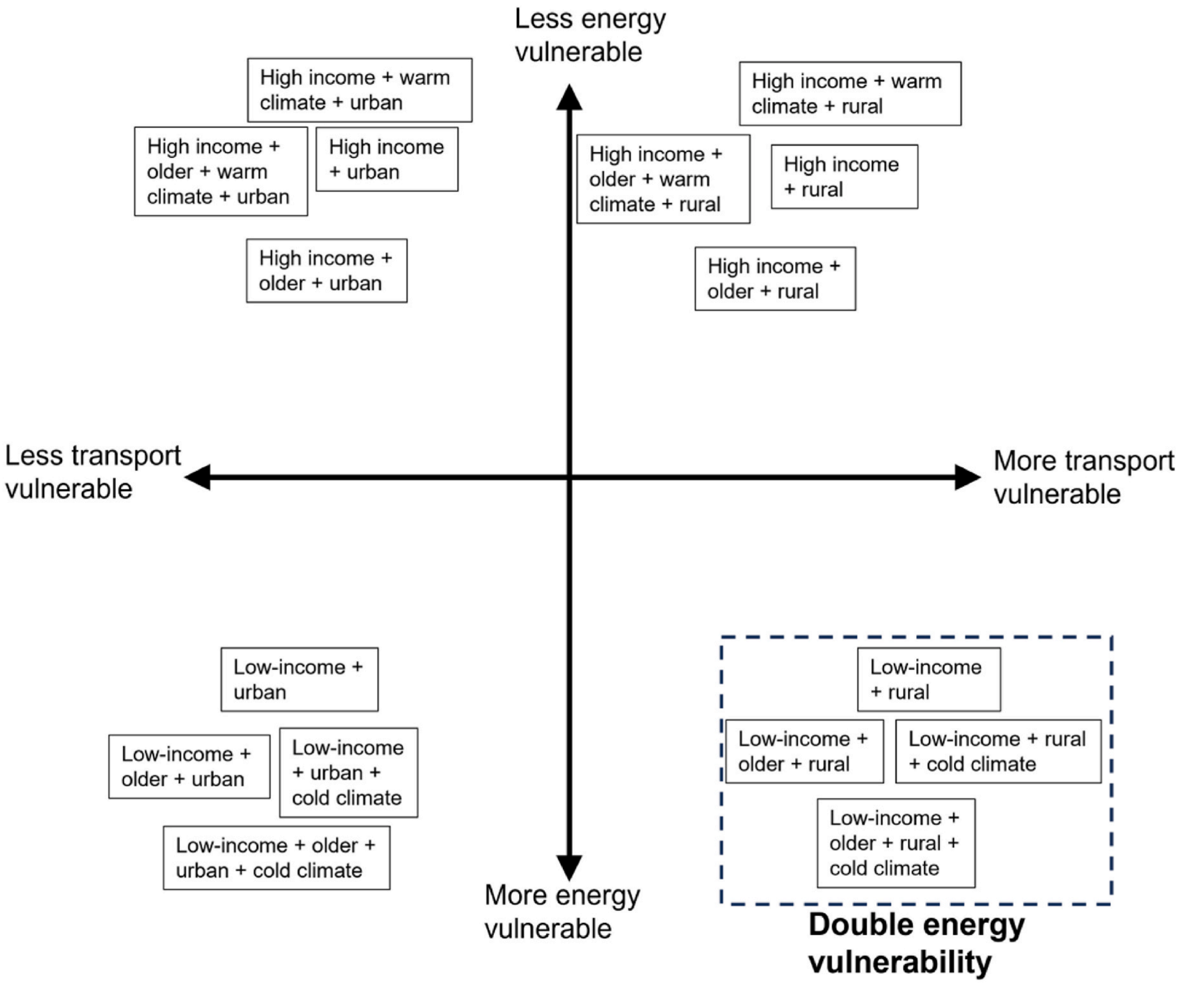

Fig. 9. Conceptual diagram to illustrate the relationship between energy vulnerability, transport vulnerability, and different social-spatial groups in Japan.

low-income and older populations. Subsidizing fuel costs for fossil fuel powered vehicles, or reducing fuel taxes, would have some benefit for affordability but would be highly problematic from an environmental and climate change perspective. Policies that reduce reliance on private cars in rural areas by improving public transportation and access to key services locally should be prioritized; for example, community buses and on-demand transport services have recently been promoted as an effective rural transport option in Japan (MLIT, 2020, 2023b).

Japan currently operates a policy of encouraging older people to return their drivers licenses. However, without first improving public transport in rural areas this policy carries the risk of creating social exclusion if a lack of car use leaves older people unable to access key services and social networks (MLIT, 2020). Some Japanese qualitative research has proposed encouraging older people to relocate to smaller homes in places with better public transport services (Yagita and Iwafune, 2021). This is arguably beneficial from an energy-sufficiency perspective (Darby and Fawcett, 2018; Lorek and Spangenberg, 2019; Okushima, 2024), and, as our results would suggest, from a double energy vulnerability perspective by reducing transport and energy burdens. However, policies relying on relocation also present challenges, and given the substantial social and psychological harms that can result from involuntary displacement (Schulz and Brenner, 1977; Slater, 2021) focusing on bringing better services and transport options to people living in more isolated places should be strongly favoured.

Although this study contributes to scholarship as the first DEV study in Japan and east Asia, there are also several areas for further research that arise from our preliminary study. Our analysis is limited by the quality of data available from the FIES. As noted in Section 2, this survey does not include data on single-person households and does not allow for longitudinal analysis. In the Japanese context, these limitations could be addressed through the creation and implementation of a new survey instrument specifically designed to measure energy poverty, transport poverty, and double energy vulnerability. Future studies could also collect more fine-grained spatial data to pinpoint specific places and communities that are at greatest risk of DEV, as our study was only able to use broad population density (as a proxy for degree of rurality-urbanity) and regional (for climate) categorizations. Quantitative and survey-based analysis could also be greatly enriched by in-depth qualitative research (similar to that undertaken by Martiskainen et al., 2023; Ortar, 2018) that examines the lived realities, nuances and impacts of double energy vulnerability among those who experience it.

As discussed in Section 2, defining fixed expenditure thresholds that firmly indicate energy and/or transport poverty (e.g., 10% of income) is very challenging – especially when researching in diverse geographical contexts with different vulnerability characteristics. In this paper we instead compare *relative* differences in energy and transport burdens between social and spatial groups, and this has proven to be a useful methodological approach for allowing assessment of relative vulnerability without defining specific thresholds. This approach could be usefully applied to the study of double energy vulnerability and inequality in other national contexts, perhaps especially when making cross-country and international comparisons. Nonetheless, more sophisticated indicators of energy and transport poverty exist, such as those proposed by Mattioli et al. (2017), and once data is available these could be utilized in Japan to allow more precise measurement of the numbers of people experiencing double energy vulnerability.

CRediT authorship contribution statement

Shinichiro Okushima: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Neil Simcock:** Writing – review & editing, Writing – original draft, Validation, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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