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Identifying double energy vulnerability: A systematic and narrative review of groups at-risk of energy and transport poverty in the global north

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ABSTRACT

The concept of 'double energy vulnerability' describes a circumstance whereby people are at heightened risk of energy poverty and transport poverty simultaneously – a particularly severe form of energy injustice. However, analysis of which people and places are most likely to experience this phenomenon remains limited. This paper begins to address this lacuna via a review of academic literature, aiming to pinpoint the overlapping socio-demographic and spatial factors that can increase vulnerability to both energy and transport poverty and thereby identify those most at-risk of experiencing double energy vulnerability. A systematic review of an extensive 5-year sample period is complemented by a narrative review of key papers. Combined, this encompasses a state-of-the-art analysis of 250 papers across 8 different academic databases. We find several overlaps in the socio-demographic groups rendered most vulnerable to energy and transport poverty, including people on low-incomes, older people, households with children or dependents, people with pre-existing health conditions or disabilities, women, and people from ethnic minorities. Spatially, however, there are more differences and contextual variations between the two problems, with inner-urban areas generally posing greater risks for energy poverty and suburban areas for transport poverty. Rural areas appear to be the spatial settings that have the greatest overlap in vulnerability. Overall, our results indicate that the highest level of double energy vulnerability is among households that face a combination of multiple socio-demographic disadvantages alongside relative spatial peripheralisation. We signal future research directions and policy implications arising from these findings.

1. Introduction

Energy poverty and transport poverty have been identified as serious forms of deprivation warranting further and urgent attention from inside and beyond academia, with each having severe and detrimental impacts upon wellbeing, health and life chances [1,2]. Within the energy and social science literature, a diverse and rapidly developing set of contributions over the last 20 years have considered energy poverty conceptually (e.g. [3–5]), empirically (e.g. [6–8]) and through a decision-making lens (e.g. [9–11]). Starting in the late 1990s, the transport poverty literature has also considered a range of applications, cases and contexts, including early and seminal contributions from Lucas [12,13]. Although Mattioli et al. [14] note some differences in their negative consequences, drivers, measurement and policy responses, the two problems are conceptually similar in many ways. Within this paper, we understand both energy poverty and transport

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poverty to refer to, and result from, situations in which people are unable to access sufficient and reliable *energy services*[1] [3].

Although research into both issues is well-established (see [15] for energy poverty in particular), they have typically been analysed as separate problems with distinct patterns of vulnerability. However, energy social science literature has begun to argue that the links and overlaps between transport poverty and energy poverty need to be examined more carefully, especially in the context of low-carbon transitions [16–18]. Some have proposed that transport poverty should be considered a particular form or dimension of energy poverty [19]. In this vein, Robinson and Mattioli [20] use the term “transport energy poverty” to refer to a lack of accessible and affordable transport services, and “domestic energy poverty” to refer to inadequate energy services in the home (see also [18]). In this paper, we use the terms “transport poverty” and “energy poverty”, respectively, as these are most commonly used in the literature; we nonetheless agree that the overlaps between transport and domestic energy poverty issues warrant further attention.

The transition to low-carbon or net zero societies is likely to mean greater integration between domestic energy and transport systems. Unless the interrelations between transport poverty and energy poverty are understood and accounted for in low-carbon transition policies, they may unintentionally exacerbate each problem or create new patterns of vulnerability [17]. Therefore, in order to alleviate inequality and injustice, both now and over the course of future (or ongoing) low-carbon transitions, there is a need for a greater understanding of the relations between energy poverty and transport poverty, who is most vulnerable to each problem, and where the most severe forms of hardship may occur [16,20].

Previous research has found that households can suffer from *both* energy poverty and transport poverty simultaneously, and that the two problems may intersect in mutually reinforcing ways [14,21]. Robinson and Mattioli [20] have proposed the concept of ‘double energy vulnerability’ (DEV) to describe households that concurrently experience energy and transport poverty. They suggest that this is likely to have a number of serious implications, as the simultaneous experience of both has the potential to further exacerbate and intensify their respective negative effects [17,20]. In this paper, we contribute to this pressing research agenda via a systematic and a narrative review of 250 peer-reviewed academic papers. Our aim is to understand the interrelations in vulnerability to both energy poverty and transport poverty across different socio-demographic groups and spatial settings, with a view to informing further research, policy and practice. In addressing this aim, we ask the following research questions:

- Which social groups and spatial settings are especially vulnerable to energy poverty and transport poverty, respectively?
- Which social groups and spatial settings are most at-risk of experiencing ‘double energy vulnerability’?

The paper proceeds as follows: Section 2 defines the key concepts of energy poverty, transport poverty, vulnerability and space. Section 3 describes our systematic review method. Section 4 presents our results, divided between socio-demographic and spatial vulnerabilities. Section 5 discusses our findings and answers our research questions, revealing the people and places at greatest risk of DEV. Section 6 concludes by arguing for further empirical research exploring the interlinkages between energy poverty and transport poverty, particularly in low-carbon transitions.

2. Defining key concepts

‘Energy poverty’ is an enduring problem experienced by millions of people globally [22,23]. It has been defined in multiple ways [24][2], and via various terminology including ‘fuel poverty’ [26], ‘energy vulnerability’ [27] and ‘energy insecurity’ [28]. In this paper, we follow Bouzarovski and Petrova [3] in seeing these various definitions and terms as referring to fundamentally the same phenomenon: “*the inability to attain a socially- and materially-necessitated level of domestic energy services*” (ibid. pp.31). We understand energy poverty to be a situation in which households, or individuals, cannot attain and/or use the energy services required for good health, wellbeing, and the ability to fully participate in society [29]. Living in energy poverty can therefore mean, for example, not being able to keep a home at a comfortable temperature, to cook hot meals, wash clothes or take a warm shower. In countries of the global north (our focus), energy poverty usually results predominantly from some combination of low-incomes, poor quality and inefficient housing, expensive energy costs and/or increased energy needs. Households thus struggle to afford their energy bills and are forced to either ration energy consumption to below socially-acceptable levels or to reduce expenditure on other essentials such as food [26,30]. The consequences of this are well-documented, and include severe and detrimental impacts on physical and mental health [31], and on children’s educational attainment [32].

In contrast, transport poverty is less precisely defined in either academic or policy literature [2,14]. Lucas et al. [2] have suggested transport poverty as an umbrella concept used to refer to problems of affordability (an inability to meet essential travel costs), mobility (difficulties in moving around due to a systemic lack of sufficient transport), accessibility (difficulty reaching key activities, such as employment or education, at reasonable time, ease and cost), and transport externalities (exposure to negative outcomes of transport systems, such as traffic pollution). In this paper, we focus on the first three – affordability, mobility and accessibility – and suggest combining these into a single working definition: *the inability to attain a socially- and materially-necessitated level of transport services* (be that due to lack of affordability, mobility or access). This definition mirrors the one we use for energy poverty in this paper. Transport poverty may, for example, mean people not being able to afford ‘essential’ transport costs required to access employment or education. It can also mean not having access to, or living far away from, public transport, forcing people to rely on expensive private cars [14] and/or creating potential mobility challenges [2,33]. Being in transport poverty has direct impacts on the ability to fully participate in society, as it restricts people’s ability to access places of work, school, healthcare, or leisure. Struggling to meet transport costs has, for instance, been associated with negative impacts on wellbeing [34] as it reduces visits to friends and family, particularly for older people [35].

In short, in this paper we define energy poverty and transport poverty as the “*inability to attain a socially and materially necessitated level of domestic energy and/or transport services*”[3].

The third concept we draw upon is *vulnerability*. Vulnerability is a term widely used in energy research (e.g., [3,27]) and policy discourse (e.g. [36]), but it has often been only vaguely defined. Our

[1] Energy services refer to those services used in the household that require energy to function, e.g. cooking, lighting, and space and water heating.

[2] For example, the widely used ’10% indicator’ defines a household as energy poor “if they are required to spend more than 10% of their income on fuel, so as to maintain an adequate standard of warmth” ([25]: p.4). Under the Low Income High Costs (LIHC) indicator, “a household is considered to be fuel poor if they have required fuel costs that are above average (the national median level); *and* were they to spend that amount, they would be left with a residual income below the official poverty line ([25]: p.1).

[3] We base this definition on the extensive previous literature that has fed into and defined these terms in the past. We also note that the reviewed literature referring to these same phenomena may articulate and word them differently.

understanding of vulnerability is informed by literature on social and natural hazards from which the concept of vulnerability originates (e.g., [37–39]), and on access to energy and transport services [27,40–42]. This previous research has defined vulnerability as comprising three interlinked dimensions: (i) *(Risk of) Exposure*: the likelihood and degree to which an individual, household or community will encounter a hazard; (ii) *Sensitivity*: the degree to which exposure to a hazard will lead to a loss of wellbeing; and (iii) *Adaptive Capacity*: the degree to which those exposed to a hazard are able to plan, respond and recover.[4] In our study, we focus predominantly on *exposure*, examining which people and places are more likely to experience energy and/or transport poverty. This is consistent with the definition of 'energy vulnerability' adopted by Bouzarovski and Petrova [3]. At the same time, we recognise that 'vulnerability' is not a set of static characteristics inherent to particular individuals; rather, it is always rooted in wider social structures and is "the product of socio-economic processes and political decisions" ([44] pp.83). In this paper, we hope to elucidate the role of such processes in producing vulnerability to energy and transport poverty.

Finally, it is important to define how we understand *space* in this paper. As we discuss in Section 4.2, vulnerability to hazards (in this case energy and transport poverty) is often geographically unequal [3,45], but this is not the consequence of static or inherent features of particular places. Rather, space (and spatial inequality) is socially constructed – that is, it results from political-economic processes and ideologies [46–49]. Because resources (political, cultural, economic) are almost always unevenly distributed in capitalist societies, the social and discursive production of space is also unequal and results in places of wealth and power in parallel with 'peripheral' places of disadvantage and dependency [49,50]. As such, residents of 'peripheralised' places can be disproportionately exposed to hazardous events, and moreover lack the investment, resources and infrastructure required to be protected from harmful impacts [51,52]. For example, it has been noted that isolated rural communities can be especially vulnerable to coastal flooding as a result of a lack of investment in flood defence systems and disaster relief assistance [51]. Yet it is important to note that these same people are also active agents in shaping the places (towns and neighbourhoods) within which they live [53].

3. Methodology

Our study combines two types of literature review: 1) *a systematic review* based on an extensive 5-year sample period and 2) a supplementary *narrative review* of key papers falling outside the systematic review sample period.

Utilising both review types enabled their relative strengths to be combined, creating a state-of-the-art analysis of 250 papers. Systematic reviews ensure comprehensiveness in the data sample, as they enable the inclusion of papers not previously known to the authors [54]. They also enable quantitative analysis of the most frequent 'codes' occurring across the article sample, thus elucidating patterns and commonalities within the reviewed literature. In addition, the inclusion of a narrative review of selected papers can allow for more in-depth, qualitative insights [55] that can provide additional explanatory understanding and assist in clarifying the quantitative trends and themes identified by the systematic review process (see also Section 3.3 on methodological limitations).

We explain next the sampling and analysis process utilised for the review.

[4] In some literature 'vulnerability' is positioned as comprising only sensitivity and adaptive capacity, with 'exposure' framed as a distinct concept – together, vulnerability and exposure are seen as being sub-components of the overarching concept of 'risk' (e.g. [43]). However, in this paper we consider exposure to be a dimension of vulnerability.

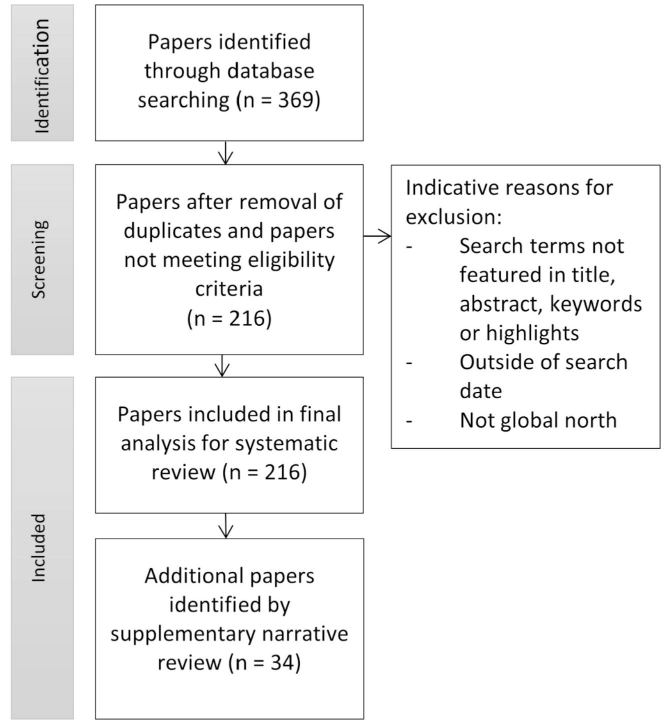

Fig. 1. Paper searching process and results.

3.1. Data sampling for the systematic review

Fig. 1 summarises the paper sampling and search process. Initially, we tested a 10-year data range, but this produced a large sample of papers (in excess of 600) that was unmanageable within our research resources. A 5-year range thus provided a balance between a large sample size (giving an initial sample of 369 papers), practicality and contemporary relevance. As a result, we sampled academic papers between the 1st of January 2014 and the 31st of December 2018.

Given the complexity of the literature in this area, a range of energy, fuel and transport-related search terms were used to identify relevant articles (Table 1). These terms were selected both as being those most commonly used in the literature and through a process of trial and error, where terms that gave either no results or revealed only duplicates were removed (e.g., "energy precarity", "mobility equity" and "transport justice"). For energy poverty, "energy poverty" and "fuel poverty" were selected as these are the most long-established and widely-used terms [56]. Additionally, "energy vulnerability" was included as a more recent term that has gained some traction as an alternative description of energy-related hardship [3,27]. For transport poverty, given the ongoing lack of agreement and consistency in the research literature regarding terms that are used to describe this phenomenon [2,13,14], a greater number of search terms was required to ensure a representative sample (Table 1).

We used 13 search terms and conducted 104 searches in eight major peer-reviewed academic article databases focusing on the social sciences and humanities (Table 1), mirroring other reviews [57], and reflecting the limitations of individual databases in terms of scope and comprehensiveness.

We searched for presence of all terms within four fields – the article title, abstract, highlights and keywords. Although the decision to search only in four article fields potentially reduces the sample size (i.e. it excludes those that mention "fuel poverty" in the main text but not in the title, abstract, highlights or key words) it also ensured that the majority of the sample articles had a strong focus on energy and/or transport poverty, rather than simply mentioning each term in passing.

Only original research articles that were peer reviewed, full-length,

Table 1
Number of articles systematic review sample included in final analysis, by database and search term (1 January 2014-31 December 2018). (Source: Authors).

Database	*"Energy vulnerability" OR "fuel poverty" OR "energy poverty"*	*"Transport poverty" OR "transport equity" OR "transport and social exclusion" OR "transport-related social exclusion" OR "transport disadvantage" OR "mobility poverty" OR "mobility disadvantage" OR "oil vulnerability" OR "forced car ownership" OR "accessibility poverty"*
Science Direct	129	32
Project Muse	0	0
Hein Online	0	0
SpringerLink	5	6
Taylor & Francis Online	13	3
Wiley Online	5	1
Sage Journals	19	2
Annual Reviews	0	0
Total:	172	44

and written in English were included. Consistent with the study context we outline in Section 1, we restricted the sample only to articles focused on the global north. The resultant sample across the eight databases is shown in Table 1.

3.2. Analytical protocol

Sampled articles were analysed using a combination of qualitative and quantitative content analysis [58]. A member of the research team read the title, abstract, highlights and article keywords (where available), then the body of the article. When an article identified a particular category of people as being at increased likelihood of experiencing energy or transport poverty, this was coded in the relevant category on a spreadsheet. To ensure reliability and consistency of coding between three researchers, all coding was checked by a second member of the research team.

To accurately identify and tally vulnerable groups, we used a combination of deductive and inductive coding, similar to previous content analysis work undertaken by Sovacool [59] and Mouter et al. [60]. We began with a pre-established coding scheme of groups and spaces typically defined as 'vulnerable' to exposure to energy and transport poverty, drawing on the definitions given in Section 2 and previous research. We then conducted a 'pilot' coding of a diverse sub-sample of 20 articles to test the applicability of our deductive coding scheme. At this stage, the coding framework was refined and further codes were added inductively. From this, we then developed the final coding scheme and applied this consistently across the entire samples (Appendix 1).

Each paper could be coded across multiple categories, including "elderly and pensioners", "rural" and "no central heating", for instance. If no specific social groups were mentioned, then no categories were coded. If a paper appeared both in the energy *and* transport sample, it was recoded in each instance.[5]

The coded dataset was then analysed in a spreadsheet using descriptive statistics, allowing the creation of a series of percentages, figures, and summary tables. Additionally, we took detailed notes of each article that provided a qualitative reading of their key messages and insights. It was at this stage that we also incorporated insights from the wider narrative review described earlier in Section 3. For example, in our discussion of the category "low-income groups", we present the quantitative results arising from the systematic review alongside qualitative and explanatory insights from both the systematic review sample and the supplementary narrative review.

3.3. Methodological limitations

We acknowledge limitations to our study, and here we reflect on the most prominent issues. First, one limitation of systematic reviews is that they can be resource intensive and time consuming [55,61]. In our study, this meant that in order to keep our review manageable within allocated timeframes and resources, we chose to limit our search to a 5-year period. This excluded both highly cited and highly topical papers (known to the authors) published *before* and *after* our search range. We also recognise that systematic reviews have been critiqued for a relatively shallow and 'additive' approach to literature analysis [62]. It was for these reasons we supplemented the systematic review with the narrative literature review of relevant papers based on a combination of convenience sampling (identifying highly-cited or very topical papers based on the authors' prior research experience in energy and transport poverty) and snowball sampling (identifying further relevant papers by examining the reference list of sample articles).

Second, and partly to keep the total number of articles read and coded manageable, we searched for only academic literature, meaning we did not include insights from non-academic contributions such as reports, policy briefings and white papers[6]. Similarly, our sample is composed only of full-length, peer-reviewed, English-language research submissions and review papers, so we did not capture other forms of contribution. Whilst this approach neglects contributions made beyond Anglophone academia – e.g., the French-speaking literature on DEV (for a review see [20]) – this was a necessary limitation to keep the review manageable. We also note a further limitation is the exclusion of academic books, book chapters, and journal papers that fall outside of the databases used for our search. Lastly, we appreciate that there may be texts that did not use our specific search terms in the title, keywords, highlights or abstract, or indeed elsewhere in the text, but may still have been of relevance.

4. Results

To structure our results, we have divided both the energy poverty and transport poverty findings into 'socio-demographic vulnerabilities' and 'spatial vulnerabilities'. By 'socio-demographic vulnerabilities', we refer to salient characteristics of populations that affect access to energy and transport services, whether financially or otherwise. By 'spatial vulnerabilities', we refer to the geographical, infrastructural and physical environmental factors that condition exposure to energy and/or transport poverty. Throughout, we also occasionally refer to 'structural vulnerabilities' and society-wide perturbations such as austerity, which affect the context in which all households live.

Across all codes, we are interested in which groups were most commonly mentioned as vulnerable in the systematic review sample, as

[5] By way of example, Mattioli et al.'s [14] 'Transport poverty and fuel poverty in the UK: From analogy to comparison' was coded both for its application of energy poverty to particular social groups and, separately, its application of transport poverty to particular social groups.

[6] However, when making policy recommendations in our conclusion, some non-academic sources are referred to.

this would indicate agreement and strong evidence of vulnerability. However, we also discuss those groups identified as vulnerable relatively infrequently in the sample, because this may represent opportunities for further research and a current under-representation of certain vulnerabilities.

From this point in the paper, we refer to transport poverty as 'TP' and energy poverty as 'EP'. Papers dated 2014–2018 are from the systematic review; more recent or older papers are from the supplementary narrative analysis.

4.1. Socio-demographic vulnerabilities

Synthesising our initial coding structure, we identified 16 different socio-demographic groups as vulnerable to EP and TP (Fig. 2).[7] Some initial observations can be made. There is substantial overlap between EP and TP in terms of the groups identified as vulnerable. Although there are some differences in the proportion of articles mentioning particular groups, for most categories the percentages are relatively similar. Additionally, many of the groups identified here are also disadvantaged in many other facets of social and economic life (such as health, education, and economic opportunity) – this is a point we will return to in the concluding discussion.

4.1.1. Households on low-incomes

In both sets of literature, the most frequently identified vulnerable group is *people on low-incomes,* appearing in 84% of the TP articles and 79% of the EP articles. This indicates widespread evidence that low-income households are at heightened risk of experiencing both EP and TP. There are similarities in the causal mechanisms that render people on low incomes vulnerable to TP and EP. Most straightforwardly, this relates to direct problems of affordability: low-income households are more vulnerable to EP because they have fewer economic resources with which to pay for domestic energy services and bills [63–68]. For TP, low-income households have been documented as unable to afford the costs of running and maintaining a motor vehicle [69] or paying for public transport fares [70,71], forcing them to make expenditure sacrifices elsewhere in their budgets [72,73].

There is also evidence that for EP especially, these direct issues of affordability can be further exacerbated by additional material disadvantages. Low-income households are, in many contexts, more likely to live in poorer quality, less energy efficient housing compared to other socio-economic groups due to a lack of affordable options in housing markets [28,66,74–80]. They also often encounter barriers to undertaking energy efficiency improvements to their home, such as an inability to afford the upfront costs or to be deemed 'credit worthy' for loans that could fund such measures [79,81,82]. Low-income households are also more likely to be on more expensive payment methods and tariffs for their energy costs, such as pre-payment meters [26,67,83,84].

In terms of TP, low-income households are less likely to own a car, which although often alleviates financial pressures, can cause accessibility problems – especially for those living in areas poorly served by public transport [72,85,86]. Some research in Australia has suggested that residents of low-income areas who do own a car are likely to own an older and therefore potentially less fuel-efficient model [87]. In contrast, a further study in the UK found that although residents of low-income areas do tend to own older cars, they are also typically smaller and so often relatively fuel efficient [42]. It is nonetheless likely that the poorest households will be unable to afford the upfront cost of electric vehicles, which have the cheapest running costs [88]. For TP, it has also been shown that, in some contexts (most notably the USA and UK), low-income households also tend to have proportionately better access to public transport due to their concentration in inner-city areas (e.g., [42]) – a point we return to in Section 4.2 below.

4.1.2. People who are unemployed

Although *unemployed* people were identified as vulnerable more than twice as frequently in the TP sample (35% to 16%), a closer reading of the texts would suggest that unemployment is actually a stronger driver of vulnerability for EP. For TP, unemployment is likely to increase vulnerability primarily due to low-incomes [89], but at the same time those who are unemployed tend to travel less (due to reduced commuting) and so experience lower transport costs [90–92].[8] For EP, in contrast, whilst people who are unemployed are again vulnerable partly due to a low-income [78,81,97,98], there is also some evidence of additional risk factors. In short, because unemployed people typically spend more time at home, they may need to make greater usage of heating and appliances which can increase their energy usage and associated costs and/or necessitate the rationing of energy services [3,27,84,99,100].

4.1.3. People in low-wage or precarious employment

A greater proportion of TP articles (27%) explicitly identify *precarious and low-wage employment* as a specific driver of vulnerability [14,70,71,86]. Following the point about unemployment made above, this may suggest that, in comparison to EP, TP relates more strongly to the low-income households in *paid employment* [92]. For such households, a low-income is combined with higher transport costs due to commuting requirements [92,101]. There is also some evidence that the spatial and temporal insecurity resulting from 'precarious' employment arrangements (e.g., where a person does not work a fixed location or hours, but is required to be temporally and spatially 'flexible') can induce car dependence and increased commuting travel, therefore further contributing to higher transport costs [70,102].

Contrastingly, we found little mention of precarious employment as a specific risk factor in the EP literature; however, this may be partly due to it simply not being previously investigated. Middlemiss and Gillard [26] do identify an unstable household income as a factor that can increase vulnerability to EP. Although they discuss this in relation to state welfare reforms rather than precarious employment per se, it is plausible that their finding also applies to insecure work since income instability is a key characteristic of precarious employment. However, the key point is that for EP, precarious employment is likely to increase vulnerability primarily or wholly due to income restrictions, whereas for TP it is the *combination* of low-income with increased transport expenses that creates an especially heightened vulnerability.

4.1.4. Older people

After low-income*, older people* were the socio-demographic group most frequently identified in our systematic review sample (42% of EP, 26% of TP articles). Older people have long been recognised in academic research and policy discourse as a group vulnerable to EP, dating back to some of the original research on the topic in the UK [56,103,104]. This vulnerability is also evident in multiple other national contexts, including the USA [75], Poland, Czechia and Hungary [97], Croatia

[7] These categories are not mutually exclusive – rather, there is substantial intersection between the social groups listed (e.g., people with pre-existing health conditions may also have a low-income), which we discuss further below.

[8] Indeed, the direction of causality is partly that TP increases the risk of unemployment, rather than the other way around; that is, the inability to afford or attain adequate transport services can negatively impact a person's ability to obtain or maintain paid work [86,93,94]. It should also be noted that low-levels of travel among unemployed people, although reducing transport costs, can also result in people being excluded from society and unable to attend social and educational activities [91,95,96].

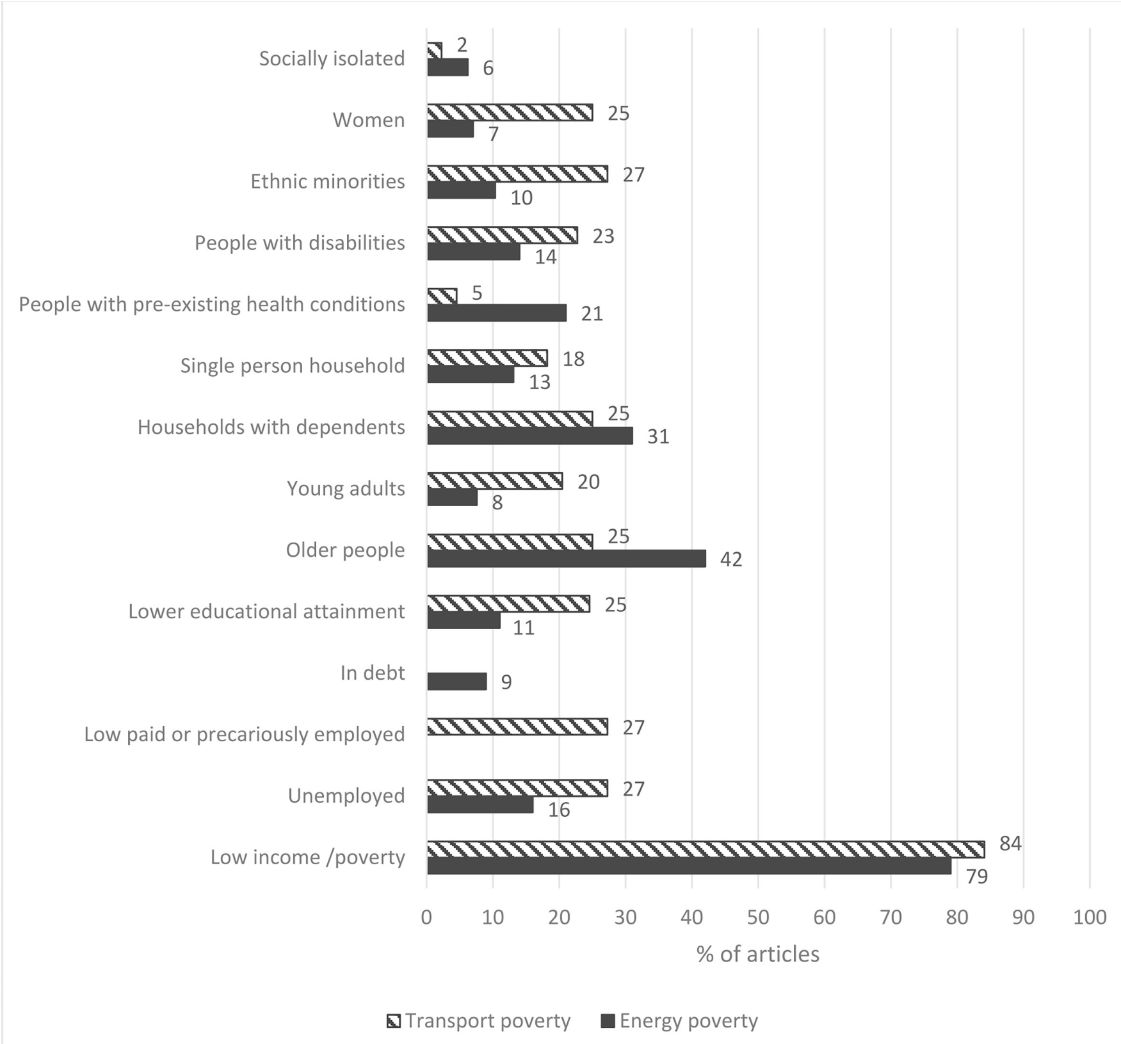

Fig. 2. *Percentage of articles in the systematic review samples identifying various socio-demographic groups as vulnerable to TP and EP* (Source: Authors) (Information for housing tenure is given in section 4.1.10 via Fig. 3.).

[105], Spain [76], and Australia [106].[9] Low-income can be one common cause of older people's vulnerability to energy poverty [75], with some research noting that single or widowed female pensioners can be particularly disadvantaged in this respect as they typically have smaller pensions and fewer savings [109–111]. Additionally, older people may have higher energy needs, such as a requirement to have the heating on for longer hours, due to them often spending more time at home than working-age adults and an increased likelihood of frailty and poor health [3,75,100,104,112]. Furthermore, they can experience barriers to investment in energy efficiency measures or 'smart' technologies, such as limited information, a lack of confidence, or uncertainty over the remainder of their lives [75,113,114]. They may also avoid seeking assistance even if living in a cold home or struggling with energy costs, due to a desire to avoid the stigma associated with 'old and frail' stereotypes [107] or simply not considering their circumstances to be problematic [100,114].

In the TP sample, older people did not appear as frequently but were still coded in over a quarter of the sample. Here, older people can be particularly vulnerable due to lower incomes, combined with decreased mobility (making 'active travel' such as walking and cycling a less feasible option) and higher reliance on public transport (sometimes due to 'car cessation', in which older people stop driving or have their licenses revoked) [13,96]. While a lack of ownership or use of a car does potentially bring financial savings, it can severely restrict the travel options of older people. This is especially the case among those living in relatively 'car dependent' societies, such as Australia and the USA, where public transport links are limited [13]. For example, one study in Perth, Australia, found that although older people were more likely to use public transport systems, they also tended to live in areas that had poor accessibility to such systems [96].

4.1.5. Households with children

Households with children were identified as a vulnerable group in 31% of EP articles and 23% of TP articles. Some articles also found that EP and TP vulnerability can be particularly heightened among households with multiple children and/or in single-parent households [66,71,105,115–120]. In both cases, this is partly because children bring additional expenditure on both energy and transport services. For TP, this can mean an increased requirement for journeys and, perhaps more significantly, more reliance on the car and thus 'forced car ownership' [89,120–122]. For EP, among families with children the energy

[9] It should also be noted that the very strong emphasis in academic and especially policy discourse on older people as vulnerable to EP has been critiqued in some literature, which has argued that it risks creating a narrow and stigmatising stereotype that equates EP only with the 'old and cold' and thus obscuring the vulnerabilities of other groups [1 0 7], [1 0 8].

consumption required to fulfil 'basic needs' (such as everyone keeping sufficiently warm) and for wider societal participation can be higher than the national average, therefore resulting in higher energy bills [63,84,108,112]. For example, households with children may need to heat multiple rooms, and have additional requirements related to appliance usage (more frequently washing clothes, running multiple ICT technologies for entertainment and schoolwork etc.). Additionally, households with children often have relatively stable routines (due to school hours, bedtimes etc.) that are difficult to change; this can exclude them from the benefits of off-peak tariffs and 'smart' appliances that can ostensibly lower energy costs [113,123].

4.1.6. People with disabilities

People with disabilities appeared more frequently in the TP sample of the systematic review (23% compared to 14% of EP articles), although in some cases, there was simply a brief recognition of this group as being 'vulnerable' to TP or having specific transport needs without much further elaboration [72,90]. This echoes some older literature that has suggested disability has received relatively little attention in TP studies, but that there is nonetheless general agreement that people with disabilities face more pronounced disadvantages in relation to transport [124]. For some, walking and cycling may not be viable modes of everyday transport [125], and people with disabilities can face barriers to using public transport due to inadequate accessibility and information provision [2,33]. Additionally, people with disabilities may struggle to afford the purchase and running costs of a private car, especially as they can experience extra cost burdens (e.g., vehicle modifications) and often have lower income levels than the general population – with these disadvantages being stronger among those with congenital or multiple disabilities, and with higher support needs for everyday living [33].

In relation to EP, people with disabilities have been proposed as an especially vulnerable group since some of the earliest research and policy work on the issue in the UK, including the initial 2001 Fuel Poverty Strategy [24,126,127]. Since then, other national governments have also recognised people with disabilities as vulnerable (e.g. [128,129]). However, there is surprisingly little empirical research that focus closely on the links between disability and EP. Exceptions to this are the studies of Snell et al. [99,130] in England, who found households that have people with disabilities or pre-existing illnesses (see also Section 4.1.7) were more likely to experience EP (see also [112]). The vulnerability of people with disabilities to EP is partly due to them being more likely to have a low-income due to insufficient state benefits and barriers to employment [26,112,131]. Like older people, people with disabilities may also have greater 'energy needs', such as a requirement to heat the home for longer hours, that raise their energy costs [24,112,131]. They may also face other additional expenditure requirements relating to their disability that further reduce their disposable income [4]. However, Gillard et al [108] note that people with disabilities are often treated as homogenous in EP research, with intragroup diversity ignored. In short, not all forms of disability will increase vulnerability to EP to the same degree, but there is a lack of research that seeks to unpack this heterogeneity [108].

4.1.7. People with pre-existing health conditions

People with pre-existing health conditions were only mentioned in a small proportion of TP articles (5%) compared to the EP articles (21%). Although ill health was mentioned in several papers, this was normally as a *consequence* rather than a cause of TP. One paper found that people with poor health can be dissuaded from walking and cycling for everyday travel [132], whilst another mentioned that people with mobility difficulties, which may include those with some chronic health problems, may be at increased risk of TP due to car dependency [92].

EP is widely acknowledged as having potentially negative consequences for people's physical and mental health [31,131,133], but there is also some evidence that certain pre-existing health conditions can increase the likelihood of a household experiencing EP. In particular, some illnesses require a relatively high and consistent room temperature to maintain comfort and treat symptoms, while others may be dependent on electricity to power medical equipment or other devices crucial to their well-being [26,99,100,130,134,135]. The mobility problems associated with some health conditions can also lead to a greater amount of time spent at home [100,114]. All of these factors, individually and in combination, can drive up household energy costs. 'Pre-existing health conditions' is a broad category that can mask heterogeneity, but there is evidence that people with illnesses relating to their circulatory and respiratory systems, and those with degenerative and terminal diseases, may be especially vulnerable to EP [100,114]. There is also some evidence, although less than that related to physical health, that suggests some mental health challenges can exacerbate EP by impinging on people's ability to manage the complexity of energy bills and engage with energy suppliers [131].

4.1.8. Women

Women were identified in the systematic review sample as at heightened vulnerability to both TP and EP; however, this occurred substantially more frequently in the TP sample (25% of TP articles, 7% of EP articles). The few EP studies that discuss or mention gender[10] do, however, provide evidence that women are disadvantaged and more likely to experience EP; therefore, the difference between the samples appears to be at least partly due to a lack of attention to gender in much of EP research [110]. In comparison, transport research has a relatively long history of more substantial investigation of gender inequalities. One possible reason for this is that, while EP has typically been studied as a 'household' phenomenon, transport accessibility problems often relate, to some extent, to individuals rather than entire households (i.e., one member of a household may experience it while others do not) [14]. As a result, TP research may have paid more attention to inequalities *within households*, thus exposing differential gender vulnerabilities.

For EP, several papers have found that households where women are the primary earner are vulnerable to EP because they typically have lower incomes due to structural disadvantage in labour markets [75,76,84,97,113,136–142]. For older women, lower wages from employment often equates to a smaller pension during retirement – as such, women of pension age have been noted as a group who are particularly vulnerable to EP, especially if they are single or widowed [75]. Furthermore, entrenched socio-cultural norms in many societies mean women typically spend a greater amount of time at home compared to men, and therefore if they are living in EP, they are more likely to experience its harmful symptoms and consequences (such as cold indoor temperatures and associated health effects) [110,143].

Lower income has also been mentioned as a factor increasing women's vulnerability to TP [90,144], alongside reduced access to car-based transportation due to gendered divisions of domestic labour [72]. At the same time as having less access to the car, women can also be more reliant on the car to make necessary journeys due to time constraints and traditional gender roles, such as family care, which tend to result in more fragmented travel patterns [145].

4.1.9. People from ethnic minorities

There is evidence of *people from ethnic minorities* being more vulnerable to exposure to EP and TP. However, in our systematic review sample, mention of this is relatively rare in both sets of literature (16% of TP articles, 10% of EP).

In terms of TP, research in the UK has found that problems of transport affordability and economic stress may be more prevalent among non-white households, which Mattioli et al. [92] suggest is primarily because they are more likely to be on a low-income. Additionally,

[10] We recognise that gender is not a binary construction and that there are more than two genders (beyond 'man' and 'women'). However, the articles in our sample approached gender as a binary.

recent migrants can face barriers to owning a personal car and using public transport due to being unfamiliar with a language and other taken-for-granted competences, including the ability to drive [146–149]. One study in the USA city of Buffalo also suggested that black and minority ethnic residents disproportionately live in areas with poor access to public transportation networks [138].

For vulnerability to EP, most evidence of ethnic and racial inequality comes from studies focused on United States. Here, research has found that non-white populations, notably Black and Hispanic people, have an increased likelihood of experiencing the problem [66,115,116,135,138,150]. This is attributed to a combination of lower incomes [138] and occupation of poor quality, less efficient dwellings in the private rented sector resulting from racialised residential segregation and discrimination [66,115,138,150]. Ethnic minority populations have also been reported as being at greater risk in the UK [74,151,152], Aotearoa New Zealand [153,154], and in some parts of Europe [56,81,137,155,156]. However, the underlying reasons for this increased exposure risk are often not fully explored or explained and requires further examination in future studies.

4.1.10. Housing tenure

Finally, we also coded for *housing tenure* type, and here we found clear differences between the TP and the EP literature. As Fig. 3 shows, specific tenure types are identified as vulnerable much more frequently in the EP literature compared to TP. This may suggest that tenure is simply a less important dimension of vulnerability to TP compared to EP. Indeed, there is good evidence that poor housing quality and inadequate energy efficiency is strongly related to tenure. Studies in several countries have found that homes in the private-rented sector, especially those marketed for low-income households, are disproportionately likely to have low levels of energy efficiency [28,66,74,157,183]. Low-income tenants often face restrictions on undertaking energy efficiency improvements, due to limited rights and split-incentives with property owners [65,76,138,157].

In contrast, the links between tenure and TP are less obvious, and are perhaps more indirect (such as when homeownership is associated with relocation to the suburbs and associated 'forced car ownership' [158]). However, a recent qualitative study by Mullen et al [102], involving interviews with 46 people on low-to-middle incomes in England, found that insecurity of housing tenure for those living in the private-rented sector can act as an incentive for car ownership and use. In their study, some participants were reluctant to give up the car because of uncertainty over whether they would be forced to move home to a location where a car would be essential for work and travel (ibid.). Further research is required to understand the generalisability of these findings, but it does suggest that for some housing tenure can be an important influence for TP.

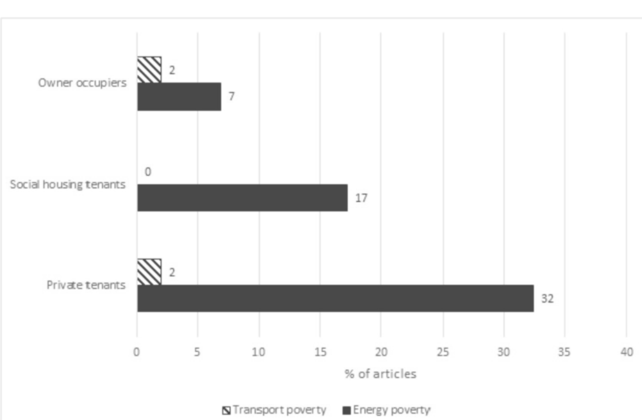

Fig. 3. *Percentage of articles in the systematic review sample identifying different tenure types vulnerable to TP or EP* (Source: Authors).

4.1.11. Summary of socio-demographic vulnerabilities

In summary, there are several overlaps in the socio-demographic groups identified as vulnerable to EP and TP, even though there are some differences between the literatures regarding the frequency that certain groups are identified as vulnerable. For both EP and TP, a common thread that underpins the vulnerability of all these groups is that they are disproportionately likely to have a low-income, due to a variety of structural disadvantages. Therefore, they are at greater risk of experiencing EP and TP partly due the financial constraints mentioned above. This lack of financial resources may intersect with social, cultural, or physiological contingencies to create additional and compounding vulnerabilities. Table 3 below synthesises the main findings of this section.

4.2. Spatial vulnerabilities

Our analysis in this section focuses on vulnerability in relation to four forms of spatial categorisation – urban, suburban, rural areas, and towns. We use these categories because these were the ones used in the vast majority of the literature surveyed. We recognise that other forms of spatial differentiation may also be relevant, such as those relating to climate (particularly for EP), but here we retain those that are both most widely used and relevant to both EP and TP.

Fig. 4 shows the percentage of articles in the systematic review that identified people living in different spatial locales as vulnerable to TP or EP, respectively. Some initial and overarching observations can be made. Similar proportions of articles in both samples identify residents of *urban* and *rural* areas as vulnerable, with urban areas identified slightly more frequently by EP articles, and rural areas slightly more frequently by TP articles. Most striking is that a much greater proportion of TP articles explicitly identify people living in *suburban* (also termed 'peri-urban') areas as especially vulnerable. The category of *towns* is relatively rare in both samples, but is again proportionally more frequent in the TP sample. We now explore the reasons for these various complexities in more detail.

4.2.1. Urban areas

A larger proportion of EP articles (37%) than TP articles (25%) identified those living in *urban areas* as vulnerable. More specifically, it was usually those living in 'inner city' areas (the residential neighbourhoods surrounding the central urban core) [69,89,120,138,159,160]. Articles in both samples identified some shared factors that contribute to urban vulnerability to both EP and TP. Housing costs (rents and mortgages) are often higher in the central and inner areas of major cities, leaving households with less disposable income with which to pay for transport and energy costs [73,97,112,125,152,160]. Additionally, patterns in the residential location of different social groups – what have been termed 'socio-spatial configurations' [161] – mean that in some contexts, several of the disadvantaged groups identified in Section 4.1 tend to concentrate in inner-urban areas. This is most notable in relation to low-income households[11] [69,78,79,89,92,97,120,138,162,163,164], but ethnic minority and immigrant households, those living in rental housing and/or with transient and precarious housing arrangements, and families with young children, have also been identified as predominantly residing in urban spaces [74,89,112,126,138,140,150,157,165,166,167]. In some contexts, this patterning may not hold – see discussions in Sections 4.2.2 and 4.2.3.

However, beyond the shared factors of high housing costs and the spatial patterning of poverty and disadvantage, there are also some notable differences between TP and EP in urban areas – particularly regarding material and infrastructural factors. For TP the material

[11] This has been noted as the case in the England [20], [73], [92], [89], Canada [69], [1 2 0], USA [1 3 8], [1 6 2], South Korea [1 6 3], Greece [78] and Spain [79], [1 6 4].

Table 3
Summary of vulnerability factors for different socio-demographic groups to EP and TP.

Social group	Vulnerability factors for EP	Vulnerability factors for TP
Low-income	Less money to pay for energy costs More likely to live in a dwelling with poor energy efficiency *(context dependent)* Less able to undertake domestic energy efficiency improvements	Less money to pay for transport costs Less likely to own a car If owning a car, unlikely to be the newest and most fuel efficient model
Unemployed	More likely to have a low income Increased time at home results in greater energy needs and costs	More likely to have a low income
Precariously employed	More likely to have a low income	More like to have a low income Spatial and temporal fragmentation and insecurity of work increases car dependency and transport costs
Older people	More likely to have a low income May face barriers to investing in energy efficiency or 'smart' technologies Greater energy needs due to time at home and physiological factors lead to higher energy bills	More likely to have a low income Decreased mobility makes 'active travel' difficult Losing driving license may restrict travel options, especially in 'car dependent' areas
Households with children	Greater energy needs lead to higher energy bills Fixed routines can present barriers to 'smart' technologies Single parents more likely to have a low income	Increased requirement for journeys and more dependence on a private car increase transport costs Single parents more likely to have a low income
People with disabilities	More likely to have a low income Some conditions may require greater use of energy (e.g., longer use of heating at higher temperatures, or specialist equipment)	More likely to have a low income Some disabilities may impair mobility and make the use of lower-cost transport modes (walking, cycling, public transport) more difficult
People with pre-existing health conditions	More likely to have a low income Some conditions may require greater use of energy (e.g., longer use of heating at higher temperatures, or specialist equipment)	More likely to have a low income Some conditions may impair mobility and make the use of lower-cost transport modes (walking, cycling, public transport) more difficult
Women	More likely to have a low income Tend to spend more time at home due to traditional gender norms	More likely to have a low income More likely to have fragmented travel patterns due to traditional gender norms, which can increase car dependency
Ethnic minorities	More likely to have a low income More likely to live in a dwelling with poor energy efficiency	More likely to have a low income Socio-cultural barriers to public transport use and car ownership In some contexts, may live in areas with poor access to public transportation networks

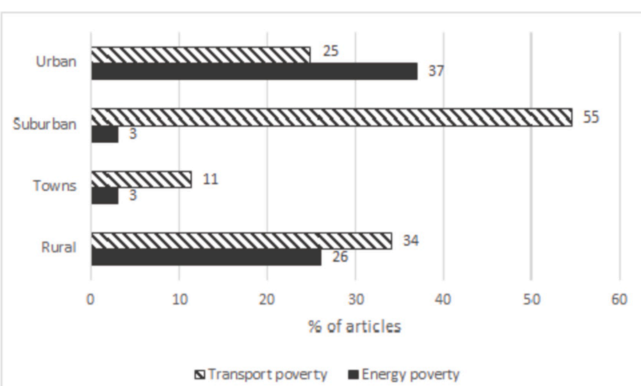

Fig. 4. *Percentage of articles in the systematic review sample identifying different spatial settings as vulnerable to TP or EP* (Source: Authors).

characteristics of urban areas tend partly alleviate and offset, rather than reinforce, vulnerability caused by low-income or other socio-demographic factors. This is because inner urban areas generally have more frequent and accessible public transport services in comparison to rural and suburban locales, and closer proximity to key services (e.g., shops, schools, workplaces, medical facilities) also means that walking and cycling can be more viable travel options [14,69,70,73,92,168].[12] Contrastingly, for EP, socio-demographic vulnerability is often *reinforced* by the infrastructural features of disinvested urban neighbourhoods. Inner-city urban housing tends to be older, and has often experienced decades of disinvestment and lack of maintenance by public authorities – as such, it tends to have relatively poor energy efficiency and is typically lived in by low-income and disadvantaged urban residents [65,74,81,97,138,164,169]. A lack of space, physical barriers, and restrictive tenancy relations for renters can also make installing micro-renewables or insulation more challenging in urban environments [82,138,142,170,171]. The 'urban heat island effect' also means that summer temperatures and heatwaves are stronger in urban spaces, contributing to EP vulnerability in terms of space cooling [3,77,162,172–175]. On the other hand, urban housing is frequently high density (which acts as a form of insulation) and terraced housing often has access to lower-cost heating infrastructure such as natural gas or district heating networks. These factors can partly alleviate EP vulnerability [20], but it should also be noted that apartment buildings (another common housing type in central urban areas) can also be reliant on expensive electric or solid-fuel heating [74,97,99,112,163].

4.2.2. Suburban areas

People living in *suburban areas* were identified as vulnerable much more frequently in TP articles compared to EP articles (55% to 3%). The vast majority of EP articles did not mention suburban areas, and tended to talk about 'urban' spaces as a homogenous whole without further disaggregation. In contrast, suburban areas were explicitly identified and mentioned in many TP papers. A key reason for this difference may be that the material features of suburban localities tend to more strongly increase vulnerability to TP than EP. Across multiple contexts it has been found that suburban areas often have more infrequent and fragmented public transport systems compared to inner-city neighbourhoods [73,86,96,120,125,168], as well as longer travel distances to key services [70,91,160,176,177]. These factors increase journey times and induce car dependency, therefore raising transport costs and vulnerability to TP. In some contexts, these material disadvantages can be reinforced by the socio-spatial configurations of income-poverty – for example, in Australia, France and Aotearoa New Zealand suburban areas tend to have lower average incomes than more central urban locales

[12] There are some important caveats to this general picture. The urban environment can be viewed as risky and unsafe for walking and especially cycling due to a lack of appropriate infrastructure such as cycle lanes and footpaths, and this can offset benefits relating to shorter travel distances [1 2 0], [1 7 7]. Furthermore, a minority of nominally 'urban' areas may still have poor access to shops and local services [1 6 0], and public transport systems do not necessarily connect people to their desired destinations [89], [1 7 8].

[41,87,178,179]. It is thus not surprising that several of the articles we sampled which identified those living in suburban areas as most vulnerable to TP were based in these national contexts.

The few articles in our EP sample that did explicitly identify suburban locales as vulnerable were based in Aotearoa New Zealand [180] and France [181], where older social housing for low-income households is often located on the outskirts of cities. One study in Central and Eastern Europe also found that some suburban low-income housing estates can lack access to networked heating provision [81], whilst another based in Hungary mentioned the presence of older detached homes in suburban areas that are extremely energy inefficient [182]. However, the evidence we reviewed suggests that, contingent on the broader national and regional context, the built environmental features of suburban areas seem to less strongly and consistently create vulnerability for EP compared to TP. In some contexts, housing in suburban areas is often newer (and so potentially more insulated/energy efficient), can be easier to retrofit with micro-renewables and energy efficiency measures compared to apartments or terraced housing, normally has access to lower-cost heating networks, and typically houses middle and higher-income residents [20].

4.2.3. *Rural areas*

A slightly greater proportion of TP articles (34%) than EP articles (26%) identified living in *rural areas* as a potential source of vulnerability. Current evidence indicates these are the settings where there is most overlap in vulnerability to EP and TP.

In terms of EP, rural areas can have a number of infrastructural disadvantages contributing to vulnerability. They often lack access to nationalised or local networked heating infrastructures (namely natural gas), leaving households reliant on significantly more expensive heating fuels such as electricity, oil, coal, LPG or other 'solid fuels' – this is a factor of relevance in multiple national and regional contexts [99,105,112,143,157,182–193]. Several studies in very isolated mountainous areas of northern Greece have also found that the longer travel distance to deliver oil can further increase prices [171,194–196]. Due to less developed and resilient electricity and transport infrastructure, security of supply for electricity and heating fuels can also be problematic in isolated rural areas leading to an increased risk of power cut-offs during periods of bad weather [50]. Additionally, homes in rural areas are also more often standalone and detached houses, which are more expensive to heat due to their greater size and higher surface-to-volume ratio [97,112,184,187,185,197,198]. In many cases they may also be older, 'solid wall' buildings that lack insulation, and can be challenging to insulate due to the financial costs involved and restrictive planning laws [50].

For TP, rurality can strongly increase vulnerability due to declining availability of local goods, services and employment opportunities, which increases travel requirements and associated financial and time expense [90,95,199,200]. Combined with more fragmented and infrequent public transport provision, this can result in difficulties in accessing key services, and affordability problems resulting from car dependence [14,92,148,201,202].

Overall, rural areas often have environmental and infrastructural characteristics that can increase vulnerability to both TP and EP. This is in contrast to urban and suburban areas, where the physical environment and infrastructure tends to predominantly increase vulnerability to one problem but not the other. In some contexts, the environmental vulnerabilities of rural areas may be offset by the fact that rural households tend to be more affluent – some TP studies note this is the case in parts of England [71,92]. However, in other contexts rural areas can actually have lower average incomes that urban areas, due to a lack of employment opportunities and a reliance on insecure, seasonal and part-time jobs (see, for example, [50,97,114,137,178,203,204].[13] Such economic deprivation can further reinforce infrastructural disadvantages, leaving such areas highly vulnerable to both EP and TP.

4.2.4. *Towns*

Towns is a somewhat ambivelant category, having shared characteristics with both rural and urban areas. As mentioned, towns were also identified as vulnerable much less frequently in both samples, occurring in 11% of TP articles and just 4% of EP ones. From the few papers in our sample that did refer to these settings, it was evident that they are vulnerable for some of the same reasons as rural areas. Namely, a relative lack of economic opportunities (resulting in lower incomes), longer journey times to access workplaces and some key services (leading to greater transport costs and/or accessibility challenges), a more fragmented and infrequent public limited public transport system in comparison to larger cities, and homes that are not connected to a low-cost heating network [90,135,144,201]. While residents of towns are more likely than rural households to be connected to gas heating networks (lowering heating costs and reducing vulnerability to EP), depending on settlement size and national context residents of some towns may still be reliant on expensive 'off-grid' fuels [74,81,186,191].

4.2.5. *Summary of spatial vulnerabilities*

Whereas in Section 4.1 we found several overlaps in the socio-demographic groups vulnerable to EP and TP, when examining the spatial dimensions of vulnerability a greater degree of difference between the two problems is evident. There is also more complexity as the spatiality of vulnerability is more variable between different national and regional contexts (the spatial patterning of vulnerability to TP and EP is somewhat different between Australia and the USA, for example). Table 4 synthesises the main findings of this section and highlights some of these contextual contingencies.

Overall, it seems that *in general and in most contexts,* inner-urban residents are more vulnerable to EP than TP, as patterns of socio-demographic vulnerability combine with features of the built environment. For TP, the inner-urban environment can to some degree offset socio-demographic vulnerability, but simplistic assumptions that TP can *never* occur among urban residents should be avoided [89,147]. The picture is different when considering suburban areas, where there appears to be a stronger vulnerability to TP. Isolated rural areas are the geographical settings where there is most often overlap in vulnerability to TP and EP – for both problems, a lack of access to networked and modern infrastructure (low-cost heating and public transport) leads to a reliance on more expensive travel and heating options [20]. As we discuss further in Section 5, however, neither EP or TP should be considered an *exclusively* 'rural' or 'urban' issue, with the literature highlighting cases of both that occurs across this broad spectrum.

[13] Specifically, this has been noted as increasing rural vulnerability to energy poverty in Belgium [197], southern Spain [137], southern Italy [128], Hungary [97], mountainous regions in northern Greece [194] and Croatia [105], Poland [184], the English region of Cornwall [204], Wales [50,187], Scotland [114,131], and New Zealand [205], and transport poverty in Australia [178,203], and Great Britian [72]. Studies in England [112] and Central and Eastern Europe [206] have also found that older people (another vulnerable socio-demographic group) tend to live in rural locations.

Table 4
Summary of vulnerability factors for different spatial settings to EP and TP. (+) indicates a factor that increases vulnerability, (−) indicates a factor that decreases vulnerability.

	Energy poverty	Transport poverty
Urban	(+) Higher rates of income poverty *(context dependent – applicable to* e.g.*, UK and USA)* (+) Higher rates of PRS and older housing (+) Higher housing costs (+) Frequent reliance on electric heating in apartment buildings (−) High rates of connection to gas network in houses	(+) Higher rates of income poverty *(context dependent – applicable to* e.g.*, UK and USA)* (+) Higher housing costs (−) Better public transport provision (−) Closer proximity to services
Suburban	(+) Higher rates of income poverty *(context dependent – applicable to* e.g.*, Australia and France)* (−) Higher average incomes (*context dependent – applicable to* e.g.*, UK and USA*) (−) Higher rates of homeownership & relatively newer housing (−) High rates of connection to gas network	(+) Longer distance to some services (+) More infrequent and fragmented public transport provision (+) Higher rates of income poverty *(context dependent – applicable to* e.g.*, Australia and France)* (−) Higher average incomes (*context dependent – applicable to* e.g.*, UK and USA*)
Rural	(+) Lack of connection to gas network (+) Higher rates of detached homes (+) Higher rates of under-occupation (+) Higher rates of income poverty *(context dependent – applicable to* e.g.*, Hungary, Australia)* (−) Higher average incomes *(context dependent – applicable to* e.g.*, UK and USA)* (−) Higher rates of homeownership	(+) Infrequent and fragmented public transport provision (+) Longer distance to multiple services (+) More expensive motor fuels (+) Higher rates of income poverty *(context dependent – applicable to* e.g.*, Hungary, Australia)* (−) Higher average incomes *(context dependent – applicable to* e.g.*, UK and USA)*

Source: Authors.

5. Identifying double energy vulnerability

We now reflect on the implications of the above findings for our second research question: what social groups and geographical settings are most vulnerable to experiencing EP and TP *simultaneously*, and so at increased risk of exposure to DEV? Overall, although there are some differences in the groups vulnerable to each problem, our results reveal that there is also a substantial degree of overlap – and it is at these overlaps where there is a heightened risk of DEV.

For both EP and TP, the most frequently identified factor that increases vulnerability was having a low income, with the vast majority of articles in both samples pinpointing this as a driver of vulnerability. This indicates that financial income is a central component of both problems and that, generally speaking, low-income households are at greater risk of experiencing DEV compared to the general population. There are, however, also some nuanced differences between TP and EP. People in low-wage and insecure employment are especially vulnerable to TP, whilst those who are unemployed are more vulnerable to EP. Alongside a low-income, there are several other socio-demographic groups that are rendered vulnerable to both EP and TP. These include: people with pre-existing health conditions and/or mobility difficulties; households with children or dependents (especially single-parent households); ethnic minorities; and women. For all these groups, social, cultural and/or physiological factors can result in specific and increased needs and costs in relation to transport and domestic energy. These factors can heighten vulnerability to EP and TP independently of whether a household or individual is on a low-income, but in reality they are often combined with financial hardship. In short, as well as often having greater energy and transport needs and costs, all these groups are also disproportionately likely to be on a lower income due to structural discrimination in labour markets and economic systems. Multiple disadvantages combine, compound and intersect [206] to create an especially heightened risk of experiencing DEV.

Spatially, EP and TP are both problems that occur in urban and rural areas alike (although in potentially different ways). Nonetheless, the literature we surveyed does indicate that *rural* locations are generally the areas where there is the greatest likelihood of overlap between EP and TP. However, although a broad urban-rural distinction is often used in the literature we surveyed, care should be taken to avoid thinking about vulnerability in 'urban' and 'rural' areas in homogenous and deterministic terms. There were some studies in our review that found residents of nominally 'urban' neighbourhoods who were nonetheless rendered vulnerable to energy and transport poverty due to inadequate infrastructure, such as a lack of access to public transport networks, long travel distances to services, a reliance on expensive heating fuels, and a disinvested and inefficient housing stock. The key factor is the extent to which an area is *spatially peripheralised* – that is, excluded from or marginal to key infrastructures and provisioning systems, as a result of unequal power relations, symbolic denigration and a lack of political-economic investment [50,207]. As O'Sullivan et al [52] note, whilst in many contexts rural areas are frequently peripheralised in this manner, this is not a 'natural' feature of such spaces but is rather the product of uneven development and the social construction of space (see Section 2). The urban/sub-urban/rural distinctions outlined above are thus about *risk* and likelihood, rather than simple determinism.

Overall, therefore, our analysis would indicate that the greatest level of DEV is among households that face a combination of multiple, intersecting socio-demographic disadvantages alongside a high degree of spatial peripheralisation. This relationship is illustrated conceptually in Fig. 5. The written examples within Fig. 5 are non-exhaustive but aim to demonstrate how an individual or household's socio-spatial positioning influences their likelihood of experiencing DEV. This finding

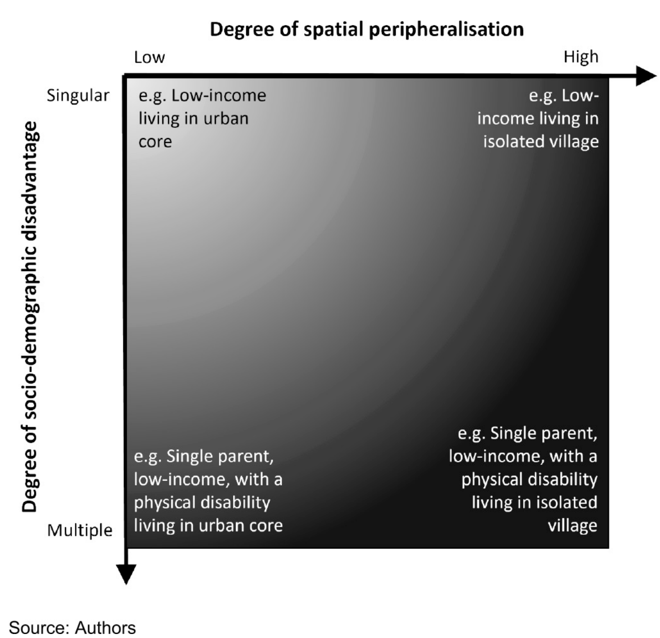

Fig. 5. Conceptual representation of risk of exposure to double energy vulnerability (n.b. darker shading illustrates higher risk).

would suggest that DEV is likely to be especially common in national and regional contexts in which disadvantaged households are disproportionately concentrated in peripheral (typically rural) localities, such as Wales, Australia, France, and much of Eastern Europe.

6. Conclusion

To date, little research has focused on the intersection between domestic energy poverty (EP) and transport poverty (TP). This paper, based on a systematic and narrative review of 250 academic peer-reviewed journal articles, has therefore provided new insights into the groups most vulnerable to experiencing EP and TP simultaneously.

In synthesising our main contributions and drawing towards policy and research recommendations, we offer some core observations. Many of the socio-demographic groups identified as vulnerable to TP and EP are often also at increased risk of exposure to multiple other social and environmental hazards (e.g. [208,209]). Likewise, in peripheralised spaces increased vulnerability to energy and transport poverty often occurs alongside and in combination with many other systemic place-based disadvantages, such as political marginalisation and economic disinvestment [50]. Wolff and de-Shalit [210] use the term "clustering of disadvantage" to describe how certain groups in society encounter discrimination and exclusion in multiple facets of social life, leading to compounding and accumulated impacts on their well-being and life chances. Our findings show that EP and TP can be added to this wider set of injustices experienced by already disadvantaged sections of society. Echoing literature on the political-ecology of vulnerability [44], such overlaps also suggest that vulnerability to EP and TP is deep-rooted and produced through structural inequalities in societies, including systemic income poverty and insecurity [211]. Further, processes of energy poverty and transport poverty and their associated vulnerabilities can also be circular and mutually reinforcing, whereby unaffordable or inaccessible transport contributes to a precarious ability to attain domestic energy services, and vice-versa [14,50,212]. This is a significant factor in sustaining situations of DEV and one that can contribute to the reproduction of structural inequalities – for example through limiting educational and work opportunities. These overlaps and interrelations make such challenges very difficult to resolve, but all the more imperative.

The core findings of this research therefore carry significant policy relevance. Policy makers need to recognise that energy and transport poverty can, and do, overlap and intersect. The multiplicity of underlying causes and groups rendered vulnerable means that tackling DEV requires *both* targeted and structural measures. This necessitates a cross-sectoral approach involving policy makers and stakeholders in housing, energy and transport planning, among others, and at all levels of government. As many of the processes underpinning vulnerability to EP and TP are structural in nature, addressing each problem (and DEV) likewise requires a focus on tackling deep-rooted inequalities in relation to class, race, gender, age and disability. For example, a strong policy focus on investing in and creating well-paid, stable, secure and long-term 'green jobs' as part of a green recovery [213,214], particularly in the communities that need it most, could assist the low-income, unemployed and precariously employed groups that are currently rendered vulnerable to DEV. At the same time, the identification of particular places as especially vulnerable to either EP or TP also suggests the possibility of more targeted and tailored interventions at more localised scales.

It has been noted that low-carbon transitions risk exacerbating both EP and TP [17]. However, there may also be opportunities for such transitions to help address and reduce DEV if concerns around equity and fairness are fully incorporated into their design and operation. In accordance with our findings on spatial vulnerabilities being a fundamental component of DEV, we argue that targeted policy interventions should focus on the provision of low-carbon networked infrastructures to those spaces and places that have been largely neglected by previous policy regimes. This could be done by 1) expanding networked energy and transport infrastructures to those households, communities and areas that are lacking access to core energy and transport services, and 2) ensuring that this expansion of energy and transport infrastructures is consistent with the aims and goals of the low-carbon transition, drawing on, for example, low-carbon energy generation sources, 'active' travel, and low emissions vehicles for energy access and transport service needs respectively. While we note that housing, energy and transport stakeholders are crucial to the delivery of such targeted interventions, tailoring such policies to local communities requires extensive consultation with affected groups, to understand their needs, aspirations and visions for their own communities. These 'place-based' approaches are gaining traction in policy, with 'place-based solutions', for example, featuring as a strategic priority in the UK's latest transport decarbonisation strategy [215], alongside energy poverty schemes in Wales [216] and Scotland [217] that advance an area-based method to the rollout of energy efficiency measures in low-income households. Tailored and targeted policy interventions to address DEV should be mindful of such area-based approaches, recognising the need for spatial justice in those communities that have been 'left behind'.

Our analysis has also revealed numerous areas for future research. First is the necessity of giving voice to marginalised sectors of society. This includes those with disabilities, people on low-incomes, recent migrants, women, and ethnic minority groups – whilst also recognising the enormous diversity within such categories. For example, disabilities are heterogeneous and variously increase vulnerability to EP or TP, though this nuance is rarely examined or discussed in social scientific research. Similarly, given the relatively small number of articles that even mention or seek to examine racial and ethnic inequalities in relation to both EP and TP, there appears to be a clear need for further research in this area – particularly as this is perhaps indicative of the under or non-recognition of a particularly disadvantaged sector of society [219]. Third, given the various differences and overlaps in EP and TP discussed throughout our paper, we require further, specialist empirical work to confirm and develop deeper understandings of their interrelations, including in countries of the Global South. As exemplar variables, this includes a further insight into the tensions and trade-offs between car dependency, energy unaffordability and low-incomes. Fourth, we require spatial analysis at a fine-grained scale that reveals the complex socio-spatial configurations of exposure to EP, TP and DEV, including their emergence in concentrated 'pockets', particularly if we are to make the targeted, context-specific recommendations alluded to above. In this regard, it important to note that the spatial categories employed in this review ('urban', 'rural', 'suburban', 'towns'), whilst the classifications employed in the literature, are generalised and 'broad-brush' and so may mask considerable complexity and inequality at a finer-scale of analysis (not all 'rural' areas are the same, for example). Further research, perhaps involving in-depth qualitative methods or tailored surveys, could investigate some of these complexities. Finally, more research is required on the possible tensions and causal linkages between EP and TP – for example, whether exposure to one problem may increase vulnerability to the other, and how households experiencing both issues simultaneously make trade-offs and compromises in their everyday lives.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: We note that G.M. has a research consultancy role via the University of Sussex as part of a larger research project funded by the Centre for Research into Energy Demand Solutions.

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