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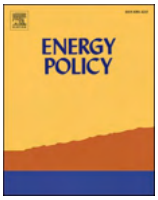

What causes energy and transport poverty in Ireland? Analysing demographic, economic, and social dynamics, and policy implications

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ABSTRACT

Energy and transport poverty have been postulated as conditions linked by overlapping causal factors such as structural economic inequality or housing stock and affecting overlapping demographics such as family size or income. The strength of the overlap of these conditions and their causal mechanisms has not been assessed across Ireland prior to this study. We apply and analyse existing and novel energy and transport poverty metrics in a survey of 1564 participants across Ireland and consider results from expenditure and consensual data examining causal mechanisms and correlations. We find that energy and transport poverty rates are broadly similar across Ireland at approximately 14% for energy poverty and 18% for transport poverty using the half-median metric, while participant knowledge of causal factors, such as lack of domestic energy efficiency and perceived desirability of potential poverty solutions, such as increased public transport provision, are low. Furthermore, we find that self-reported data concerning energy and transport expenditures and preferences do not correspond to expected outcomes. We thus conclude that ever refined targeting of individuals and households for support measures is not optimal for either decarbonisation or alleviation of energy and transport poverty conditions and suggest some salient policy implications.

1. Introduction

Energy and transport poverty can co-occur and reinforce each other leading to a "*double energy vulnerability*". Historically, energy and transport poverty were treated as different problems with their own causes and consequences (Simcock et al., 2021). Recently, however, it has been postulated that these conditions are not distinct and have overlapping causes and links (Mattioli et al., 2017). One of the key characteristics of this double energy vulnerability is that it could force individuals or groups of individuals to choose which service to prioritise, for example, choosing between heating the home or paying for school transport (Sovacool and Furszyfer Del Rio, 2022).

This dichotomic issue ought to take more policy relevance. It has been shown that as many as 6% of neighbourhoods, or 3 million people in England, are at risk of "double energy vulnerability" clustered in isolated rural areas, due to a lack of both energy and transport infrastructure (Robinson and Mattioli, 2020). The current energy crisis is expected to place enormous pressure on households and public services during the winter of 2022 (Bolton and Stewart, 2022) (Torjesen, 2022). We position our research focused on the extent of energy and transport poverty and their causal mechanisms with a view to uncovering routes to their alleviation across the Island of Ireland.

The literature has defined fuel (or energy) poverty as the inability to secure materially and socially-necessitated energy services, such as heating a home or using appliances (Bouzarovski and Petrova, 2015). This lack of energy provision results in a range of physical health, mental

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health and social impacts, including increased risk of circulatory and respiratory disease, increased social isolation and thousands of excess winter deaths annually (National Audit Office, 2003) (Rudge and Gilchrist, 2005) (Marmot Review Team and Friends of the Earth, 2011). Those most vulnerable to energy poverty are those least able to adapt to it, i.e., low-income households with children, the elderly, and the disabled, or those whose pre-existing health vulnerabilities are most acutely exacerbated (Bednar and Reames, 2020). Assessing energy poverty typically takes the form of either expenditure measures, where energy expenses are measured against a certain threshold, or via consensual measures, which assess the subjective lived experiences of households to determine poverty. Concerning expenditure measures, either *modelled expenditure* or *need to spend* (to maintain a certain heating regime) is used, such as with the widespread *10%* metric (where household expenditure on energy exceeds 10% of their income after deductions), or actual spend, such as in the *half-median* metric (where household expenditure on energy is less than half the sample median) (Thomson et al., 2017), can be used.

Transport poverty, meanwhile, deals with the lack of mobility services necessary for participation in society, resulting from the inaccessibility, unaffordability or unavailability of transport (Lucas et al., 2016; Mattioli et al., 2017; Mullen and Marsden, 2016). Depending upon the definition, up to 90% of households may be affected by transport poverty (Lucas et al., 2016). The consequences of transport poverty are no less severe than those of energy poverty, given the increased likelihood of low-income and marginalised groups being exposed to transportation-related air pollution, violence, sexual harassment and crime (Furszyfer Del Rio and Sovacool, 2023). Other effects include restricted access to employment and the increased difficulties posed to the disabled (Lucas et al., 2016). Transport poverty metrics focus on one of the aspects of inaccessibility, unaffordability or unavailability of transport that were outlined by Lucas et al. (2016). However, as there is no standard definition of transport poverty, the metrics applied are not (yet) as sophisticated as those in the energy poverty domain.

Assessments of causal mechanisms and options for the alleviation of energy poverty are scarce but increasing in number. For example, one recent study has assessed the causal instruments of energy poverty in eleven countries, while another has examined the global potential for alleviating energy poverty with renewable energy (Rao et al., 2022) (Zhao et al., 2022). Such assessments are also increasing in the transport poverty literature, for example, with recent studies examining the relationship between income and commute satisfaction in China and the accessibility of public transport in Oslo (Shi et al., 2022) (Lunke, 2022). Furthermore, studies are also increasingly paying attention to these issues as a joint subject, for instance, recent work in Iceland concerning the lived experience of energy and transport poverty (Upham et al., 2022).

Assessing transport and energy poverty together, however, is not a simple task. Research in this area has concluded that measuring these problems poses a key challenge for researchers and impacts real-world outcomes (Mattioli et al., 2017). Challenges for uniting their measurement begin with the unit of measurement; *households* are energy poor while *individuals* are transport poor. Furthermore, while there are standards for household energy use, there are no standards for transport use. To compound this issue, a problem arises as to which comes first, data collection or metric definition, which creates the common chicken and egg problem. Additionally, no single metric captures all aspects of either condition, so using multiple metrics simultaneously is required for a more complete picture. The introduction of vulnerability lenses, i.e., assessing who is more likely to be vulnerable to each condition, is less technically challenging than measurement. We have argued in previous work that this ought to be used in conjunction with energy or transport poverty metrics (Lowans et al., 2021).

Of contextual relevance is the Covid-19 pandemic. The Covid-19 pandemic had a profound impact on energy consumption in 2020, causing demand to contract by 5% (International Energy Agency, 2020). Beyond consumption, the Covid-19 pandemic has been noted to have implications for energy justice, energy poverty, and transport poverty (Sovacool et al., 2020). However, the pandemic also has been noted to create opportunities for sustainable responses (Griffiths et al., 2021). Consequently, a more thorough understanding of the impacts of the pandemic at the household level is required to assess the impacts of the pandemic and the opportunities arising from it.

This research examines the Island of Ireland, which is comprised of 2 distinct political and legal jurisdictions, yet shares a common market for electricity, in addition to many areas of economic interdependence allowing for the comparison of causal factors. The Island of Ireland has a large proportion of rural dwellers (a demographic known to be vulnerable to energy and transport poverty), yet no assessment of energy and transport poverty as a joint issue exists for either jurisdiction. Furthermore, assessments of energy and transport poverty are not up to date in either jurisdiction; we, therefore, aim to be more comprehensive with recent empirical and original data.

To fill data gaps and examine the intersections between energy and transport poverty and the decarbonisation of the energy and transport systems, we conducted a nationally representative survey (n = 1564) with participants from the Island of Ireland. This work is the first cross border study across the Island of Ireland, which examines the conditions of energy and transport poverty simultaneously to inform future research on decarbonising each area in a just manner which is of particular importance given the ongoing energy price crisis.

This paper has three aims, which are presented here and examined in Sections 4 and 5.

1. Assess and record self-reported expenditures on energy and transport services and use these and other collected data to assess contemporary energy and transport poverty on the Island of Ireland.
2. Assess the strength of the causal mechanisms of these conditions and assess their overlap.
3. Analyse how the Covid-19 pandemic affected energy and transport usage.

The outcomes and conclusions of this research will be useful to researchers and practitioners seeking to alleviate energy and transport poverty, individually or as a joint issue.

The article proceeds as follows. First, we begin by outlining the context of energy and transport trends across the Island of Ireland. Second, we discuss our research design and subsequently present our results and discuss them. Last, we derive conclusions from our findings and suggest some policy implications of these findings.

2. Contextualising energy and mobility trends and energy and transport poverty in Ireland

As remarked in the introduction, insufficient provision of modern energy and transport services contributes significantly to deprivation across the developed world. Considering energy in Northern Ireland (NI) first, the latest House Condition Survey showed that in 2016, 22% of households in NI were in fuel poverty[1], decreasing to 18% in 2018 due to a reduction in fuel prices (Northern Ireland Housing Executive, 2016). According to this official data, energy poverty data in NI is based upon *modelled* expenditure, which ignores actual spending patterns, exposing a data gap. In the Republic of Ireland, energy poverty rates are calculated using data from the EU SILC database and have also historically been assessed using the 10% metric. During the development of indicators for EU wide comparison, the Energy Poverty Observatory found energy poverty rates in Ireland to range from 5% to 18%, depending on the chosen indicator (Energy Poverty Advisory Hub, 2020).

[1] Note that our previous research has already criticised current metrics for being insufficient, and thus this number may be an underestimate.

Work is emerging in interrogating the causal mechanisms of energy poverty and its effects on household incomes in the Republic of Ireland. Researchers have found that (using EU SILC data) fuel poverty is indistinct from general deprivation as defined by the National Measure of Deprivation for Ireland finding that when aspects of fuel poverty are included in the National Measure of Deprivation, fuel poverty and deprivation are subsequently indistinct (Watson and Maitre, 2015).

Transport poverty remains somewhat indirectly quantified and has not been directly examined for quite some time, but NI's problem in this area is considerable (General Consumer Council Northern Ireland, 2001). In NI, transport data forms the Travel Survey for Northern Ireland (TSNI), while the equivalent in Ireland is the National Travel Survey (NTS) (Department for Infrastructure, 2020) (Central Statistics Office, 2021). Common survey questions and outcomes include items such as average journey length and the main mode of transport. However, none of the data collected are used to explicitly measure transport poverty.

Indicators of energy poverty are used for high level monitoring of energy poverty rates. However, access to support is often devolved to sub-national governments and subject to stringent targeting criteria such as having a very low household income, and often the incentives for landlords to access such schemes are greatly diminished. In Northern Ireland for example, access to the main retrofit funding scheme is a "postcode lottery" where access is only available in areas where fuel poverty is highest (Northern Ireland Housing Executive, 2022).

Transport poverty indicators and vulnerability lenses are typically not used explicitly in any context but are implicitly acknowledged in accessing transport related supports. For example, in Ireland, people with disabilities are eligible for the Motorised Transport Grant, provided they require a vehicle to access employment, cannot use public transport, and are subjected to a means test (Citizensinformation.ie, 2022). However, these support measures can ignore the fact that the causal mechanism of transport poverty can often be related to the built environment. For example the Irish National Travel Survey notes that the greatest contributor to encouraging more cycling would be safer cycling routes (Central Statistics Office, 2021).

In the literature concerning the alleviation of energy poverty, access to support measures for those in energy poverty to undertake building fabric upgrades is seen as nearly essential. Middlemiss and Gillard find that social housing providers are the most common source of lasting built fabric improvements, and that most respondents would not consider debt mechanisms to improve their dwelling fabric (Middlemiss and Gillard, 2015). It is noted that in similar research for the Scottish Government, most participants' awareness about the availability of support is low, and few believe that they require help or advice and thus would not actively seek either (Ipsos MORI Scotland and Alembic Research Ltd., 2020).

Regarding alleviating transport poverty, many barriers relate to the insufficient provision of or high cost of public transport or are related to infrastructural issues. Indeed, research concludes that street connectivity, bus provision and neighbourhood safety are more significant contributors to spatial variation in transport use than demographic factors (Lucas et al., 2018). However, some barriers are more related to perception. In Northern Ireland, for instance, fear of travelling into unknown areas arises. Thus, not only must more transport options be available, but they must also be considered safe by users (Crisp et al., 2017). Overcoming transport poverty, therefore, requires changes to the provision of public transport and should avoid exacerbating existing inequalities. Unfortunately, subsidies for more sustainable mobility options such as EVs, which are noted as inequitable, have been found in Ireland (Caulfield et al., 2022).

Furthermore, means of alleviating energy poverty and transport are often linked to climate goals in that they also present effective mechanisms for emissions reduction and are frequently key components of sectoral targets in climate change laws or plans. Northern Ireland and the Republic of Ireland have passed net-zero emissions laws with a deadline of 2050 for net-zero emissions and with various sub-sector targets (Minister for Agriculture, Environment and Rural Affairs, 2022) (Oireachtas, 2021). Sufficient support for vulnerable groups will be essential to meet climate goals. Our results also discuss their effectiveness for energy and transport poverty alleviation and climate change mitigation.

3. Research design

Our survey instrument combines existing energy and transport poverty measurements as adapted from the EU Energy Poverty Advisory Hub with new assessments (Energy Poverty Advisory Hub, 2020). Moreover, it aims to determine how households think about financial trade-offs between energy and transport and thus points the way for prioritising current and future solutions. The survey asked questions according to the research aims of the project as well as to glean information beyond the data represented in current statistics (e.g., how households trade-off between energy/transport services and other essentials). The key objectives of this household survey are the following:

1. Record self-reported expenditure on energy and transport services and consequently assess energy and transport poverty in the same data set.
2. Assess the strength of the causal mechanisms and measure the relationship between energy and transport poverty.
3. Provide an analysis on the effects of the Covid-19 pandemic on respondents' energy and transport use.

Once the survey data was processed, it was applied to previously unused energy and transport poverty metrics. These metrics, subjective experiences and the overlap of these conditions are the key knowledge gaps we seek to fill. Furthermore, although some data being collected already exists for Ireland, collecting it again in tandem with data from Northern Ireland allows for an accurate cross-jurisdiction comparison across the Island.

3.1. Expenditure metrics of energy and transport poverty

Expenditure metrics can be subcategorised according to the expenditure used: either modelled or actual spending. The collection of data regarding actual energy and transport expenditure is advantageous as fuel poverty figures in NI are based upon *modelled* expenditure (i.e., what a household needs to spend, according to a household energy model to maintain a certain heating regime) ignoring actual spending patterns, which are the means of measurement in Ireland. The main drawback of actual expenditure is that it makes it difficult to assess whether a certain level of energy expenditure indicates financial circumstances or deliberate choice of the household (Lowans et al., 2021). Hence, we have also collected data for consensual measures. The measures applied, drawing from the EU Energy Poverty Observatory and other sources, are as follows.

- 2Mexp: a household (energy) or individual (transport) can be considered energy/transport poor if expenditure on energy/transport exceeds twice the sample median. For energy, this metric may capture households that are energy inefficient and spend an excessive amount. However, it may also or instead capture the richest individuals who have the most to spend and may not therefore be limited to its ability to measure energy poverty (Energy Poverty Advisory Hub, 2020). We use this metric for two additional reasons. First, it comprises half of Mattioli's "Car related economic stress" metric in transport (Mattioli et al., 2016). Second, due to data limitations in our survey, we were not able to collect household income data, only individual respondent income.
- M/2: a household (energy) or individual (transport) is energy/transport poor if its absolute energy/transport expenditure (in financial terms) is below half the national median or abnormally low.

This could be due to high energy efficiency standards but may also be indicative of households that are dangerously under-consuming energy.[2]

3.2. Consensual measures of energy and transport poverty

In addition to expenditure metrics, we used consensual metrics of energy and transport poverty as follows.

- *Arrears on bills*: households that report falling into arrears on their energy (or transport) bills once or more during the past 12 months. This metric is useful for uncovering households that self-report financial difficulties in paying for energy or transport, which may not be revealed by the M/2 indicator (Energy Poverty Advisory Hub, 2020).
- *Inability to keep warm*: households that self-report the inability to keep their home adequately warm when needed are considered energy poor under this metric. This can uncover either financial hardship caused by energy bills or the effects of buildings in poor condition (Energy Poverty Advisory Hub, 2020).
- *Essentiality of car ownership*: an individual is transport poor if they consider a car essential to meet their needs. This borrows from Mattioli's "Forced Car Ownership" metric, but makes this a consensual measure rather than a financial one (Mattioli, 2017).
- *Adequacy of public transport*: as a compliment to the essentiality of car ownership, individuals can be considered transport poor if they do not believe public transport in their area is sufficient to meet their needs. This borrows from research by the Social Exclusion Unit identifying the availability and accessibility of private and public transport to be a barrier to social inclusion (Social Exclusion Unit, 2003).

3.3. The survey instrument

The main aim of designing the survey was to achieve empirical novelty rather than aiming for conceptual or methodological novelty, which is becoming an established practice in the social sciences (Sovacool et al., 2021). As with this prior referenced work, the survey designed and conducted here had no theoretical framework. The aims of the overall project require quantitative data as a deliverable. We did not wish to retrofit our hypotheses to fit the collected data (Sovacool et al., 2021).

The questionnaire was designed to take 15–20 min to complete and consisted of 39 questions. The first section assessed the demographics of the respondents. The second section assessed respondents' attitudes and behaviours regarding domestic energy use. The third section asked respondents questions regarding their attitudes and behaviours regarding transport energy use. A mix of answer types were used, ranging from allowing respondents to input numerical values to ranking categorical values. Lastly, some questions were open ended (e.g., allowing respondents to describe how they cope with and manage their energy expenditures.) The survey was implemented online by the market research company Dynata, which used a representative respondent panel. Dynata scripted the survey using their software, which the research team checked before being sent to respondents. These respondents agreed to participate in Dynata's respondent panels in return for incentives from Dynata: the researchers had no contact with the respondents and were not involved in providing incentives. All respondents were at least 18 and resident in one of the study jurisdictions.

A standard data assessment procedure of inspection for incorrect or inconsistent data, cleaning for removal of anomalies, visual inspection and verification, and a recording of the changes made to the stored data was followed. A total of 328 respondents were removed based on quality checks. These quality checks included "flat-liners," i.e., where respondents gave straight-line responses on blocks of questions; those who gave incomplete, contradictory, or unrealistic responses; and respondents who had unrealistically fast survey completion times. The final sample comprised 1564 respondents, with 431 in Northern Ireland and 1133 in Ireland. These provided a representative sample of each respective jurisdiction and the Island as a whole and are illustrated in Table 1.

3.4. Statistical testing and analysis

Our analysis has used multiple methods of testing to determine the strength of relationships between variables. The need for multiple methods arises from the multiple formats of data collected. The methods we use are: linear and logistic regression, Pearson correlation coefficient, chi-square tests, point biserial correlations, Spearman's rank correlation, and Cramer's V tests.

Regression analysis was carried out on the collected survey data to determine the strength of the drivers of energy and transport poverty. The Pearson correlation coefficient is used to determine the linear correlation between data sets. The Chi-square test is used to determine whether there is a statistically significant difference between observed and expected outcomes in categorical variables. Point biserial correlation coefficients are used when one variable is binary and the other is continuous. It is equivalent to the Pearson correlation coefficient, which applies to two continuous variables. Spearman's rank correlation coefficient is used to test the strength of the association between two ranked variables, or one ranked variable and one continuous variable. Here we have used it to measure the correlation between 2 binary variables. Cramer's V test is another test of association based upon the chi-squared test, used to measure the association between nominal variables, and may be used on variables with multiple categories.

All significance tests are conducted at the 0.05 level. Depending upon the statistical test used, we calculate significance either as a P-value or with a two-tailed test.

3.5. Demographics of respondents

The full demographic profile of our respondents is outlined in Table 1 below.

Table 1 shows our respondents' demographic and socioeconomic profiles, which were ensured to be representative for the Island of Ireland in terms of dwelling type, dwelling tenure, personal income, and location. However, we cannot guarantee representativeness beyond these categories (e.g., educational attainment). The survey was completed by respondents in November 2021, making our results very up to date at the time of publication, albeit preceding 2022 international energy crisis and the consequences of Russia's invasion of Ukraine (European Commission, 2022) (International Energy Agency, 2022).

Note that energy and transport poverty are calculated for each jurisdiction using the median for each jurisdiction, and when displayed together as a rate for the whole Island this is the sum of the number of energy or transport poor for each jurisdiction as a percentage of the sample size.

3.6. Study limitations

Overall, we identify three key potential limitations related to surveying as a methodology, namely, the acquiescence bias in responses (Messick, 1966) (Furr, 2011), perceived social desirability of responses (Fisher, 1993) (Huang et al., 1998) and respondent knowledge (Melchert, 2011) (van de Mortel, 2008) (Kruger and Dunning, 1999). These will be discussed in turn.

The acquiescence bias in responses is a phenomenon exhibited by

[2] Note that we have not used metrics which include a relative threshold for income as we have been unable to collect household incomes, as mentioned above.

Table 1
Demographic profile of respondents.

Demographics		
Jurisdiction of residence		
	Frequency	Percent
Northern Ireland	431	27.6%
Republic of Ireland	1133	72.4%
Number of Household inhabitants		
	Frequency	Percent
1	234	15%
2	444	28.4%
3	336	21.5%
4	329	21%
5	131	8.4%
6	60	3.8%
7	21	1.3%
8	7	0.4%
9	2	0.1%
Age of respondent		
	Frequency	Percent
18–24	127	8.1%
25–39	548	35%
40–49	356	22.8%
50–59	242	15.5%
60–74	253	16.2%
75+	38	2.4%
Gender of respondent		
	Frequency	Percent
Male	637	40.7%
Female	922	59%
Other	5	0.3%
Is the respondent a member of the Black, Asian or other ethnic minority community		
	Frequency	Percent
Yes	112	7.2%
No	1452	92.8%
Area of residence		
	Frequency	Percent
Armagh	6	0.4%
Belfast	65	4.2%
Derry/Londonderry	8	0.5%
Lisburn	9	0.6%
Newry	1	0.1%
Dublin	136	8.7%
Cork	29	1.9%
Limerick	17	1.1%
Waterford	13	0.8%
Galway	19	1.2%
Large Town (18,000 inhabitants to 75,000 inhabitants)	453	29%
Small/Medium Town (4500 inhabitants to 10000 inhabitants)	342	21.9%
Intermediate Settlement/Village (1000 inhabitants to 4500 inhabitants)	150	9.6%
Small Village/Hamlet/Open Country (less than 1000 inhabitants)	316	20.2%
Respondent employment status		
	Frequency	Percent
Working full-time	845	54%
Not Working	134	8.6%
Retired	195	12.5%
Permanently Sick/Disabled or Looking After Family/Home	135	8.6%
Working part-time	255	16.3%
Respondent home ownership status		
	Frequency	Percent
Owned by respondent	926	59.2%
Rented	391	25%
Social Housing	79	5.1%
Owned by respondent's family	168	10.7%
Respondent dwelling type		
	Frequency	Percent
Bungalow	231	14.8%
Terraced House	263	16.8%
Semi-Detached House	466	29.8%
Detached House	372	23.8%
Flat/Apartment	215	13.7%
Caravan	2	0.1%
Other	15	1%
Respondent monthly income		
Northern Ireland [GBP]	Frequency	Percent
0–1000	93	21.6%
1001–2000	163	37.8%
2001–3000	107	24.8%
3001–4000	42	9.7%
4001+	26	6%
Republic of Ireland [EUR]	Frequency	Percent
0–1000	175	15.4%
1001–2000	291	25.7%
2001–3000	354	31.2%
3001–4000	204	18%
4001+	109	9.6%

respondents whereby they have a tendency to give positive answers to questions, regardless of the content of the question, and do not consider their "true" response (Messick, 1966). Furthermore, a related known contributor to this trend occurs when there is an unbalance of positively or negatively described items in a survey, i.e., a string of positively described items exacerbates tendencies to respond affirmatively (Furr, 2011).

The perceived social desirability of responses presents an issue such that respondents may edit their responses in order to be perceived in a more favourable light (Fisher, 1993). This presents an issue in that the reported responses do not reflect respondents' true behaviour. Indeed the respondents may over or under-report so that their answers could be seen as more moderate than their true response (Huang et al., 1998).

Respondent knowledge presents issues in several ways. Firstly, respondents unaware of their emotions may not fully understand or be aware of their behaviours or tendencies and so may give misleading answers (Melchert, 2011). Secondly, some respondents may prefer to present a façade rather than be truthful in their responses (note this is related to but not the same as responding in a way the respondent suspects would be perceived as more socially desirable) (van de Mortel, 2008). Thirdly, a widely recognised issue is that people hold overly favourable views of their capabilities in many intellectual and social domains, that do not reflect their true capabilities (Kruger and Dunning, 1999).

Additionally, the length of the survey instrument may have contributed to some fatigue in responses. This risk was deemed acceptable when considering the survey aim of understanding energy and transport poverty among the same respondent panel.

Our survey relies entirely on self-reported data, which can present limitations e.g., some respondents may not accurately recall information. Moreover, we expected collecting household income data to be highly inaccurate in rented properties, and to have posed ethical questions for respondents who may be unwilling or unable to disclose information regarding others in their household who in turn might not consent. Relatedly, some weakness exists in our methodology in that we have had to minimise the questions asked, and thus the data collected, to measure both energy and transport poverty while not exhausting respondents. This has come at the expense of slightly imperfect methods for each of energy and transport poverty measurement. Ideally, we would find household incomes in addition to individual incomes so that we could also run analysis using relative as well as absolute thresholds for our expenditure metrics of energy and transport poverty. In these circumstances, we and others argue that the main drawback of actual expenditure is that it makes it difficult to assess whether a certain level of energy or transport expenditure indicates financial circumstances or deliberate choice of the household. However, we believe the merits of collecting the data to examine the overlap of these conditions outweigh

the drawbacks of limiting our data collection in each sub-area.

When calculating expenditure rates of energy and transport poverty, it was our intention during data collection to account for the support measures that individuals receive. However, when examining these collected data, many erroneous entries were noted e.g., where respondents claimed to receive more in supports than is possible. Thus, we omitted all supports data from energy (and transport) poverty expenditure metric calculations. This has unavoidably affected the calculation of energy and transport poverty rates and possibly also the correlation analysis, but we are unable to say by how much in either case.

Finally, due to constraints on the length of this paper, we cannot deeply analyse all 39 questions in this paper or present the entirety of the results. Thus, the results which are most relevant to the research aims are presented alongside the most pertinent analysis.

4. Results & analysis

This section presents our results and analysis, beginning with the energy and transport questions, and lastly, their overlap as outlined by our paper aims in Section 3. Note that the abbreviations NI and ROI should be taken to mean Northern Ireland and Republic of Ireland respectively.

4.1. Patterns of energy use and expenditures

In this section, we discuss the results and analysis pertinent to respondents' domestic energy use. This pertains to all three of our paper aims: to uncover the extent of energy poverty, assess the causal mechanisms, and examine the effects of the Covid-19 pandemic on energy usage Ireland wide.

Firstly, Fig. 1 and Table 2 below show respondents' monthly energy bills. The distribution of self-reported energy expenses is displayed in Fig. 1, whilst the median and mean of self-reported energy expenses are listed in Table 2. As can be seen, the median and mean energy bill rose across this time by 14% in NI, 10% in ROI and 17% in NI and 16% in ROI, respectively.

In Tables 3 and 4 we show responses to questions concerning thermal comfort and dwelling issues. The first questions deal with consensual

Table 2
Median energy expenditures in each jurisdiction.

Jurisdiction	Median Monthly energy Bill before pandemic	Median monthly energy bill during the pandemic	Mean Monthly energy Bill before pandemic	Mean monthly energy bill during the pandemic
Northern Ireland [GBP]	150	171	181	212
Republic of Ireland [EUR]	138	151	177	206

Table 3
Respondents' ability to keep their household comfortably warm when needed.

Q13. Can your household keep your home comfortably warm when needed?			
		Frequency	Percentage
Island wide	Yes	1340	85%
	No	224	14%
Northern Ireland	Yes	381	88%
	No	50	12%
Republic of Ireland	Yes	959	85%
	No	174	15%

Table 4
Showing the percentage of respondents per jurisdiction reporting issues with their dwelling.

Do you have any of the following problems with your dwelling/accommodation?			
Percentage of respondents	Island wide	Northern Ireland	Republic of Ireland
A leaking roof	7%	5%	7%
Damp walls/floors/foundation	17%	13%	18%
Rot in window frames or floor	8%	5%	8%
Other structural problem(s)	8%	4%	10%
I have none of these problems with my dwelling	71%	80%	68%

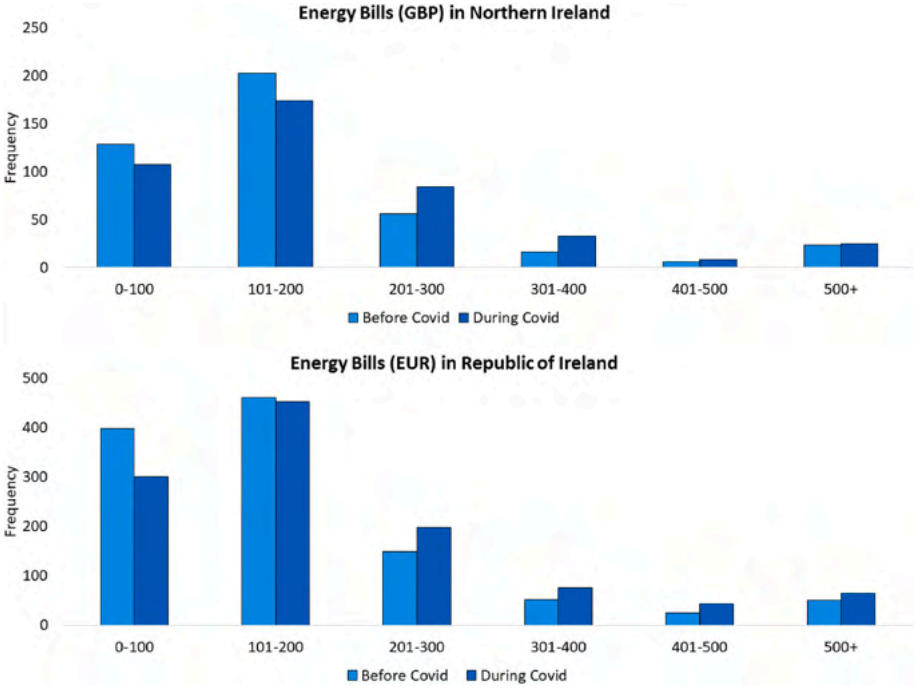

Fig. 1. Respondent's energy bills in each jurisdiction, prior to and during the Covid-19 pandemic. Panel A) Northern Ireland, Panel B) Republic of Ireland.

measures of energy poverty that concern respondents' self-reported ability to keep their home comfortably warm and the presence of the problems with their dwelling that are known to relate to energy poverty. Under the consensual measure of ability to keep their home comfortably warm, as shown in Table 3, some 14% of respondents can be considered energy poor, whilst 17% of respondents report at least one problem with their dwelling, as shown in Table 4.

In Table 5 we correlate answers displayed in Table 3 with expenditure metrics of energy poverty. Chi-squared tests and Spearman's ρ tests show weak, statistically insignificant correlations between these metrics.

As stated in section 3.2, a key consensual measure of energy poverty is the presence of arrears on household energy bills (Energy Poverty Advisory Hub, 2020). As shown in Table 6 below, when asked "In the past 12 months, have you been unable to pay for such a heating or electricity bill on time due to financial difficulties?" 10% of respondents reported falling into arrears at least once, and 11% reported falling into arrears twice or more; thus, the rate of falling into arrears is 21%.

Table 7 below shows the correlations between the results from Table 6 and financial metrics of energy poverty. Chi-squared tests and Cramer's V tests show weak, statistically insignificant correlations between the falling into arrears on an energy bill and financial metrics of energy poverty, despite the design aim of this metric; to capture households experiencing difficulties paying for energy due to financial circumstance.

The results displayed in Table 8 below pertain to respondents' heating fuels. This question provides important context as to which fuels the energy poor are consuming, and the ease with which the switch to low carbon options might occur. Regarding heating fuels, when asked what the primary heating fuel of their dwelling is, 38% of respondents reported oil, 33% reported gas, 20% reported electricity, with the remainder made up of coal, peat, other, and "don't know".

Table 9 shows that chi-squared tests show strong associations between primary heating fuel and financial metrics of energy poverty; however, these are statistically insignificant except for the 2Mexp metric for energy expenditure before Covid-19, which is significant; that is that over-expenditure on energy is correlated significantly to heating fuel. Cramer's V test on the same 2Mexp metric shows a weak but significant correlation. All other associations found by Cramer's V tests are weak and not statistically significant.

Table 10 shows a list of energy technologies and whether respondents have these installed. When asked which energy related technologies they have installed at home, or plan to install within the next 12 months, except for low energy lightbulbs, most respondents did not have, nor planned to install solar PV, smart meters, smart appliances, EV chargepoints, or "other". These results suggest that either respondents have limited knowledge that alternative technologies could lower their energy bills, or that they are aware of these opportunities yet have no plans to install such technologies regardless of the potential savings.

As shown in Table 11 below, when asked to identify which option would make the greatest difference in meeting their domestic energy needs, 46% of respondents identified lower costs, 26% identified more income, and 25% identified more efficient home and appliances i.e., even though more efficient homes and appliances would decrease energy bills, lower unit costs are the more popular means of improving the ability of respondents to meet their needs.

In Fig. 2 below, we depict the rates of energy poverty calculated from our data, as per our first paper's aim. Calculated rates of energy poverty show that under the M/2 metric, both jurisdictions have approximately the same rates of energy poverty. This suggests that the proportion of the population that under-consumes energy is roughly the same in each jurisdiction and has remained approximately constant from before the Covid-19 pandemic to during the pandemic. However, under the 2Mexp metric, over-expenditure on energy is roughly 4% higher in ROI than in NI.

Table 12 below shows the correlations between income and financial metrics of energy poverty and illustrates that point biserial correlations uncover no associations between self-reported monthly post-tax income and financial metrics of energy poverty. Furthermore, a binomial regression model using all demographic factors together as predictors could not predict instances of energy poverty. The coefficient results of this model are not presented here to conserve space.

Table 5
Correlations between self-reported ability to keep homes warm and financial metrics of energy poverty.

Can you keep your household comfortably warm when needed?			
	Chi Squared	Spearman's Rho	P value
M/2 (pre-Covid-19)	0.066	0.007	0.797
M/2 (during Covid-19)	0.116	0.09	0.734
2Mexp (pre-Covid-19)	0.275	0.013	0.6
2Mexp (during Covid-19)	0.036	−0.05	0.849

Table 6
Respondents' reporting difficulty paying energy bills.

In the past 12 months, have you been unable to pay for such a heating or electricity bill on time due to financial difficulties?			
Percentage of respondents	Island wide	Northern Ireland	Republic of Ireland
Yes, once	10%	8%	10%
Yes, twice or more	11%	6%	13%
No	79%	85%	77%

Table 7
Correlations between the inability to pay for an energy bill and financial metrics of energy poverty.

Correlations between the inability to pay for an energy bill in the past 12 months and financial metrics of energy poverty			
	Chi Squared	Cramer's V	P value
M/2 (pre-Covid-19)	1.324	0.029	0.516
M/2 (during Covid-19)	0.175	0.011	0.916
2Mexp (pre-Covid-19)	1.71	0.033	0.425
2Mexp (during Covid-19)	2.195	0.037	0.334

Table 8
Respondents' primary heating fuel.

Primary heating fuel			
Percentage of respondents	Island wide	Northern Ireland	Republic of Ireland
Oil	38%	52%	33%
Gas	33%	35%	32%
Electricity	20%	10%	24%
Coal	3%	2%	3%
Peat	4%	1%	5%
Other	2%	2%	2%
Don't know	1%	33%	1%

Table 9
Correlations between primary heating fuel and financial metrics of energy poverty.

Correlations between primary heating fuel and financial metrics of energy poverty			
	Chi Squared	Cramer's V	P value
M/2 (pre-Covid-19)	9.217	0.077	0.162
M/2 (during Covid-19)	6.399	0.064	0.38
2Mexp (pre-Covid-19)	12.369	0.09	0.049
2Mexp (during Covid-19)	12.082	0.088	0.06

Table 10
Technologies installed, or planned to be installed at respondents' dwellings.

Technologies installed, or planned to be installed at respondents' dwellings						
Percentage of responses	Solar panels	Smart meter	Smart appliances (networked)	Electric vehicle chargepoint	Low energy lightbulbs	Other
This is installed at my home	9%	20%	16%	4%	71%	8%
This will be installed at my home within the next 12 months	6%	18%	15%	8%	11%	6%
I have no plans to install this	85%	63%	69%	88%	18%	73%

Table 11
Respondents' perception of item which would make greatest difference to meeting household energy needs.

Respondents' perception of item which would make greatest difference to meeting household energy needs			
	Island wide	Northern Ireland	Republic of Ireland
More income	26%	25%	27%
A more efficient home and appliances	25%	23%	26%
Lower heating and electricity costs	46%	48%	45%
Other	3%	4%	3%

4.2. Patterns of transport use and expenditures

In this section we will discuss the results and analysis pertinent to respondents' transport energy use. This pertains to all three of our paper aims: to uncover the extent of transport poverty, assess the causal mechanisms, and examine the effects of the Covid-19 pandemic on transport usage Ireland wide.

Firstly, Fig. 3 and Table 13 below show respondents' monthly transport bills. The distribution of self-reported transport expenses (comprising expenses on cars, public transport, and taxis) is displayed in Fig. 3, whilst the median and mean of self-reported transport expenses are listed in Table 13. As can be seen, the median and mean transport bill fell across this time by 22% in NI, 27% in ROI and 17% in both NI and ROI respectively.

In Tables 14 and 15 we show the results of our questions pertaining to perceptions of different transport modes. We see in Table 14 that across the Island, over 90% of responses say that owning a motor vehicle is essential to fully participate in society. However this contrasts with the results in Table 15, showing that a combined 48% of respondents said that public transport in their area is sufficient to meet most or all of their needs.

Table 16 shows the correlations between the perception based responses in Table 14 with financial metrics of transport poverty. Chi-squared tests and Spearman's ρ tests show no statistically significant correlations between the belief in the necessity of vehicle ownership and financial metrics of transport poverty.

Table 17 shows the correlations between the perception based responses in Table 15 with financial metrics of transport poverty. Chi-squared tests and Cramer's V tests show no statistically significant correlations between the belief in the sufficiency of public transport and financial metrics of transport poverty, except for a very weak correlation

Table 12
Statistical associations between monthly post-tax income and financial metrics of energy poverty.

Statistical associations between monthly post-tax income and financial metrics of energy poverty		
	Point biserial correlation	Significance test
M/2 (pre-Covid-19)	0.008	0.752
M/2 (during Covid-19)	0.031	0.225
2Mexp (pre-Covid-19)	−0.004	0.877
2Mexp (during Covid-19)	−0.005	0.848

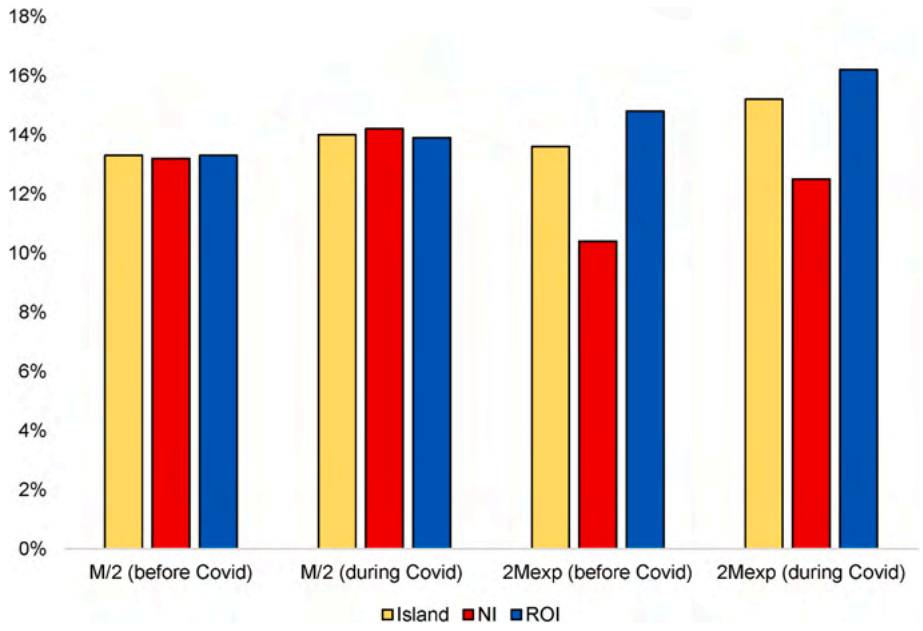

Fig. 2. Calculated rates of energy poverty across the Island of Ireland using the M/2 and 2Mexp metrics. Note NI = Northern Ireland. ROI = Republic of Ireland. Island = both.

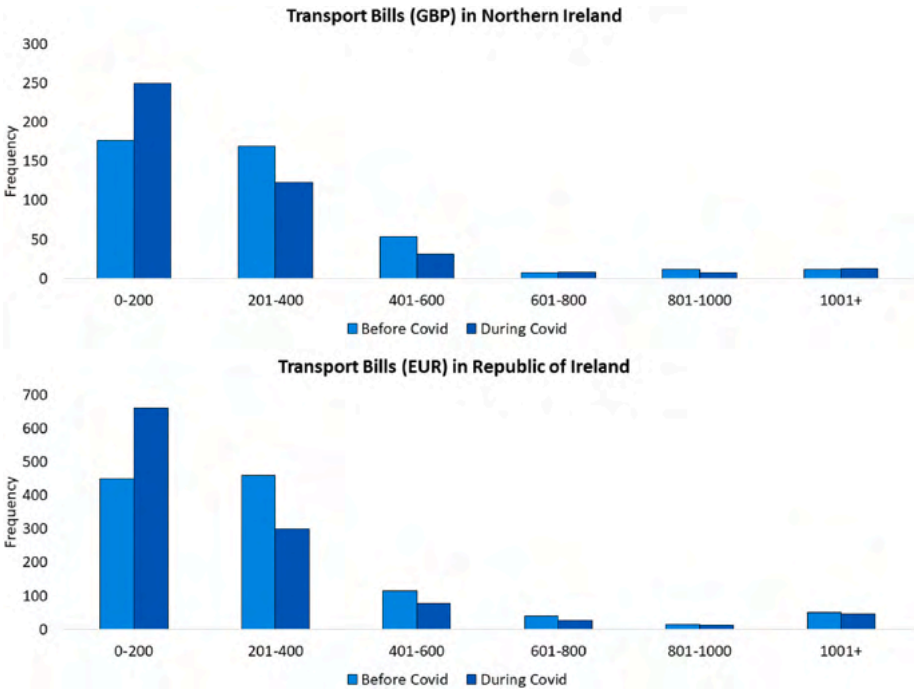

Fig. 3. Respondent's transport bills in each jurisdiction, prior to and during the Covid-19 pandemic. Panel A) Northern Ireland, Panel B) Republic of Ireland.

Table 13
Median and mean transport bills before and during the Covid-19 pandemic in NI and ROI.

Jurisdiction	Median Monthly transport Bill before pandemic	Median monthly transport bill during the pandemic	Mean Monthly transport Bill before pandemic	Mean monthly transport bill during the pandemic
NI [GBP]	231	174	298	248
ROI [EUR]	237	173	318	265

Table 14
Respondents' perception of the essentiality of owning their motor vehicle.

Respondents' perception of the essentiality of owning their motor vehicle			
	Island wide	Northern Ireland	Republic of Ireland
Essential	85%	85%	85%
Not-essential	7%	5%	7%
N/A	3%	4%	3%

Table 15
Respondents' perception of public transport sufficiency.

Respondents' perception of the sufficiency of public transport in their area			
	Island wide	Northern Ireland	Republic of Ireland
Sufficient to meet most transport needs	37%	43%	35%
Sufficient to meet all transport needs	11%	11%	11%
Not sufficient	52%	46%	55%

with the M/2 metric during Covid-19 as shown in Table 17.

The results of asking respondents what would aid in meeting their transport needs are shown in Table 18. Namely, 28% say they require more income, 30% say they require lower fuel costs whilst only 16% would like greater public transport provision. The remaining 25% is divided across increased vehicle efficiency, greater access to vehicles, an increased ability to work from home, increased provision of EV public charging and "other".

Table 16
Statistical associations between belief in the necessity of owning a vehicle and financial metrics of transport poverty.

Statistical associations between belief in the necessity of owning a vehicle and financial metrics of transport poverty			
	Chi Squared	Spearman's Rho	P Value
M/2 (pre-Covid-19)	0.587	−0.018	0.498
M/2 (during Covid-19)	0.803	−0.017	0.520
2Mexp (pre-Covid-19)	0.85	−0.020	0.435
2Mexp (during Covid-19)	1.669	−0.029	0.268

Table 17
Statistical associations between belief in public transport sufficiency and financial metrics of transport poverty.

Statistical associations between belief in public transport sufficiency and financial metrics of transport poverty			
	Chi Squared	Cramer's V	P Value
M/2 (pre-Covid-19)	4.315	0.053	0.116
M/2 (during Covid-19)	6.782	0.066	0.034
2Mexp (pre-Covid-19)	9.019	0.076	0.011
2Mexp (during Covid-19)	1.966	0.035	0.374

Regarding the inability to pay for personal car use and public transport, the responses for car and public transport have moved in the same direction following the Covid-19 pandemic, as shown in Table 19. Before the pandemic, 13% of respondents report an inability to pay for their car expenses at least once, but this falls to 10% during the pandemic, perhaps due to decreasing volumes of travel. As for public transport, 8% report an inability to pay for public transport at least once prior to the pandemic, falling to 7% during the pandemic.

Chi-squared tests and Cramer's V tests, as shown in Tables 20 and 21, show no statistically significant correlations between respondents' inability to pay for any of their means of transport before and during the

Table 18
Respondents' perception of item which would make greatest difference to meeting transport needs.

Respondents' perception of item which would make greatest difference to meeting transport needs	Island wide	Northern Ireland	Republic of Ireland
More income	28%	24%	30%
A more efficient vehicle	9%	10%	9%
Lower petrol/diesel/electricity costs	30%	35%	29%
More public transport	16%	16%	16%
Owning or having access to more vehicles	2%	1%	2%
Ability to work from home more	10%	8%	10%
More public electric vehicle charging stations	2%	2%	2%
Other	3%	4%	2%

Table 19
Respondents' self reported inability to pay for modes of transport, before and during the pandemic.

Respondents' self reported inability to pay for modes of transport, before and during the pandemic	Island wide	Northern Ireland	Republic of Ireland
Personal vehicle – before the pandemic			
Yes, once	5%	4%	5%
Yes, twice or more	5%	4%	6%
No	84%	88%	83%
I have adapted my behaviour instead of not paying	6%	4%	6%
Personal vehicle – during the pandemic			
Yes, once	7%	7%	8%
Yes, twice or more	6%	3%	7%
No	79%	84%	76%
I have adapted my behaviour instead of not paying	8%	6%	9%
Public transport – before the pandemic			
Yes, once	3%	4%	3%
Yes, twice or more	4%	2%	4%
No	88%	90%	88%
I have adapted my behaviour instead of not paying	5%	4%	6%
Public transport – during the pandemic			
Yes, once	5%	6%	4%
Yes, twice or more	3%	2%	4%
No	86%	87%	86%
I have adapted my behaviour instead of not paying	6%	6%	6%

pandemic and financial metrics of transport poverty.

In Fig. 4 we show the rates of transport poverty calculated from our data, as per our first aim. Expenditure rates of transport poverty show

Table 20
Statistical associations between inability to pay for transport and financial metrics of transport poverty, prior to the Covid-19 19 pandemic.

Statistical associations between inability to pay for transport and financial metrics of transport poverty, prior to the Covid-19 pandemic			
Car			
	Chi Squared	Cramer's V	P Value
M/2	6.305	0.063	0.098
2Mexp	2.492	0.04	0.477
Public transport			
	Chi Squared	Cramer's V	P Value
M/2	6.347	0.064	0.096
2Mexp	4.803	0.055	0.187

Table 21
Statistical associations between inability to pay for transport and financial metrics of transport poverty, during the Covid-19 19 pandemic.

Statistical associations between inability to pay for transport and financial metrics of transport poverty, during the Covid-19 pandemic			
Car			
	Chi Squared	Cramer's V	P Value
M/2	1.019	0.026	0.797
2Mexp	2.48	0.04	0.479
Public transport			
	Chi Squared	Cramer's V	P Value
M/2	1.776	0.034	0.620
2Mexp	4.496	0.054	0.213

that under the M/2 metric, both jurisdictions have approximately the same rate of transport poverty during the pandemic, and additionally the rate was lower prior to the pandemic. This suggests that the proportion of the population that under-consumes transport is roughly the same in each jurisdiction. As with energy, under the 2Mexp metric, over-expenditure on transport is higher in ROI than in NI, but the difference is small.

Table 22 illustrates that, there are no statistically significant correlations between monthly post-tax income and financial metrics of transport poverty except for the M/2 metric during the pandemic which is significant, but the association is very weak and negative. Furthermore, as with energy poverty, a binomial regression model using all demographic factors together as predictors could not predict instances of transport poverty. The coefficient results are not presented here to conserve space.

4.3. Intersection of energy and mobility poverty

In this section, we will discuss the results and analysis concerning the overlap in respondents' domestic energy and transport use. This pertains to our second aim concerning the overlap of energy and transport poverty, and to our third aim of examining the effects of the Covid-19 pandemic on these issues.

Table 23 shows there are statistically significant correlations between all measures of energy and transport poverty and that these are all significant. This is likely explained by a strong association between being *not* energy poor and *not* transport poor, i.e., between respondents measuring as a 0 on each of the binary measures.

Table 24 shows statistically significant but very weak correlations between monthly energy and monthly transport bills. That is to say that very little of the change in energy bills is explained by a change in transport bills, despite the significance of the finding, with the magnitude of this influence decreasing by a factor of ten during the Covid-19 pandemic, as would be expected with greatly reduced travel behaviour.

5. Discussion

This paper had three aims. First, we sought to record self-reported energy and transport services expenditure and assess consensual and financial metrics of energy and transport poverty. Second, we sought to determine the strength of the causal mechanisms for energy and transport poverty and measure the relationship between these conditions. Third and finally, we sought to evaluate the impact of the Covid-19 pandemic on respondents' energy and transport expenditures.

For aims 1 and 3, our results indicate that mean and median energy expenses rose from the period preceding the pandemic to the period during the pandemic, while mean and median transport expenses fell over this period. We found no statistically significant associations between self-reported incomes and energy or transport bills. This is perhaps surprising given that one might expect higher earners to spend more on these services.

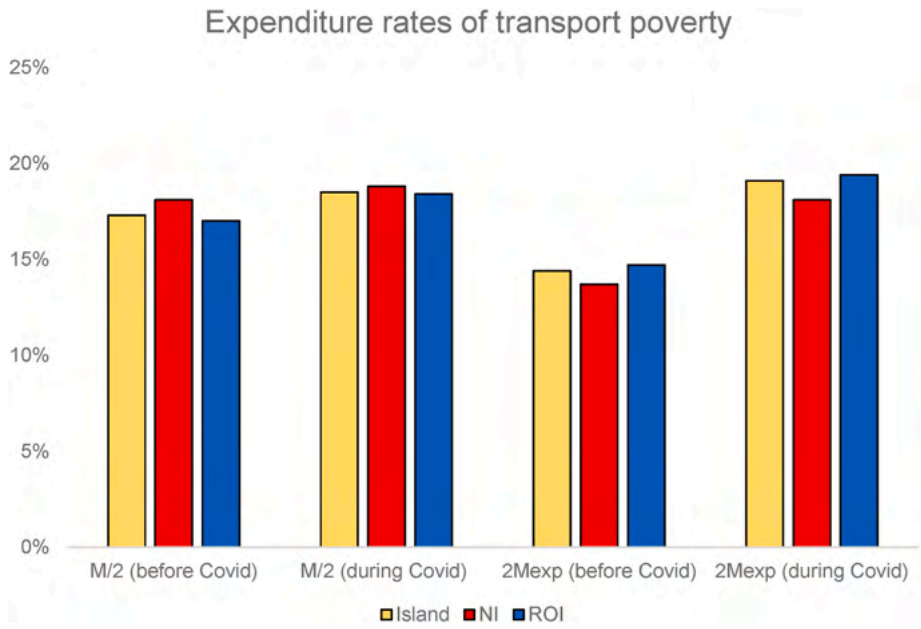

Fig. 4. Calculated rates of transport poverty across the Island of Ireland using the M/2 and 2Mexp metrics.

Table 22
Statistical associations between monthly post-tax income and financial metrics of transport poverty.

Statistical associations between monthly post-tax income and financial metrics of transport poverty		
	Point biserial correlation	Significance test
M/2 (pre-Covid-19)	−0.024	0.349
M/2 (during Covid-19)	−0.056	0.027
2Mexp (pre-Covid-19)	−0.009	0.731
2Mexp (during Covid-19)	−0.032	0.213

Regarding financial metrics of energy poverty and aim 1 of this paper, the rates of energy poverty under the M/2 metric are similar across the Island of Ireland, while overconsumption is higher in Ireland than in Northern Ireland. This pattern holds for financial metrics of transport poverty although the differences are smaller. Possible explanations for these patterns include higher wages or higher fuel prices in ROI, but we have not been able to determine the causal mechanism from the data collected.

As for consensual energy poverty measures, up to 21% of respondents can be considered energy poor. However, no statistical association was uncovered between financial metrics of energy poverty and the consensual measures. This is surprising, as we would expect to find an association between the M/2 metric, designed to uncover underconsumption of energy, and those who report an inability to keep their home warm or arrears on bills. As for transport poverty, the lack of association between arrears on bills and the M/2 metric persists. Regarding motor vehicles, 90% of respondents considered owning a motor vehicle a necessity, yet 48% of respondents stated that public transport in their area is sufficient to meet most or all of their needs. This result suggests that reasons for owning cars or other motor vehicles extend beyond meeting "needs" and includes wants based on cultural norms and perhaps negative preconceptions concerning public transport (Mattioli et al., 2020). As with energy, there are no meaningful correlations between financial and consensual measures of transport poverty. This would suggest that under-expenditure and over-expenditure on transport in our results are distinct from the perceptions of the factors that indicate transport poverty.

A consequence of collecting self-reported individual incomes, which we cannot verify, and lacking full household income responses is that we do not have the data needed to determine if energy and transport poverty are distinct from income poverty to corroborate or refute research outlined in section 2 regarding energy poverty in the Republic of Ireland (Watson and Maitre, 2015). However, determining this distinction may not be very useful to the research or policy communities given that our results show that with each change of indicator, there is a change in who is identified as energy or transport poor. This concurs with our earlier research suggesting that there is no single perfect

Table 24
Regression analysis results showing the relationship between monthly energy bills and monthly transport bills before and during the Covid-19 19 pandemic.

		Monthly energy bills	
		R^2	P value
Monthly transport bills	Before the pandemic	0.032	0.000
	During the pandemic	0.0037	0.000

Table 23
Statistical associations between metrics of energy and transport poverty.

Statistical associations between metrics of energy and transport poverty								
		Energy						
Transport		*M/2*		*M/2 Covid-19*		*2Mexp*		*2Mexp Covid-19*	
		Chi Sq	*P value*	*Chi Sq*	*P value*	*Chi Sq*	*P value*	*Chi Sq*	*P value*
	M/2	89.035	0.000	92.862	0.000	15.036	0.000	20.106	0.000
	M/2 Covid-19	93.376	0.000	100.216	0.000	18.209	0.000	22.163	0.000
	2Mexp	4.433	0.035	3.895	0.048	20.128	0.000	19.373	0.000
	2Mexp Covid-19	6.681	0.01	6.488	0.011	21.007	0.000	24.996	0.000

indicator, nor should one be sought. Rather an appropriate set of indicators should be used (Lowans et al., 2021). Given this indicator imperfection, we suggest that more broad approaches should be adopted for identification and alleviation of energy and transport poverty. In policy terms this means identification of the energy poor should continue to be devolved to local governments who know local situations best. The Affordable Warmth Scheme in Northern Ireland is one example of this. The same should apply for transport poverty schemes and criteria for identifying these people should be widened beyond the current stringent conditions.

Regarding aim 2 of this paper concerning causal mechanisms, our analysis has not uncovered any statistically significant correlations between the demographic data and the energy and transport poverty results (under expenditure metrics), nor between demographic data and self-reported energy and transport bills. That is to say that vulnerabilities known to contribute to energy and transport poverty (such as age, income etc.) do not, according to our results, have a statistical association with being energy or transport poor. As for the relationship between energy and transport poverty, we have observed statistically significant associations between all financial energy and transport poverty metrics as outlined in Table 23. However, we suspect that what is being identified is the link between being *not* energy poor and *not* transport poor as most respondents gave these answers.

Concerning energy poverty alleviation, despite a desire for lower domestic energy costs, respondents are broadly unwilling to install new technologies to reduce these costs. Hence, perceived barriers opposing the uptake of such technologies must be considered. A household might, for instance, object to taking out debt to finance a solar PV installation even though the installation would reduce the carbon footprint of the dwelling and possibly lower per-unit energy costs. Although the net financial impact on the household might be positive, the perceived benefits of undertaking the installation may not outweigh perceived costs (Middlemiss and Gillard, 2015). Therefore, for successful outcomes, not only must energy cost burdens be lifted, but also any related barriers must be addressed as well. Lastly, as indicated by low uptake rates, the reliance on market signals to trigger mass retrofits is insufficient, which could be overcome by expanding the groups subject to targeted interventions. The Republic of Ireland has a 2030 climate goal to roll out 2.7 TWh of district heating in cities and to install 400,000 heat pumps in existing homes (Department of the Environment Climate and Communications, 2021). However, at the time of writing, Northern Ireland lacks housing-specific decarbonisation targets (in the form of estimated numbers of installations and retrofits per year) (Northern Ireland Department for the Economy, 2021). Hence, greater efforts are needed to match policy goals with implementation in the Republic of Ireland.

As for transport poverty, the most prevalent responses indicated that more income or lower fuel costs would make the most difference. Despite widespread policy recognition that technology and modal shifts in energy and transport, if managed correctly, would benefit consumers, there is very little recognition of this by consumers themselves. This finding, in conjunction with the finding in the energy poverty literature from Middlemiss and Gillard that support schemes should actively seek participants, suggests that there is much more work to be done yet by governments to provide and promote sustainable mobility (Middlemiss and Gillard, 2015). Our finding regarding the perceived need for car ownership suggests once again that much more work is required to reach the Irish Government's 2030 goal of reducing the amount of "fossil fuelled distance" by 10% (Department of the Environment Climate and Communications, 2021). If most respondents do not believe public transport to be sufficient to meet their needs, they are very unlikely to forego personal vehicles for another transport mode. As with domestic energy, Northern Ireland lacks quantified targets for transport decarbonisation and modal shift.

Lastly, the lack of statistical correlations between our expenditure metrics, causal factors, and consensual metrics highlights the challenge associated with defining energy and transport poverty and categorising those impacted. Our results contradict findings that the drivers of energy and transport consumption are those that are accounted for in housing energy models and vulnerability lenses (e.g., house age or dwelling location). That is, we have found self-reported spending on energy and transport is distinct from expected behaviour, but we cannot determine why this is the case. Furthermore, we have found no discernible single or multiple root causes when examining self-reported energy and transport poverty, nor can we explain why we cannot find these causes.

6. Conclusion and policy implications

The first policy implication of our work is that in the absence of revamped national surveying in Northern Ireland to collect actual expenditure alongside modelled data, the focus on modelled expenditure data that is currently collected will remain necessary going forward for monitoring energy poverty rates at the national level and should remain in place for consistent monitoring of "need to spend" and for assessing energy performance gap purposes in the future. The second policy implication of our work is that we believe it necessary in both jurisdictions for official transport poverty indicators to be adopted and collected alongside energy poverty indicators to monitor overlaps and characteristics at a national level.

A third policy implication is that the energy or transport poor should be anyone identifiable by *any* of a series of energy or transport poverty indicators or vulnerability lenses, as opposed to stringent targeting criteria. As we have not been able to correlate our findings with the outcomes we expected, we believe further refining of targeted support is a poor policy approach. Indeed, we have noted that support schemes are most effective when they are comprehensive and when local governments proactively reach out to the vulnerable, rather than the other way around.

It is widely recognised that national domestic retrofit programs, active travel schemes and improvement of public transport services are among the measures required for meeting decarbonisation targets and at deployment rates exceeding what is currently observed. With continued locally devolved selection of support recipients, the more widely defined and identified energy or transport poor can be the first to access the support schemes or necessary infrastructure. As we have noted, many transport poverty barriers are infrastructural which require solutions in the built environment. Improved and sustainable public transport and active travel schemes should thus be the focus of transport policy efforts. Furthermore, and as noted in the discussion, debt mechanisms are the least attractive means of support for the energy poor (and by analogy, the same could be said of the transport poor). In many cases, respondents were not inclined to acquire technologies that may ameliorate their energy and/or transport poverty situation. Therefore, as a final policy implication of this work, and building on other literature, support measures should not pose a debt burden to vulnerable households and should be large enough to enact lasting change rather than merely lessening the financial burden of consumption of contemporary energy and transport services.

Regarding furthering the literature, we have two recommendations. First, we recommend similar studies are carried out in other jurisdictions (within and beyond Europe) to explore the reported outcomes further and to see if the reasons for the difference between actual and expected outcomes can be determined, which is a key weakness of our study. Second, we recommend that detailed surveys of vulnerable groups, as identified by vulnerability lenses, are conducted to determine the reasons for the difference between actual and expected outcomes, or to see if more focused surveys contradict our findings. We are excited to see the outcomes of such studies regardless of whether they agree or contradict our findings.

CRediT authorship contribution statement

Christopher Lowans: Conceptualization, Methodology, Investigation, Data curation, Software, Formal analysis, Writing – original draft, Writing – review & editing, Project administration. **Aoife Foley:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Funding acquisition. **Dylan Furszyfer Del Rio:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Brian Caulfield:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Benjamin K. Sovacool:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Funding acquisition. **Steven Griffiths:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **David Rooney:** Writing – review & editing.

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 data that has been used is confidential.

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Nomenclature & Abbreviations

2Mexp	A household (energy) or individual (transport) is energy/transport poor if its absolute energy/transport expenditure (in financial terms) is below half the national median
EU	European Union
EU SILC	European Union Statistics on Income and Living Conditions
EUR	Euro
EV	Electric Vehicle
GBP	Pound Sterling
M/2	A household (energy) or individual (transport) can be considered energy/transport poor if expenditure on energy/transport exceeds twice the sample median
NI	Northern Ireland
ROI	Republic of Ireland
TWh	Terawatt Hours

References

Bednar, D.J., Reames, T.G., 2020. Recognition of and response to energy poverty in the United States. Nat. Energy 5, 432–439. https://doi.org/10.1038/s41560-020-0582-0.

Bolton, P., Stewart, I., 2022. Domestic Energy Prices Research Briefing. House of Commons Library (House of Commons Library Research Briefing No. 9491).

Bouzarovski, S., Petrova, S., 2015. A global perspective on domestic energy deprivation: overcoming the energy poverty–fuel poverty binary. Energy Res. Social Sci. 10, 31–40. https://doi.org/10.1016/j.erss.2015.06.007.

Caulfield, B., Furszyfer, D., Stefaniec, A., Foley, A., 2022. Measuring the equity impacts of government subsidies for electric vehicles. Energy 248, 123588. https://doi.org/10.1016/j.energy.2022.123588.

Central Statistics Office, 2021. National Travel Survey [WWW Document]. URL, 3.21.2022. https://www.cso.ie/en/methods/transport/nationaltravelsurvey/.

Citizensinformation.ie, 2022. Motorised Transport Grant [WWW Document]. URL, 3.26.2022. https://www.citizensinformation.ie/en/travel_and_recreation/transport_and_disability/motorised_transport_grant.html.

Crisp, R., Gore, T., McCarthy, L., 2017. Addressing Transport Barriers to Work in Low Income Neighbourhoods: A Review of Evidence and Practice. Sheffield Hallam University. https://doi.org/10.7190/cresr.2017.3465773384.

Department for Infrastructure, 2020. Travel Survey for Northern Ireland [WWW Document]. Infrastructure. URL, 3.21.2022. https://www.infrastructure-ni.gov.uk/articles/travel-survey-northern-ireland.

Department of the Environment, Climate and Communications, 2021. Climate Action Plan 2021. Government of Ireland.

Energy Poverty Advisory Hub, E.C., 2020. Energy Poverty Observatory: Indicators [WWW Document]. URL, 3.10.2022. https://energy-poverty.ec.europa.eu/energy-poverty-observatory/indicators_en.

European Commission, 2022. Joint European action for more affordable, secure energy [WWW Document]. Eur. Comm. - Eur. Comm. URL, 4.19.2022. https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1511.

Fisher, R.J., 1993. Social desirability bias and the validity of indirect questioning. J. Consum. Res. 20, 303–315. https://doi.org/10.1086/209351.

Furr, R.M., 2011. Scale Construction and Psychometrics for Social and Personality Psychology. SAGE Publications Ltd. https://doi.org/10.4135/9781446287866, 1 Oliver's Yard, 55 City Road, London EC1Y 1SP United Kingdom.

Furszyfer Del Rio, D.D., Sovacool, B.K., 2023. Of cooks, crooks and slum-dwellers: exploring the lived experience of energy and mobility poverty in Mexico's informal settlements. World Dev.. 161, 106093. https://doi.org/10.1016/j.worlddev.2022.106093.

General Consumer Council Northern Ireland, 2001. THE TRANSPORT TRAP - How Transport Disadvantages Poorer People (No. 2), the Price of Being Poor.

Griffiths, S., Furszyfer Del Rio, D., Sovacool, B., 2021. Policy mixes to achieve sustainable mobility after the COVID-19 crisis. Renew. Sustain. Energy Rev. 143, 110919 https://doi.org/10.1016/j.rser.2021.110919.

Huang, C.Y., Liao, H.Y., Chang, S.H., 1998. Social desirability and the clinical self-report inventory: methodological reconsideration. J. Clin. Psychol. 54, 517–528 https://doi.org/10.1002/(sici)1097-4679(199806)54:4<517::aid-jclp13>3.0.co;2-i.

International Energy Agency, 2020. World Energy Outlook 2020 464.

International Energy Agency, 2022. Russian supplies to global energy markets [WWW Document]. IEA. URL, 4.19.2022. https://www.iea.org/reports/russian-supplies-to-global-energy-markets.

Kruger, J., Dunning, D., 1999. Unskilled and unaware of it: how difficulties in recognizing one's own incompetence lead to inflated self-assessments. J. Pers. Soc. Psychol. 77, 1121–1134. https://doi.org/10.1037//0022-3514.77.6.1121.

Lowans, C., Furszyfer Del Rio, D., Sovacool, B.K., Rooney, D., Foley, A.M., 2021. What is the state of the art in energy and transport poverty metrics? A critical and comprehensive review. Energy Econ. 101, 105360 https://doi.org/10.1016/j.eneco.2021.105360.

Lucas, K., Mattioli, G., Verlinghieri, E., Guzman, A., 2016. Transport poverty and its adverse social consequences. Proc. Inst. Civ. Eng. - Transp. 169, 353–365. https://doi.org/10.1680/jtran.15.00073.

Lucas, K., Philips, I., Mulley, C., Ma, L., 2018. Is transport poverty socially or environmentally driven? Comparing the travel behaviours of two low-income populations living in central and peripheral locations in the same city. Transplant. Res. Part Policy Pract. 116, 622–634. https://doi.org/10.1016/j.tra.2018.07.007.

Lunke, E.B., 2022. Modal accessibility disparities and transport poverty in the Oslo region. Transplant. Res. Part Transp. Environ. 103, 103171 https://doi.org/10.1016/j.trd.2022.103171.

Marmot Review Team, Friends of the Earth, 2011. The Health Impacts of Cold Homes and Fuel Poverty. Friends of the Earth & the Marmot Review Team, London.

Mattioli, G., 2017. 'Forced car ownership' in the UK and Germany: socio-spatial patterns and potential economic stress impacts. Soc. Incl. 5, 147–160. https://doi.org/10.17645/si.v5i4.1081.

Mattioli, G., Wadud, Z., Lucas, K., 2016. Developing a novel approach for assessing the transport vulnerability to fuel price rises at the household level. In: Transportation Research Procedia. Presented at the World Conference on Transport Research - WCTR 2016 Shanghai. Elsevier B. V., Shanghai.

Mattioli, G., Lucas, K., Marsden, G., 2017. Transport poverty and fuel poverty in the UK: from analogy to comparison. Transport Pol. 59, 93–105. https://doi.org/10.1016/j.tranpol.2017.07.007.

Mattioli, G., Roberts, C., Steinberger, J.K., Brown, A., 2020. The political economy of car dependence: a systems of provision approach. Energy Res. Social Sci. 66, 101486 https://doi.org/10.1016/j.erss.2020.101486.

Melchert, T., 2011. Foundations of Professional Psychology, first ed. Elsevier B. V. first ed.

Messick, S., 1966. The psychology of acquiescence: an interpretation of research evidence. ETS Res. Bull. Ser. 1966 https://doi.org/10.1002/j.2333-8504.1966.tb00357.x i–44.

Middlemiss, L., Gillard, R., 2015. Fuel poverty from the bottom-up: characterising household energy vulnerability through the lived experience of the fuel poor. Energy Res. Social Sci. 6, 146–154. https://doi.org/10.1016/j.erss.2015.02.001.

Minister for Agriculture, Environment and Rural Affairs, 2022. Climate Change (No. 2) Bill. Northern Ireland Assembly.

MORI Scotland, Ipsos, Alembic Research Ltd, 2020. Research into the Lived Experience of Fuel Poverty in Scotland, People, Communities and Places. Scottish Government.

Mullen, C., Marsden, G., 2016. Mobility justice in low carbon energy transitions. Energy Res. Soc. Sci., Energy demand for mobility and domestic life: new insights from energy justice 18, 109–117. https://doi.org/10.1016/j.erss.2016.03.026.

National Audit Office, 2003. Warm Front: Helping to Combat Fuel Poverty - National Audit Office (NAO) Report [WWW Document]. Natl. Audit Off. URL, 3.18.2022. https://www.nao.org.uk/report/warm-front-helping-to-combat-fuel-poverty/.

Northern Ireland Department for the Economy, 2021. Energy Strategy - Path to Net Zero Energy. Department for the Economy.

Northern Ireland Housing Executive, 2016. House Condition Survey [WWW Document]. URL, 3.18.2022. https://www.nihe.gov.uk/Working-With-Us/Research/House-Condition-Survey.

Northern Ireland Housing Executive, 2022. Affordable Warmth Scheme [WWW Document]. URL, 3.26.2022. https://www.nihe.gov.uk/Housing-Help/Affordable-Warmth-Boiler-Replacement/Affordable-Warmth-Scheme.

Oireachtas, H. of the, 2021. Climate Action and Low Carbon Development (Amendment) Act 2021 – No. 32 of 2021 – Houses of the Oireachtas [WWW Document]. URL, 4.19.2022. https://www.oireachtas.ie/en/bills/bill/2021/39.

Rao, F., Tang, Y.M., Chau, K.Y., Iqbal, W., Abbas, M., 2022. Assessment of energy poverty and key influencing factors in N11 countries. Sustain. Prod. Consum. 30, 1–15. https://doi.org/10.1016/j.spc.2021.11.002.

Robinson, C., Mattioli, G., 2020. Double energy vulnerability: spatial intersections of domestic and transport energy poverty in England. Energy Res. Social Sci. 70, 101699 https://doi.org/10.1016/j.erss.2020.101699.

Rudge, J., Gilchrist, R., 2005. Excess winter morbidity among older people at risk of cold homes: a population-based study in a London borough. J. Public Health 27, 353–358. https://doi.org/10.1093/pubmed/fdi051.

Shi, K., Yang, Y., De Vos, J., Zhang, X., Witlox, F., 2022. Income and commute satisfaction: on the mediating roles of transport poverty and health conditions. Travel Behav. Soc. 29, 297–307. https://doi.org/10.1016/j.tbs.2022.07.004.

Simcock, N., Jenkins, K.E.H., Lacey-Barnacle, M., Martiskainen, M., Mattioli, G., Hopkins, D., 2021. Identifying double energy vulnerability: a systematic and narrative review of groups at-risk of energy and transport poverty in the global north. Energy Res. Social Sci. 82, 102351 https://doi.org/10.1016/j.erss.2021.102351.

Social Exclusion Unit, 2003. Making the Connections: Final Report on Transport and Social Exclusion [WWW Document]. URL, 3.10.2022. http://www.ilo.org/emppolicy/pubs/WCMS_ASIST_8210/lang–en/index.htm.

Sovacool, B.K., Furszyfer Del Rio, D.D., 2022. We're not dead yet!": extreme energy and transport poverty, perpetual peripheralization, and spatial justice among Gypsies and Travellers in Northern Ireland. Renew. Sustain. Energy Rev. 160, 112262 https://doi.org/10.1016/j.rser.2022.112262.

Sovacool, B.K., Furszyfer Del Rio, D., Griffiths, S., 2020. Contextualizing the Covid-19 pandemic for a carbon-constrained world: insights for sustainability transitions, energy justice, and research methodology. Energy Res. Social Sci. 68, 101701 https://doi.org/10.1016/j.erss.2020.101701.

Sovacool, B.K., Martiskainen, M., Furszyfer Del Rio, D.D., 2021. Knowledge, energy sustainability, and vulnerability in the demographics of smart home technology diffusion. Energy Pol. 153, 112196 https://doi.org/10.1016/j.enpol.2021.112196.

Thomson, H., Bouzarovski, S., Snell, C., 2017. Rethinking the measurement of energy poverty in Europe: a critical analysis of indicators and data. Indoor Built Environ. 26, 879–901. https://doi.org/10.1177/1420326X17699260.

Torjesen, I., 2022. NHS leaders warn of "intolerable" winter pressure without action on rising energy prices. BMJ 378, o2060. https://doi.org/10.1136/bmj.o2060.

Upham, P., Sovacool, B.K., Monyei, C.G., 2022. Energy and transport poverty amidst plenty: exploring just transition, lived experiences and policy implications in Iceland. Renew. Sustain. Energy Rev. 163, 112533 https://doi.org/10.1016/j.rser.2022.112533.

van de Mortel, T.F., 2008. Faking it: social desirability response bias in self-report research - southern Cross University. Aust. J. Adv. Nurs. 25, 40–48.

Watson, D., Maitre, B., 2015. Is fuel poverty in Ireland a distinct type of deprivation? Econ. Soc. Rev. 46, 267–291.

Zhao, J., Dong, K., Dong, X., Shahbaz, M., 2022. How renewable energy alleviate energy poverty? A global analysis. Renew. Energy 186, 299–311. https://doi.org/10.1016/j.renene.2022.01.005.