

## ARTICLE OPEN



# A cross-country analysis of sustainability, transport and energy poverty

Dylan D. Furszyfer Del Rio<sup>1,2,3</sup>✉, Benjamin K. Sovacool<sup>1,4,5</sup>, Steve Griffiths<sup>6</sup>✉, Aoife M. Foley<sup>2,6</sup> and Jonathan Furszyfer Del Rio<sup>7</sup>✉

Poverty impacts people's choices and opportunities and can perpetuate a disadvantaged status. Poverty remains a prevalent global issue due to disproportionate wealth distribution, which often translates to inequality in energy consumption and emissions. This research investigates if low-income households and minorities from four countries with very different national cultures, contexts, and levels of wealth experience a 'double energy vulnerability', a concept that simultaneously positions people at heightened risk of transport and energy poverty. Our research identifies that low-income households and minorities are at higher risk of simultaneously experiencing energy and transport poverty regardless of the national context in which they live. Our study also contests the achievement of Sustainable Development Goals (SDGs) by 2030, showing that even in relatively wealthy countries, many individuals still face energy and transport poverty. We conclude that global sustainable development requires significant shifts in policy action, resource distribution and investment in social services.

*npj Urban Sustainability* (2023)3:41; <https://doi.org/10.1038/s42949-023-00121-0>

## INTRODUCTION

Nearly half of the global population (47%) lives below the poverty line<sup>1</sup> (US\$ 6.85 per day) with limited access to basic services<sup>2</sup>. Although poverty rates have substantially decreased since the year 2000, recent health and geopolitical events, such as the Covid-19 pandemic, have reversed much of this progress with particularly detrimental impacts on vulnerable groups<sup>3</sup>. In turn, eradicating poverty by 2030, as stipulated in the Sustainable Development Goal (SDG) No 1, seems out of reach. In fact, by 2030, over 430 million individuals are projected to still be living in such poverty conditions<sup>4</sup>. SDG 7, which deals with access to affordable, reliable, sustainable and modern energy for all, also seems increasingly distant from its 2030 target. About one billion people still lack energy access<sup>5</sup>, and the World Health Organization estimates that about one-third of the global population (circa 2.4 billion people) still lack access to clean cooking technologies<sup>6</sup>. In Asia alone, over 1.5 billion people still rely on solid and biofuels to satisfy their cooking needs<sup>7</sup>. As a consequence, the International Energy Agency (IEA) estimates that close to 280 million people must gain access to clean cooking technologies annually to achieve the 2030 SDG 7 targets.

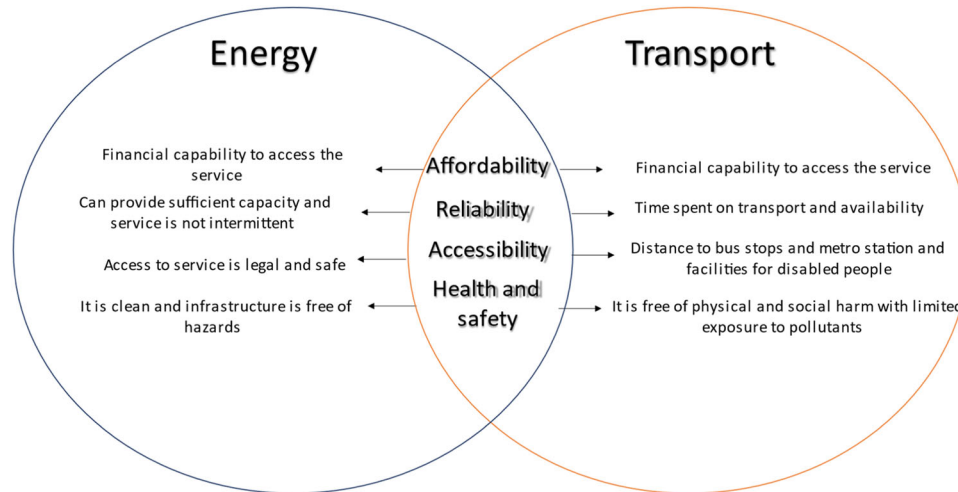
Poverty thus remains a prevalent issue with income and wealth disproportionately distributed globally, where the top 1% of income earners benefit the most from economic growth<sup>8</sup>, and the richest five countries hold more than 45% of the global GDP. Such economic inequality translates to inequality in energy consumption as well as in emissions<sup>9,10</sup>, resulting in carbon inequality<sup>11</sup>. Other studies have shown that minority groups are more exposed to energy poverty, inequality and negative climate impacts<sup>12–20</sup>, are less likely to adopt renewable energy systems, less aware of clean energy services<sup>21–25</sup> and more likely to live in dwellings that are less energy efficient<sup>26</sup>. Although energy poverty is associated with income, it needs to be dealt with from a multidimensional perspective since it may also happen when households are not

income-poor<sup>27</sup> but are still unable to access desired energy services or maintain a comfortable temperature indoors<sup>28–30</sup>.

Transport poverty, which deals with the lack of access to the resources required for mobility<sup>31</sup>, is yet another theme that depicts how poverty exacerbates inequality through reduced mobility. Transport poverty affects numerous people worldwide due to lack of infrastructure (e.g. access to an all-weather road), the distance or time involved in travel, expenses, fuel scarcity or a combination of these issues<sup>32</sup>. Transport poverty contributes to social exclusion, imposes restrictions in choosing different modes of transport, hinders people's wellbeing, limits individuals' capacity to participate in society fully, and negatively influences productivity and personal utility<sup>33–35</sup>. Transport further cuts across several SDGs and targets, especially those dealing with health (SDG 3), education (SDG 4), energy (SDG 7), infrastructure (SDG 9), mitigating inequalities (SDG 10) and sustainable cities and communities (SDG 11)<sup>36</sup>. Although transport plays a key role in achieving the SDG targets, inequalities are more pervasive among vulnerable groups and, similar to energy, result in a hindrance to attaining SDG targets<sup>37–39</sup>. To put transport inequality in perspective, while about half the world's urban population can access convenient public transport, over 70% of Africa's rural population is still unconnected to transport systems and infrastructure<sup>40</sup>.

Building on this background, our research centres on the themes of energy and transport poverty. We argue that minorities and vulnerable groups are more likely to experience a 'double energy vulnerability', a situation that positions people at a higher risk of simultaneously experiencing transport and energy poverty<sup>12,41,42</sup>. In doing so, we consider different energy and transport poverty dimensions<sup>32,43–45</sup> illustrated and summarized in Fig. 1. As shown, energy and transport poverty are multidimensional, interrelated and often occur simultaneously. The key energy and transport poverty themes of this paper, affordability, reliability,

<sup>1</sup>Science Policy Research Unit (SPRU), University of Sussex Business School, Brighton, UK. <sup>2</sup>School of Mechanical and Aerospace Engineering, Queen's University Belfast, Belfast BT9 5AH, UK. <sup>3</sup>Khalifa University of Science and Technology, Abu Dhabi, UAE. <sup>4</sup>Department of Earth and Environment, Boston University, Boston, MA, USA. <sup>5</sup>Center for Energy Technologies, Department of Business Development and Technology, Aarhus University, Aarhus, Denmark. <sup>6</sup>UK School of Engineering, The University of Manchester, Manchester, UK. <sup>7</sup>Graduate School of Business, Stanford University, Stanford, CA, USA. ✉email: d.d.furszyfer-del-rio@sussex.ac.uk



**Fig. 1** The overlap between energy and transport poverty in the key dimension of energy poverty. Source, authors but compiled from refs. <sup>32,43–45</sup>.

accessibility and health and safety, are depicted along with how they are manifested in the energy and transport domains.

Our rationale for exploring the overlap of energy and transport poverty is that its causes and subsequent impacts on individuals remain vastly underexplored<sup>42</sup> and the common role of energy consumption in this overlap can impose a particularly high toll on low-income households. Additionally, prior research<sup>31,46,47</sup> provides empirical evidence that policies aimed at decarbonization can exert considerable influence on both energy and transport poverty, thus exacerbating the vulnerabilities of energy users. The bulk of this work, however, remains focused on countries that are Western, Educated, Industrialized, Rich Democracies, or WEIRD countries.

This research explores the intersecting issues of energy and transport poverty in a collection of mostly non-WEIRD countries. It does this through carefully designed qualitative and quantitative methods conducted in Northern Ireland, Mexico, the Republic of Ireland and the United Arab Emirates (UAE). We selected these countries following recent research calls from the energy, climate, geography, psychology and political science literature calling from original data collection from non-WEIRD countries<sup>30,48–50</sup>. Moreover, we argue that policy considerations for non-WEIRD countries are distinct and offer a breadth of contexts that need to be studied to address global climate targets. In developing countries, for instance, policy considerations for energy sufficiency should focus on improving energy accessibility and affordability, while in most WEIRD countries, the reduction of energy consumption by technical and non-technical means is the priority<sup>51</sup>. Furthermore, it is often sense of place, and cultural and national context shaped strongly by factors such as industrialization or wealth, that determine public preferences for the adoption of new low-carbon innovations such as solar power<sup>52</sup> and wind energy<sup>53,54</sup> as well as energy transmission networks<sup>55</sup>, coal phase-out<sup>56</sup>, and shale gas development<sup>57</sup>. Place-based attachment, or the spatial setting of energy and climate policy, is a recurring theme in the geography, urban studies, and rural studies literatures in revealing the connection that communities have with their geographic location or homeland<sup>58,59</sup>, and yet it is one that differs meaningfully across the Global North and Global South Divide, or the WEIRD and non-WEIRD divide<sup>60,61</sup>.

Our methods include nationally representative surveys with both qualitative and quantitative questions. The surveys were distributed in the UAE ( $N = 1141$ ), Mexico ( $N = 1205$ ) and Ireland (inclusive of the Republic and Northern Ireland) ( $N = 1860$ ). We also conducted seven public focus groups: two in the UAE

( $N = 16$ ), three in Northern Ireland ( $N = 24$ ) and two in Mexico ( $N = 18$ ) with rural and urban participants. We considered it important to approach individuals from rural and urban backgrounds to highlight differences in access, needs and barriers to transport and energy services. Finally, we conducted 138 household interviews with extremely vulnerable groups in 15 locations distributed in (1) the Mexico City Metropolitan Area (MCMA), where we conducted interviews with slum dwellers living in irregular settlements, (2) Northern Ireland, where we approached Gypsies and Travellers and, (3) the United Arab Emirates, where we interviewed temporary migrants living in labour camps. Given the systematic exclusion of transport and energy planning from these groups, we decided it was extremely important to conduct direct interviews with each group. Through this mixed method approach, our study aims to scrutinize the validity of the double energy and transport vulnerability across diverse contexts and countries by unpacking vulnerable groups' reported lived experiences and coping strategies. From a methodological standpoint, we seek to enhance the accuracy and nuance of the indicators that contribute to developing a more comprehensive transport poverty index (TPI) and energy poverty index (EPI).

Our results show that energy and transport poverty often coincide and that although these issues are most notable for minorities and individuals living in periurban and rural areas, non-vulnerable groups living in urban areas can also experience energy and transport poverty irrespective of the wealth and level of development of the countries in which they live. In this regard, we note that these types of poverty are exacerbated by peripheralization and spatial injustices<sup>62,63</sup> resulting from the unjust and unequal allocation of resources and opportunities for engagement. Moreover, our analysis reveals that energy and transport poverty cannot be explained solely by affordability, which is commonly assumed to be the main issue in relatively poorer countries, such as Northern Ireland and Mexico. Instead, our findings show that inadequate infrastructure contributes to access to and the reliability of energy and transport services. Further, broader social and economic contexts play a crucial role in determining individuals' ability to make productive use of these services. Finally, our research contests the 2030 timeline for achieving the SDGs by demonstrating that, even in countries with abundant resources and high per capita income, many people experience similar multidimensions of poverty, albeit often manifested differently based on context. Hence, achieving the SDGs over anytime will require integrated, focused consideration of both energy and transport poverty, their overlaps and the

**Table 1.** Illustrative statements from our participants about difficulties in affording energy services.

Respondent	Jurisdiction	Confirmatory statement
UAEU04	UAE	30 to 35% of my income goes to cover my energy bills. I want to move out of this place because I don't want to continue paying 5K on utility bills.
UAER03	UAE	We belong to the low-income category, we are not paid well, and we cannot afford many things. We need to be extra careful about how we spend our money. I would say, expats, like me [Asians], all of us are having problems paying for energy because it is very expensive.
Teo10	Mexico City	Like everyone that lives in this area, it is often the case that you either complete to pay for the gas and electricity or you cut on your transport and car use.
CHI06	Mexico City	Because energy prices are now too high, we cook with wood more often, maybe once or twice every week, especially when I know preparing the food will take a while. Unlike gas, we get the wood for free.
GR16	Northern Ireland	I struggle to pay the bills. Sometimes, I do not put on the heating at all, even if it is winter and I am freezing to death. Sometimes in winter, I am sick for a long time, and I have depression, so everything is worse. Freezing, with no money, just stay underneath all day. That's my life in winter.
NIR&UFG06	Northern Ireland	The cost of energy for low-income people like myself is impossible to afford. Period. Families and pensioners with minimum wage cannot keep their homes warm during winter. That is the cruel reality. People now are facing cold, people now are dying or ill because they do not have money to pay their energy bills. Governments have ignored the poorest for decades. It is a matter of survival; you pay for your heating or freeze to death.

Source, authors.

extent to which sub-national context plays a role in hindering the achievement of SDGs at the national, regional and global levels.

## RESULTS

Our results are disaggregated following the themes of affordability, reliability, accessibility and health and safety. We reflect on these themes by capturing the lived experiences of individuals through the focus groups and household interviews conducted. Later, we present our survey results, where we elaborate on the transport and energy nexus and how these dimensions of poverty often overlap and are more recurrent among vulnerable groups

### Affordability in transport and energy services

Income is central to affording energy and transport services. Put simply, having a lower income makes it more challenging to pay for or access these services. When affordability becomes an issue, often, individuals try to reduce the services they consume, cut the consumption of other services or products, and incur debt and/or drain their savings. Affordability becomes more relevant when energy or transport becomes households' main expenditure<sup>12,20</sup>.

In terms of energy affordability, participants in our research, regardless of their location, elaborated on the idea that energy bills represented a burden within their household expenditure as Table 1 depicts. In the UAE, energy bills for those working as labourers could represent between 30 to 35% of total income; in Northern Ireland, being unable to pay for energy services represented, as one person stated, "*a matter of survival; you pay for your heating or freeze to death*". Meanwhile, in Mexico, more than one participant expressed that since the increase in energy prices, their families have been pushed to "*cook with wood more often*".

The consequences of being unable to afford their energy bills took a toll on our participants. The effects ranged from stealing electricity to closing their business. We found it surprising, for instance, that more than half of our Mexican sample resorted to the first practice either because their households were irregularly established or because they considered this service truly expensive. To these dynamics, ECA07 and UAEU03 commented, respectively:

I stopped paying for my electricity since the prices had increased. I am not a thief, and I do not like stealing; I just cannot afford this service anymore.

I used to own a salon, and my bills usually came to about 4,000/5,000 dirhams. Then, one day, it came to about 8,000 dirhams. I was shocked. How come it increased so much? Because of that sudden unexpected change, I had to close my salon.

The difficulties affording transport services were also a constant struggle in our participants' lives, regardless of their location. In this sense, while for temporary migrants from the UAE, paying for a single trip to the city centre would affect their entire family's monthly income, and therefore, they "*won't be able to do any fun stuff for the rest of the month*". For participants from Mexico and Northern Ireland, the increasing costs of transport services were comparable to "*renting a flat*" or even "*more expensive than*" their "*housing mortgage*". Table 2 illustrates participants' experiences affording transport.

### Reliability in transport and energy services

Energy reliability deals with dependable and predictable energy supply with consideration of all aspects of energy, including generation, transmission and distribution<sup>44</sup>. The importance of energy reliability is based on an energy supplier's capacity to provide customers with the energy they require or demand with confidence<sup>64</sup>. In terms of transport, we consider that reliability deals with time spent commuting, transportation system capacity, system usage and speed<sup>65</sup>. Transport reliability is important because it is a key component of the transport system's efficiency.

Energy reliability was a concern in all the countries studied here, as depicted in Table 3. However, and perhaps unsurprisingly, issues around the network's capacity and unpredictable outages were more recurrent with vulnerable groups living in periurban and rural areas. For instance, a participant from Ecatepec, Mexico, mentioned that due to power outages and poor energy access, residents were "*always in the dark*" or because they are Gypsies, fixing blackouts was never the government's priority. In other cases, also presented among the Gypsies and Travellers and slum-dwellers communities, participants commented that since the "*energy is too low*" when they use the "*drier or washing machine*"

**Table 2.** Illustrative statements from our participants about difficulties affording transport services.

Respondent	Jurisdiction	Confirmatory statement
NIR&UFG03	Northern Ireland	I work in Belfast, and I do not work from home, and the train ticket every month is more expensive than my housing mortgage. It feels like I always have debts.
A-FGUNIO1	Northern Ireland	I cannot drive at free will without feeling constrained that driving is going to drain my pockets.
CDMXR	Mexico City	I travel from the State of Mexico to Mexico City and I spend a fortune on transport. I think it is cheaper to rent a flat and live near where I study. I spend so much on taxis and buses that it has been years since I have been unable to buy new clothes.
Neza03	Mexico City	With my income, sometimes it is not enough to pay for my transport, and many times I have to sacrifice having lunch because otherwise, I cannot afford my way back home. The only extra money I have, I use it to buy food for my children. That is why we stopped paying for our electricity and started stealing it because we did not have money to afford both. I cannot keep up this rhythm; my body is in pain, and I am completely demotivated.
CP01	UAE	I cannot afford a taxi of 100 Dirhams in a day; that would represent a big chunk of my income. Spending that much in one taxi means that my family will receive less money that month, and I won't be able to do any fun stuff for the rest of the month.

Source, authors.

**Table 3.** Illustrative statements from our participants that capture the lived experiences of unreliable energy systems.

Respondent	Jurisdiction	Confirmatory statement
ECA05	Mexico City	They need to improve the electricity services because around here they cut the lights very often. So we are always in the dark. There are times when we are without light for hours, even days. A few months ago, they even cut our electricity for over a month; they wouldn't mind explaining what went wrong because we are the most abandoned town in all the Ecatepec's communities.
Neza01	Mexico City	My fridge stopped working because the electrical power is intermittent, so whenever the electricity is back, our appliances stop working because it returns with too much power.
GR20	Northern Ireland	I know electricity blackouts are a priority, but here, for some reason, they are not.
GS1	Northern Ireland	The electricity is a problem because you can use the washing machine, but there is not enough power to use a drier, so you need to go and drive to a laundry place to dry your clothes. Because no one has their own meters, there is not enough power to use some appliances.
ARV03	UAE	Sometimes the AC stops working and when it stops working, there is nothing we can do. We spend two or three days without using the AC and suffering at temperatures above 44, sharing the room with 12 people. This has had negative impacts on our health and wellbeing.
CCMV02	UAE	Sometimes the AC is suddenly off and stops working. It takes two days to fix it. Sometimes the lights also stop working. Not having AC is the worse. I lived here for more than a decade, and I'll never be able to sleep at 44 °C. No one can.

Source, authors.

the “*electricity cuts off*”. In the UAE, on the other hand, more than one participant commented that lack of agency in energy decision making has led to a chronic deterioration of health and even “*suffering*” when air conditioning is not available in extreme heat.

Similar to energy reliability, transport reliability issues were more notorious in rural and periurban areas, with more deleterious impacts on low-income and vulnerable groups. Participants from our focus groups commented, for instance, that in the UAE, public transport is “*unreliable*” and due to the time spent commuting, “*they didn't have time to do anything else*”. Time spent on public transport was perhaps the most common concern expressed among slum-dwellers in Mexico City, with some participants spending up to “*six hours*” commuting and others highlighting that time spent on public transport has had negative impacts on their health and “*academic performance*”. In Northern Ireland, issues around reliability were varied, and these ranged from “*timetables never*” being accurate and that they could spend “*up to one hour*” waiting “*for the next bus to come*” to being “*completely dependent on owning a car if you live in the countryside*”. Table 4 below presents numerous statements about the unreliability of transport in the countries studied.

### Accessibility to transport and energy services

Energy access, in our study, includes safe, clean and legal energy being available when needed<sup>45</sup>. Hence, energy access should not negatively impact a user's wellbeing and health and should not have a toll on their integrity. Regarding transport accessibility, the concept deals with the connectivity to basic services (e.g. schools, hospitals and employment opportunities, etc.) and people's needs and abilities to use such services<sup>66</sup>. Meanwhile, private transport options depend on an individual's resources (mainly financial) and social networks<sup>67</sup>.

Participants from all countries studied presented issues regarding energy access, as Table 5 shows. However, energy access concerns were more prominent in Mexico, where the lack of infrastructure constrained individuals from accessing electricity grid services in the first place. For instance, one participant from Tlahuac commented that because her family lived “*in a common rural land, CFE did not want to provide them with this service*”. As a consequence, their only option to access this service was stealing it. Another participant from Mexico City elaborated that since he does not have energy access (gas and electricity), “*there is no other way, I cook and heat the water with wood*”. Even in more developed countries, like Northern Ireland, infrastructure limits users' energy access. One participant commented that “*the*

**Table 4.** Illustrative statements from our participants that capture the lived experiences of unreliable transport systems.

Respondent	Jurisdiction	Confirmatory statement
NIR&UFG03	Northern Ireland	I have to go by car to my work because public transport in rural areas is unpredictable; buses are terrible, timetables are never accurate, and I cannot take the train from where I am. On the other hand, Belfast is awful. I couldn't live there. My head would explode because you could be on a bus for 30 min without moving
A-FGRNI07	Northern Ireland	You are dependent on owning a car if you live in the countryside. The dark side is that not everyone is attainable to own a car. And in rural areas, only a few learn to drive because there are only a few instructors. So the prices of having an instructor are very high for people living in rural areas. It could be up to 20 pounds an hour.
MCMAU05	Mexico City	I used to work as a bus driver, and I recognize that the transport in the State of Mexico is all messed up; it is expensive, unsafe, and unreliable.
MCMAR04	Mexico City	I spend six hours on public transportation every day. Spending so much time commuting affects my academic performance. I feel extremely tired when I arrive at school and have little time to study and do my homework. My life and grades would tell a different story if I lived near where I study.
CP05	UAE	Buses are extremely unreliable. We never know when the next will come or how to use them. Because there is no shade near the bus stop, we cannot afford to spend 45 min waiting for the next bus to come. That will kill us.
UAEU01	UAE	I used to work in Dubai Industrial City, which is beyond Al Maktoum airport, and I used to live in Ajman. I used to wake up to work at 4 am to get to work at 8 am. I left work at 6:00 pm and got home at 10:30 pm. I didn't have time to do anything else because of the time I spent commuting.

Source, authors.

**Table 5.** Illustrative statements from our participants that capture the lived experiences of inequities in energy access.

Respondent	Jurisdiction	Confirmatory statement
MCMAR04	Mexico City	In Tlahuac, where I live, which is common rural land, CFE did not want to provide us with this service because we are a rural community. So we never had electricity poles installed. We had to steal our electricity from a distant urban area; it was the only way to have access to it.
Teo08	Mexico City	Currently, we live in darkness because some crooks stole all the wires from the street. I think they did it to sell the copper. We do not know when the electricity will come back. But I am sure that the authorities were accomplices in this act; there is no way they could have done this on their own.
CCMV4	UAE	We do not have a voice over energy decisions making in the camp. The services are there, but we cannot use them accordingly.
CCMV01	UAE	I do not have control over the room's temperature; that is decided by my roommates, not me. It is like the energy service is there but it is not for me because I cannot use it according to my preferences.
GR13	Northern Ireland	Heating pipes often freeze in winter. So the heating goes off all the time. We are unable to keep our caravans warm because the infrastructure where we live is broken.
CA6	Northern Ireland	This is different to other camps, we live in a yard, so although the energy is cheaper, the power is too low. It is so low that if someone from another caravan is using their kettle, we cannot use ours because the power is insufficient and the lights would go off. So we have access to energy, but we cannot use it freely.

Source, authors.

infrastructure where we live is broken" and therefore, their heating systems "goes out of all the time". In the same vein, participants from Belfast also experienced trouble accessing this service because of high costs and the nature of their dwellings (particularly nomadic Gypsies and Travellers living in caravans). In the UAE, heating is not the issue; rather, cooling as an energy service becomes consumers' main concern. In the UAE, labourers residing in worker compounds lack agency, while social and spatial exclusion limits their energy access. One participant put it simply when he commented: "We do not have a voice over energy decision making in the camp".

Transport accessibility, like energy, was a multidimensional challenge experienced in all countries. This ranged from a lack of facilities for disabled people and people living in rural areas to not having sufficient means to commute to the city. Our research notes that all vulnerable groups living on the city's outskirts had limited access to public transport services. In Belfast, for instance, a focus group participant living in a peri-urban area commented that infrastructure for public transport in his location was "inexistent". Historically low fuel prices in the UAE, once subsidized but now simply untaxed, have led to policies prioritizing single-car

use. Consequently, low-income households that cannot afford a personal vehicle have limited options to commute to the city affordably. One participant commented, "In many places in Dubai and the UAE, there is no form of public transport". In Mexico City, although public transport could reach isolated locations, they had limited options and public vehicles' design limits usability for people with disabilities. Table 6 recapitulates participants' experiences regarding transport accessibility.

### Health and safety difficulties experienced in transport and energy systems

In this section, we not only comment on how users may compromise their health and safety through the use of energy and transport services but also on how the lack of, or the difficulties in affording, energy or transport has negatively impacted their wellbeing.

In terms of energy, participants from Northern Ireland mainly elaborated on issues about how not turning their heating on during the cold weather season has put a toll "their mental and physical health". In Mexico, participants' health was mostly compromised by combusting solid fuels; as a consequence of

**Table 6.** Illustrative statements from our participants that capture the lived experiences of transport inaccessibility.

Respondent	Jurisdiction	Confirmatory statement
ECA05	Mexico City	I have a hernia, and my spine is messed up, and the combis and busses do not have facilities for people with disabilities. So every time I hop in, I feel that my health deteriorates.
CHI02	Mexico City	We should have more options regarding transport because, here, where we live, we only have access to mototaxis and combis. Local authorities should promote bicycles, electric scooters, and other means of transport Mexico City has.
FGUNI05	Northern Ireland	Northern Ireland has just retained progress. Not many people where I live have a chance to use public transport because it is inexistent; you need a car to get from one place to another.
A-FGUNI03	Northern Ireland	The infrastructure in Northern Ireland is either for cars or busses; trains are a disaster.
UAEU04	UAE	I have lived in Dubai my whole life and still haven't figured out how to use the bus. I just don't get it. It is not easy to understand. I think understanding how the bus works is the biggest issue; it is extremely time-consuming and difficult.
UAEU08	UAE	The Metro in Dubai doesn't take you to all the places you need to go, taxis could be extremely expensive, and busses could take ages to come. In many places in Dubai and the UAE, there is no form of public transport, and walking is impossible; either the distances are too big, or the weather makes it impossible.

Source, authors.

**Table 7.** Illustrative statements from our participants about declining health and safety due to energy poverty.

Respondent	Jurisdiction	Confirmatory statement
FGUNI04	Northern Ireland	I am autistic, and worrying about paying my bills definitely builds upon my mental and physical health. It is a constant worry that you simply cannot escape it.
CA5	Northern Ireland	I had chest infections during the winter, and I ended up in hospitals because of not turning the heating on. So not being able to keep my caravan warm makes me very nervous about getting ill again. The worries get worse because I have children now, and I just want them safe and not have any chest infections because of the cold.
A-FGRNI07	Northern Ireland	We use wood to keep the house warm. It only heats one room, but it is cheaper than other fuels. I do not know if it is the cold weather or burning wood, but I have been coughing more often now.
ECA08	Mexico City	Look how low the electricity cables are. This is a real danger for all pedestrians. The lack of interest in fixing this issue shows how negligent the government really is. They do not care if people die if they save a few pesos for their pockets.
NEZA06	Mexico City	In winter, I get a lot of chest infections and chest pains, I have trouble breathing and burning wood is making it all worse. I'm afraid of dying because of this.
CCMVM02	UAE	When I was sleeping next to the AC I was sick all the time. I was coughing and sneezing all day. My throat hurt, and I had headaches.
MBZ01	UAE	In my country, we did not have AC, so when I first came here, I was always getting sick because of it. Now, I do not get sick anymore. Now, I only wake up with chest pains and a hurt throat.

Source, authors.

this continued practice, some participants even mentioned that they were “*afraid of dying*” due to the health risks this practice posed. It is worth noting that even in developed countries, such as Northern Ireland, some participants also resorted to using wood to heat their food and homes. Although such a practice, unsurprisingly, was presented at the lower scale. In the UAE, the lack of agency for labourers and the cultural change that entailed using an AC system at high levels represented the main cause of “*getting sick all the time*.” Table 7 presents how the lack of and access to fuels have threatened our participants’ health and safety.

Participants from all countries also raised concerns about health issues emerging from using or lacking transport services. For instance, in the UAE, most participants commented that the extreme weather conditions, in tandem with the lack of infrastructure to walk and cycle, have put their lives at risk. In Mexico and Northern Ireland, on the other hand, most people commented on issues about safety, irresponsible driving and lack of infrastructure, as Table 8 illustrates.

Another prominent theme, although this only emerged in Northern Ireland and Mexico, was that related to violence against women in the mobility dimension. This sort of violence consisted

of not only verbal and physical abuse, but also sexual harassment, which was more prominent in Mexico. Table 9 captures the lived experiences of women facing acts of violence in the mobility dimension.

### The transport and energy poverty nexus

To further explore this “double vulnerability” of energy and transport poverty, we employed the survey instruments rolled out in Mexico, the UAE and Ireland. First, we selected five questions related to energy vulnerability and six related to transport inaccessibility. Second, we dichotomized each level within the 11 questions to produce eight dummy variables from the energy poverty questions and 12 dummy variables from the transport poverty questions (see in Supplementary Table 1). Since the structure of the variables is nominal or ordinal, we used nonlinear principal components analysis (NLPCA)<sup>68,69</sup> to derive the first canonical variables in the energy and transport poverty questions. In turn, each dummy variable helps identify the direction of the components. As expected, the first dimension of the energy poverty index (EPI) and the first dimension of the transport poverty index (TPI) are positively correlated ( $\rho = 0.552$ ). Figure 2

**Table 8.** Illustrative statements from our participants about declining health and safety in transportation.

Respondent	Jurisdiction	Confirmatory statement
A-FGUNI04	Northern Ireland	The other time, there were a group of drunks spitting over the bus and fighting with each other, and that was in the morning at 7:30 am. Seeing that behaviour definitely has held me back from using public transport. It made me feel extremely unsafe.
NIR&UFG08	Northern Ireland	Some of the routes are also very dangerous for the busses. Either the infrastructure is too poor, or people drive too fast. So you never really feel safe on the bus. I often think I could die at any time.
GS5	Northern Ireland	From here, walking down the road is a bit dangerous; you can easily get killed because the lorries go very fast up this road.
MCMAR01	Mexico City	I also think that being in traffic affects your health because of all pollution and toxic gasses you are inhaling.
CHI01	Mexico City	If we are paying for a service, the least we could expect is to be clean and safe. Well, transport in this area is none of it, in fact, it is the opposite: dirty and unsafe. Every day, people are robbed and murdered in transport in Mexico. Plus, the drivers do not care about their passengers. Many times they are drunk driving or drugged. Public transport drivers are perhaps the most irresponsible people in Mexico City.
Neza08	Mexico City	well, I've been knocked out by cars twice. Once I was run over by combi, and the second time, a gas truck hit me. Since that truck driver struck me, I cannot walk well. The last time I had an accident cycling was this summer. It was raining too hard, and I didn't see a pothole, I kid you not, I went flying two meters hands down.
CCMV06	UAE	Never mind, you could not walk or cycle to the city. You would die dehydrated before getting there, especially in summer.
CP10	UAE	There is no infrastructure for cycling or walking. It is not safe to do that around here. Those options do not exist for us.

Source, authors.

shows the linear relationship between the first dimension of the energy poverty index (EPI) and the first dimension of the transport poverty index (TPI). The NLPCA loadings and the crosswalk for the questions and their respective recoded dummy variables are summarized in Supplementary Fig. 1.

We also assessed if EPI and TPI vary by gender and over minority vs non-minority populations. Figure 3 shows the pairwise comparisons for each pair of profiles. First, Fig. 3A shows that minority groups, on average, have a higher TPI than non-minority respondents, with statistically significant results at the 95% confidence level. In every comparison, females also have a larger TPI score than their male counterparts, and the results are statistically significant at the 95% confidence level. Second, Fig. 3B shows that minority groups also have a higher EPI than non-minority respondents, on average, and with statistically significant results at the 95% confidence level. However, energy poverty is, on average, equivalent between male and female populations within minority groups and balanced between male and female respondents from non-minority groups. Overall, our results suggest that irrespective of how developed the countries are, minority groups are often in a more vulnerable position in terms of energy and transport access.

Our qualitative data, resulting from the household interviews, also illustrates that energy and transport poverty could be exacerbated by discrimination and government inaction emerging from thematic around peripheralization, and spatial justice, as Table 10 depicts. Indeed, regardless of the country, participants often commented on their lack of representation and constant exclusion in energy and transport services decision-making and how this is reflected in perpetual marginalization. Comments in the UAE mostly refer to the higher electricity prices paid by expatriates and UAE National citizens.

## DISCUSSION

Our research has shown that although energy and transport are often studied separately, they share a number of similarities. Specifically, both involve energy consumption for services that could represent a significant portion of vulnerable groups' income; both are currently linked to the consumption of fossil fuels with volatile prices that can significantly and simultaneously impact

energy and transport affordability; and finally, decarbonization policies, particularly those related to transport electrification, are likely to have impacts on both types of poverty given the sector coupling involved. Hence, we argue that energy and transport poverty are increasingly intertwined and must be considered collectively<sup>30,42</sup>.

Our household interviews also showed how vulnerable groups are more prone to experience energy and transport poverty simultaneously. For instance, in terms of energy, we found it surprising that most of the Gypsies and Travellers we interviewed spent at least 20% of their income to cover their energy bills. While in terms of transport, more than 80% of our Mexican sample commented they struggle to afford this service, which in many cases, represented their biggest expenditure. In the UAE, the story was different. While we note that people living in labour camps had little to no agency regarding decision-making in their energy services, in terms of transport, their options were limited to using the bus since taxis were too expensive and soft mobility options (i.e. walking, cycling, or using other devices such as scooters or skates) were unavailable.

Although participants from our household interviews have learned to cope by merely going without energy or transport services, this came at a tremendous cost, where their health, integrity and well-being have been compromised. Perhaps a bit more sombre, most of the sample interviewed had little hope that their circumstances would change. Instead, participants felt that the future seemed even more gloomy due to increasing fuel prices. Meanwhile, our survey analysis corroborates that energy and transport poverty often overlap and this is particularly acute in minorities and vulnerable groups regardless of how developed the countries in which they live are. As Supplementary Table 2 shows, none of the countries in this study is poor at the macro level, although significant poverty exists within subsets of the overall national populations. This finding is consistent with other work showing that economic and social conditions can vary substantially across sub-national locations, alternatively called microregions<sup>70</sup>. Supplementary Table 2 also shows how our case countries vary by income, wellbeing, development, energy production/consumption and political factors.

Our research, therefore, contests the 2030 timeline to achieve Sustainable Development Goals (SDGs) since it shows that even in

**Table 9.** Illustrative statements from our participants about mobility and violence against women.

Respondent	Jurisdiction	Confirmatory statement
FGUNI03	Northern Ireland	My neighbour was walking back home and a guy tried to rape her a couple of weeks ago. She was followed home from the bar she was in. It was only until people heard her scream that they came out and helped her.
A-FGRNI05	Northern Ireland	For women to travel alone at night is not safe, for sure.
MCMAR06	Mexico City	My sister was on the bus; she fell asleep and woke up with the gun touching her forehead. She gave them everything she had.
MCMAR02	Mexico City	Once, I took the wrong combi going to uni. I was the only woman inside the vehicle. A man sat next to me, and he started petting my hand and touching himself. I was terrified. I didn't know what to do. It took me like five minutes to get up and leave the combi
MCMAU03	Mexico City	Now, you need always to be careful, because what happens if a crazy man is standing next to you? You react violently to his touching and words, and he may punch you or try to rape you just because he feels like doing it. Overall, I think that the experiences between males and females in public transport are different. Perhaps men's incidents are violent because, in the case of robberies, they are more often getting murdered or punched, but in the case of females is more psychological damage. They can scare you for life.
CHI03	Mexico City	At the Metro, they robbed me with a knife close to my neck. In the combi, the crooks that robbed were carrying handguns. As a woman, during peak hours, men are too abusive. They touch you, put their hands around you and put their genitals too close to you. It is disgusting. Men need to know that if we do not say anything is not because we are enjoying it. It is because we are afraid of being hurt.

Source, authors.

countries rich in resources and with a high income per capita, many individuals still face similar, yet differentially manifested, multidimensions of poverty. A shared expression of poverty is related to affordability of basic services, an issue that has been exacerbated by health and geopolitical events in recent years, such as the Covid-19 pandemic. In fact, research on this topic suggests that the recent crises have set back the 2030 Sustainable Development Agenda by five to ten years<sup>71</sup>. The challenge, under these circumstances, is then to deliver policy actions that have global influence yet are tailored to diverse national and, in many cases, sub-national contexts, explicitly accounting for marginalized and vulnerable groups. Otherwise, the international mission to deliver the SDGs by 2030, or anytime for that matter, will likely fail in terms of equity, fairness and justice<sup>72</sup>.

The results of this work show that although SDG 13 (Climate Action) and SDG 7 (Affordable and Clean Energy) are receiving considerable attention, SDG 1 (No Poverty), SDG 3 (Good Health and Well-Being), SDG 10 (Reduced Inequalities) and SDG 11 (Sustainable Cities and Communities) are all found wanting. Each of these noted SDGs gives attention in some way to “the poor and those in vulnerable situations”, yet from our research, we see that this segment of society is generally overlooked, particularly within countries that do not receive poverty attention at the macro level. In support of this finding, we argue that the SDGs, at least to date, have led mainly to discursive effects and shown limited evidence of transformative impact<sup>73</sup>. Policies focused on fairer resource distribution in tandem with investments in social services are therefore essential to fostering more coherent development goals and addressing pervasive issues such as transport and energy poverty.

In conclusion, our research reveals that minorities and low-income households are at a higher risk of experiencing energy and transport poverty simultaneously and that such patterns are exacerbated by persistent discrimination, peripheralization and spatial injustice. Moreover, we show that being exposed to this “double energy vulnerability” negatively impacts people’s health and wellbeing, and it does so soberingly across four very different national contexts. Our research also reveals that affordability is not the only dimension that must be tackled when dealing with energy and transport poverty. Rather, for people not to experience this double energy vulnerability, these services must be available, accessible, affordable and acceptable with regard to

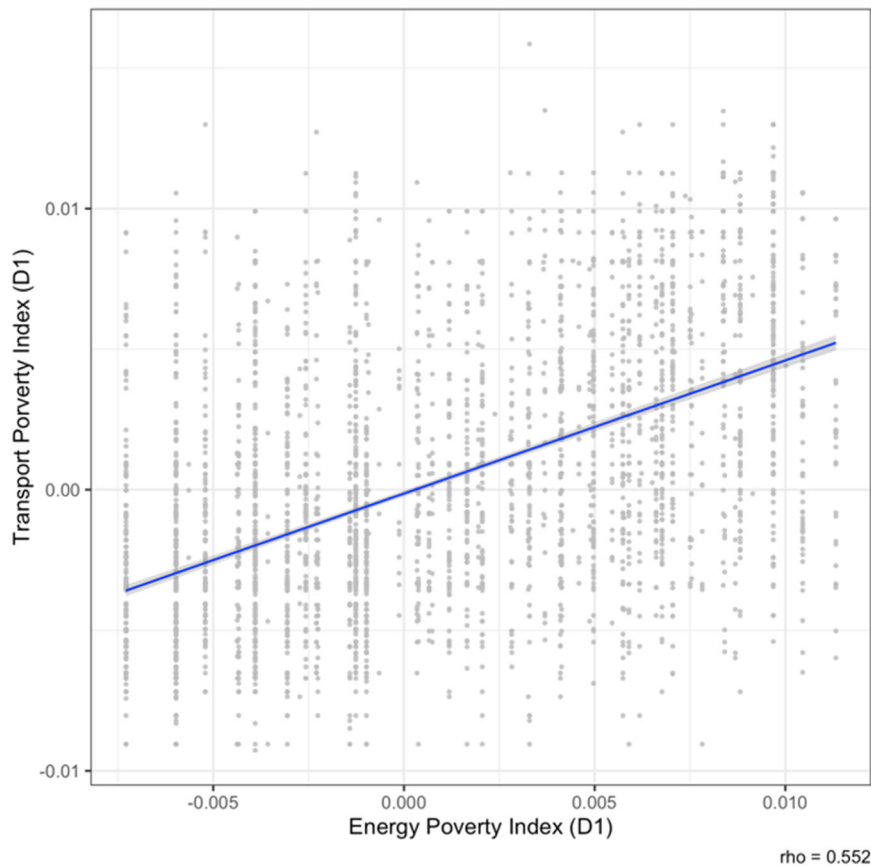
environmental sustainability, health and safety, convenience and legal means of access.

We raise concerns that although transport and energy poverty are multidimensional, their effects are exacerbated by increased fuel prices and hence lack of affordability. The current global context is one of geopolitical disruptions and climate change, which are made all the worse given that society is just emerging from a global health pandemic that placed a tremendous economic toll on the global population regarding access to energy, transport and other basic services.

However, such burdens have been much heavier on households with scarce resources. Hence, the 2030 timeline for achieving all SDG aspirations now seems more challenging than ever. Although social protection policies can have positive impacts, the broad SDG goal of “leaving no one behind” seems now beyond reach by 2030. Only if governments take drastic policy action may we see a change in circumstances where justice and equity prevail. Diversification away from fossil fuels<sup>74</sup> and decoupling economic growth from resource use<sup>75,76</sup> are important measures as both are feasible and consistent with sustainability targets<sup>77</sup>.

Although such approaches are neither simple nor serve as a silver bullet for achieving ambitious sustainability targets, they represent necessary policy instruments for economies to provide energy and transport services available to the broadest possible number of citizens, regardless of economic class. In short, while much of the world is focused on achieving sustainable development through an environmental lens via advanced technologies like solar power, battery storage, hydrogen and electric vehicles, our findings show the critical importance of placing equal focus on policies, technologies and systems that can help alleviate energy and transport poverty with explicit consideration of the overlaps between both forms of poverty, even if those technical options are more mundane, and involve “technologies” or “practices” such as insulation, walking, and cycling. As already noted at the beginning of this section, sector coupling via electrification, as well as via novel energy vectors such as hydrogen, make the joint consideration of energy and transport poverty increasingly important. Likewise, affordability, reliability, accessibility, and acceptability (i.e. healthy and safe) are invariant issues to consider. Hence urgent policy measures include but are not limited to, support for accessible, reliable and environmentally sustainable centralized and distributed energy, cost-effective, safe and accessible public transport systems, energy-efficient





**Fig. 2** Relationship between transport poverty and energy poverty. Source, authors.

equipment standards and building standards that not only achieve reliable and efficient energy delivery, but also ensure the health and comfort of occupants across all segments of society. Perhaps most importantly, all such measures need to take into consideration appropriate sector couplings and sub-national contexts, the latter of which we have referred to as microregions. It is in these very local scales where conditions that lead to energy and transport poverty may differ considerably from those visible only at a national level.

## METHODS

Our cross-country comparison of energy and transport poverty is grounded in four different locations (see Supplementary Fig. 2). To explore the theme of energy and transport poverty, our primary data sources for the study were fourfold: three nationally representative surveys (with quantitative and qualitative questions) distributed in the UAE, Mexico and Ireland. We also conducted seven public focus groups: two in the UAE, three in Northern Ireland and two in Mexico. Another method consisted of household interviews. We visited 15 locations distributed in Mexico City Metropolitan Area (MCMA) ( $n = 5$ ), Northern Ireland ( $n = 5$ ) and the UAE ( $n = 5$ ). Finally, we did 17 site visits to conduct naturalistic observations.

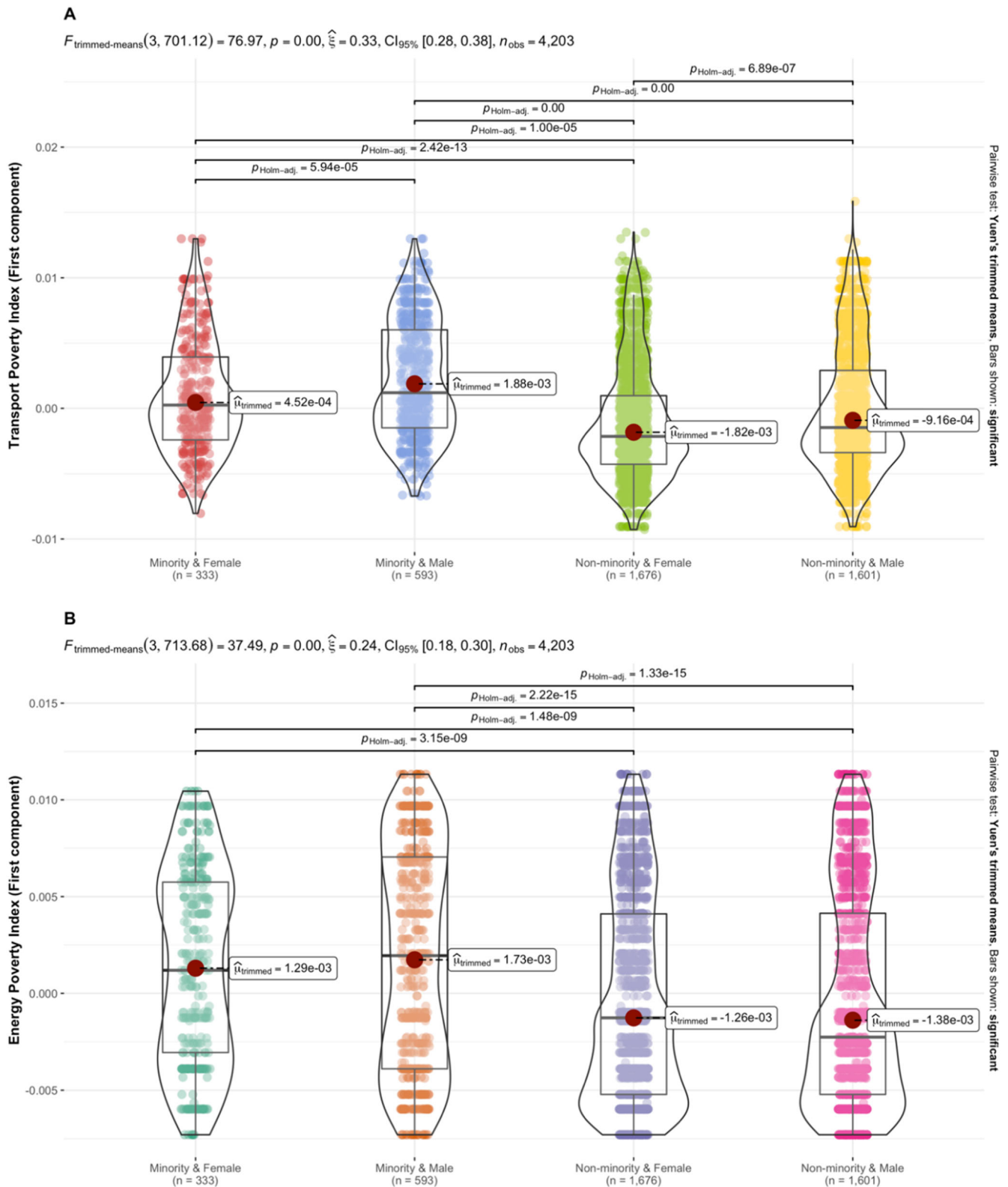
Our study also envisaged gathering data from rural, urban and periurban participants for three reasons. Namely to identify (1) if energy and transport needs are different in these settings, (2) if the access to these services varies according to geographical context and (3) if barriers to accessing and adopting sustainable energy systems (i.e. in transport or household energy consumption) are shared according to geographic context. Our study defines rural, urban and periurban settings as follows:

- Urban: a continuous urban fabric with a minimum population density of 1500 per square kilometre<sup>78</sup>.
- Rural: a region located outside of cities and towns and characterized by low population density, dispersed settlement patterns, and a predominance of agricultural and natural resource-based economic activities<sup>79</sup>.
- Periurban: a transitional zone between urban and rural areas where rural and urban land use coexists and frequently intermingle. Periurban regions are also characterized by populations that are typically more heterogeneous than in rural and urban settings<sup>80</sup>.

We note that urban and rural definition is a complex subject with multiple factors, such as population density, land use patterns, economic activities, and social and cultural characteristics, requiring consideration. In our study, although we used the definitions provided for guidance, we note that in this concept, we focused on the relationships between different settlements and their surrounding regions rather than definitions alone.

## Case study selection for surveys

Our case study selection was designed to explore the energy and transport contexts of countries on three distinct continents, characterized by diverse sociodemographic profiles, political systems, and economic levels of development (see Supplementary Table 2). Moreover, our objective was to broaden our scope beyond traditional WEIRD (Western, Educated, Industrialized, Rich, and Democratic) countries. Our specific objective was to explore how transport and energy poverty are not only experienced due to issues around affordability, but also how context may impact individuals' capabilities to use these services productively. Below we provide some context and justification for our case study selection.



**Fig. 3 Comparison of Transport Poverty Index and Energy Poverty Index between minority and non-minority groups by gender.** **A, B** present both statistical and graphical results. Starting from the top, we provide the Yuen's trimmed-means test statistic for comparing groups, the associated  $p$  value, the 95% confidence interval for the effect size estimate, and the number of observations. Below the horizontal lines, which indicate significant pairwise comparisons, we display the adjusted  $p$  values obtained through Holm's method for multiple comparisons. The graphical analysis includes (a) box plots featuring the median as a bold horizontal line, quartiles as the limits of the box, and whiskers; and (b) violin plots showcasing the mirrored kernel density distribution, where the width represents the density or frequency of data points at different values, the centre line denotes the median, and coloured points represent individual data points (including outliers). The mean is depicted as a bold circle at the centre of the figures and summarized in a box positioned on the right side of the plots.

**Table 10.** Illustrative statements from our participants concerning perceived inaction from governments, peripheralization, discrimination and marginalization.

Respondent	Jurisdiction	Confirmatory statement
UAEU02	UAE	I don't get it. We are a fuel exporting country, rich in resources, and we are paying lots for our energy services. Not everyone pays the same, which is a form of discrimination; I think that those who are not nationals are subsidizing the energy services of those who are nationals, which is absurd and discriminatory.
UAER07	UAE	I don't know if you're aware of this, but if you're a local here, you will get a discount on the price of electricity and water. They get all the perks because they are locals. From my side, I see we're not equal. Europeans and some Asians they're always in the top categories while we do all the work, and we are treated differently.
CCMV07	UAE	They will never do anything to improve our transport services. For them, it would be better if we never came to visit the city and we stayed hidden in our camps. That is why we are far from everything.
FGUNI05	Northern Ireland	I do not understand how the government is not taking action after seeing how many people die in winter because they cannot afford their energy bills. Why are they not helping those who cannot be warm in their own homes? Why they keep increasing energy prices when they know thousands are unable to afford it?
GR14	Northern Ireland	Many people in the camp spend a lot of money on electricity and transport, and we have no voice to raise concerns about these services. And the worse is that everyone knows that we exist and where we are, but we are still being ignored and excluded. People sometimes will refuse to get us in transport because of who we are.
GS1	Northern Ireland	In energy and transport, we are discriminated all the time, no one comes and fixes our problems. For example, we have asked for a footpath for years, but no one really cares. I can bet that I'll die before they put the footpath.
MCMAU03	Mexico City	I'm paying my taxes and spending a lot of money on them; however, the streets in my neighbourhood are full of potholes, public lighting is scarce, the lights go off frequently and delinquency rates are on the skies. However, if you go to Polanco, the streets are well paved, and the roads are full of lights. I'm paying my taxes, and so are my family and friends; we would like to have the same services they do. It is unfair that Iztapalapa is one of the biggest counties in Mexico and is the most fucked. From top to bottom is ruined. It is not fair how our taxes are distributed and how much discrimination against us exists.
ECA01	Mexico City	People, instead of helping low-income and indigenous migrants, they discriminate against us. They have told me many times, "why don't you get a job instead of begging for money, you deadbeat" or "return to your town, indian" They judged me without knowing that I work more than anyone else I know to feed my children.

Source, authors.

In Mexico, over 90% primary energy consumption originates from fossil fuels<sup>81</sup>. Consequently, Mexico is the Latin American country with the largest share of fossil fuel in total primary energy consumption<sup>82</sup>, regardless of its abundance of renewable energy sources<sup>83</sup>. Prior to the Energy Reform of 2013, the generation, transmission, and distribution of energy was exclusively handled by CFE, Mexico's national electricity provider. Historically, electricity and gasoline consumption in Mexico have been heavily subsidized, with costs extending beyond the local and global environmental impacts<sup>84,85</sup>. Urban areas commonly consume natural gas for heating and cooking, while rural households often resort to fuel oil and firewood. In regards to transport, research indicates that public transport could be relatively cheap; however, their services are often considered unsafe, unreliable and have inadequate coverage in certain regions, particularly rural geographies<sup>86</sup>. In turn, as households experience an increase in income, they tend to buy motorized vehicles instead of relying on public transport<sup>87,88</sup>.

The UAE, a member of the Gulf Cooperation Council (GCC) countries, is a federation consisting of seven emirates: Abu Dhabi, Ajman, Dubai, Fujairah, Ras al-Khaimah, Sharjah, and Umm al-Quwain. The UAE holds the rank of the world's seventh-largest oil producer and sixth-largest exporter<sup>89,90</sup>. Moreover, the UAE possesses significant reserves of natural gas, and historically, its power and water sector has relied heavily on this resource. The benefits of the UAE's oil reserves are predominantly centred in the emirate of Abu Dhabi, which reported a GDP of around 229 billion USD in 2021<sup>91</sup>, equivalent to 57% of the entire country's GDP. Dubai's economy ranks second, with a GDP of about 99 billion USD in 2021 (24% of the country's total)<sup>92</sup>. The remaining five emirates, commonly known as the Northern Emirates, are inhabited by just under one-third of the country's population<sup>93</sup> and have a total GDP contribution of approximately 77 billion USD (19% of the country's total). The UAE has diverse demographic attributes, with only 11% of the population being UAE nationals.

The rest of the population comprises expatriate residents; the largest nationality in the UAE is Indian (about 28%), trailed by Pakistani (about 13%)<sup>93</sup>. Although the UAE has made significant efforts toward economic diversification, energy intensive industries dominate the energy context, with more than 60% of total final energy consumption in the UAE coming from the industrial sector<sup>94,95</sup>. An arid and hot climate requiring substantial energy for cooling and water desalination and subsidizing energy prices in end-use sectors has made the UAE one of the world's highest per capita energy-consuming countries<sup>96</sup>. That said, UAE subsidies for water and electricity have decreased substantially in the past years, with UAE expats having the highest water and electricity prices among all residents of all GCC countries<sup>97</sup>. Although UAE citizens continue to have highly subsidized electricity and water tariffs, their small relative population has relatively diminished the impact on the country's total energy and environmental footprint. Subsidies for UAE fuel prices, which are set at the federal level, were completely removed in 2015<sup>98</sup>. Hence, all residents, regardless of nationality, pay the same fuel price set monthly based on global oil prices. Moving forward, the UAE has set an ambitious environmental agenda that sets clean and renewable energy and energy efficiency at the core and hence will require significant adoption of new energy technologies across all sectors<sup>99</sup>.

Northern Ireland is the UK's least developed region, has the weakest economy and the highest prevalence of fuel poverty in the UK<sup>100,101</sup>. The significant majority of fuel poverty among the population is primarily due to the cold weather conditions, the extensive reliance on costly heating methods (such as fuel oil), and inadequate gas grid connectivity in rural areas<sup>102,103</sup>. Others indicate that fuel poverty in Northern Ireland is primarily caused by the high cost of heating oil and, more recently, by the instability of gas prices and the absence of energy-efficient measures installed in households<sup>104</sup>. The Warm Homes Scheme, introduced in 2001, is Northern Ireland's primary initiative to

combat fuel poverty. Through this programme, households that meet the eligibility criteria from any region of the country can apply for several energy efficiency measures for their homes at reduced or no cost<sup>105</sup>. Renewable energy sources accounted for 41.3% of total electricity consumption in the country in 2021. During this time, the total electricity consumption was approximately 7574 Gigawatt hours (GWh), of which 3131 GWh was generated from renewable sources<sup>106</sup>.

Ireland has a temperate maritime climate that is greatly influenced by the North Atlantic Current, resulting in cool summers and mild winters with high humidity throughout the year. The Irish energy system is characterized by a high proportion of fossil fuels, which accounted for 90% of the country's total primary energy supply in 2017. However, despite its high reliance on fossil fuels, Ireland has one of the highest shares of wind electricity generation among IEA member countries<sup>107</sup>. Ireland improved its energy security by decreasing its oil share in the energy supply and by increasing domestic gas production<sup>107</sup>. Meanwhile, the transport sector makes up approximately 37% of the total final energy consumption, while the industrial, residential, and commercial sectors account for 25%, 24%, and 14% of the total, respectively. The transport sector is primarily fuelled by oil, while natural gas and electricity are the primary energy sources for the other sectors. Coal and peat have a smaller share in the industrial and residential sectors<sup>108</sup>. Regarding energy poverty, a recent report<sup>109</sup> shows that about 297,500 households, or around 17.5% of Irish homes, experience energy poverty. To address this issue, Ireland has focused on enhancing the energy efficiency of "at-risk" homes and providing assistance to those with chronic health conditions via the Household Benefits package (Gas Allowance or Electricity Allowance) or the National Fuel Scheme (Fuel Allowance). Despite these efforts, critics contend that the policy's scope is insufficient<sup>110</sup>, given the high incidence and prevalence of energy poverty<sup>111</sup>.

### Survey instrument

The survey was designed with a limit of 30 min for completion and comprised 39 questions across three sections (see Supplementary Methods). The initial section gathered demographic and socio-economic data from respondents, while the second and third sections delved into expenditure and energy/transport behaviours. The survey was created in English but was also translated into Spanish and Arabic to enhance accessibility and completion rates in Mexico and the UAE. Using their proprietary software, an online market research company, Dynata, developed and

executed the survey with a representative panel of participants from the Republic of Ireland and Northern Ireland, Mexico, and the UAE. Upon revision by the research team, Dynata sent individualized links to participants who agreed to participate in the survey. The sample frame included adults aged 18 and over from the four countries, and a sample size of over 1000 participants per country was deemed sufficient to meet gender, location, age, and income quotas. The survey was piloted between September and December 2021, but due to a system error, data from the UAE was re-collected in July 2022.

After conducting data quality checks, we identified 633 participants in the UAE provided unrealistic, incomplete, or contradictory responses and were therefore removed from the survey. To maintain the sample size, these participants were replaced in a second round of surveys conducted in July 2022. Our quality checks identified three types of problematic responses: "rushers", who provided unrealistic or incomplete answers (e.g., claiming to have 99 children), "speeders", who completed the survey too quickly; and "flat-liners", who provided straight-line responses to blocks of questions. In total, our final sample included 4216 respondents from Mexico ( $n = 1205$ ), Ireland ( $n = 1860$ ), and the UAE ( $n = 1141$ ), with each participant answering all survey questions to ensure complete response rates. We believe that our final country samples accurately represent the region's demographics, including gender, income, and age.

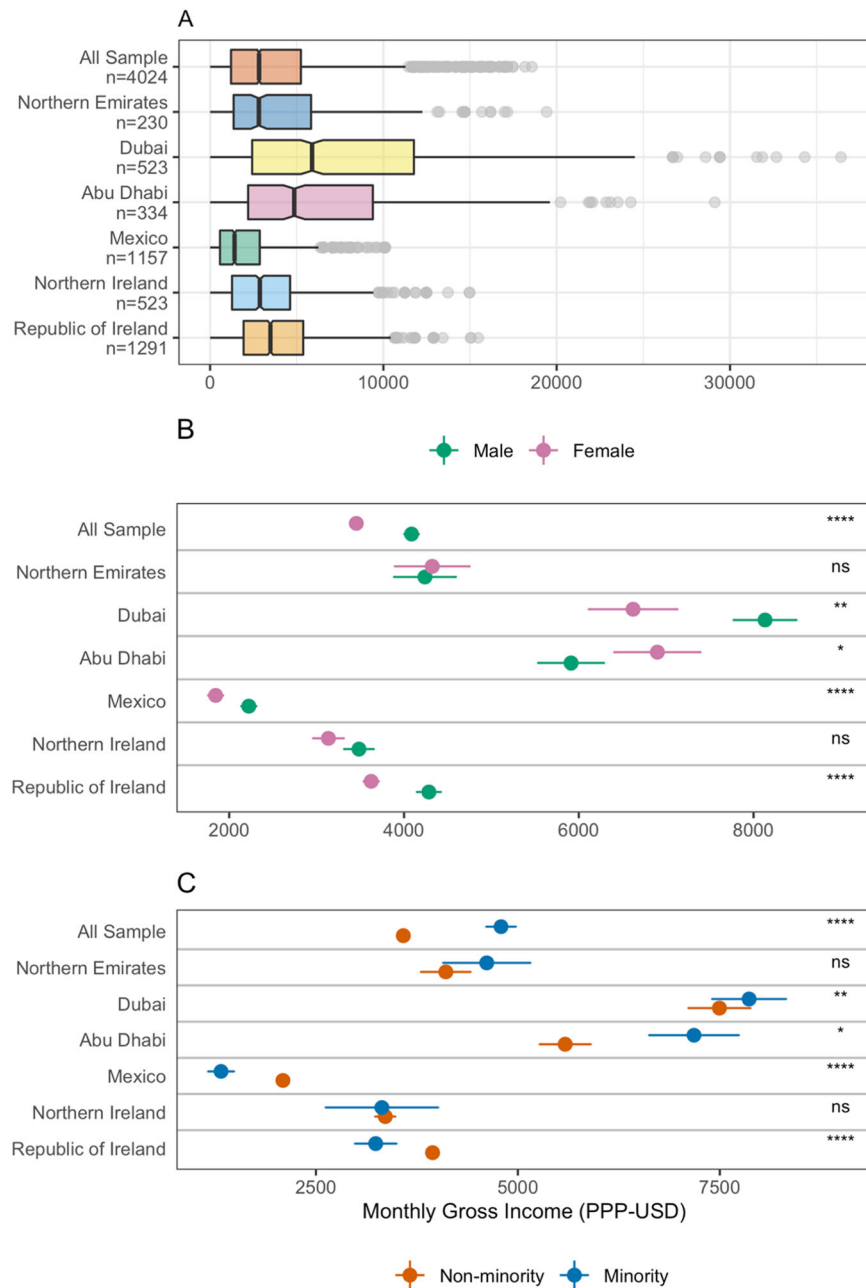
An overview of our samples' sociodemographic variables by country are presented in Table 11. The majority of our sample population resided in urban areas, with 85.65% living in urban and 14.35% in rural areas. Mexico had the highest percentage of urban participants at 91.5%. We also considered respondents from minority communities, including Asians, Blacks, Indigenous, and Nationals in the UAE, with the lowest representation in Mexico at 6.39% and the highest in Dubai at 55.89%. Most of our participants were female and the largest share of female participants was found in Republic of Ireland (62.1%), while the largest share of male respondents in Mexico (52.5%).

To account for abnormal values at the top of the distribution, we converted monthly gross income and rent to 2021 Purchase Parity Power (PPP) US Dollars for all countries and identified extreme outliers based on the interquartile rule:  $Q_3 + 3*(Q_3 - Q_1)$  for each continuous variable and country. After removing outliers, the mean income for the entire sample was US-PPP \$38,771 (SD  $\pm$ /\$3826). The highest monthly rents were estimated in the

**Table 11.** Summary statistics.

Country	Minority	Urban	Gender	Household size	Age	Home age	Net monthly income (PPP)	Monthly rent (PPP)
Republic of Ireland	0.116 (0.320)	0.790 (0.407)	0.621 (0.485)	2.247 (1.233)	40.858 (14.053)	35.758 (72.864)	3447.4 (7886.474)	1045.302 (3482.692)
Northern Ireland	0.0799 (0.271)	0.877 (0.328)	0.371 (0.483)	1.959 (1.070)	47.676 (15.698)	42.396 (93.258)	14,227.93 (258,148.9)	522.3811 (826.4345)
Mexico	0.063 (0.244)	0.914 (0.279)	0.475 (0.499)	2.825 (1.264)	40.906 (15.571)	19.366 (17.221)	2376.373 (5580.665)	153.7108 (595.2903)
Abu Dhabi	0.467 (0.499)	0.859 (0.347)	0.388 (0.488)	3.365 (1.328)	33.343 (8.974)	8.726 (8.249)	6773.253 (11,905.81)	2179.205 (8127.84)
Dubai	0.441 (0.496)	0.915 (0.277)	0.316 (0.465)	3.370 (1.294)	33.672 (8.984)	12.799 (91.708)	18,130.66 (21,0571.3)	3244.513 (22,964.62)
Northern Emirates	0.334 (0.472)	0.747 (0.435)	0.427 (0.495)	3.549 (1.316)	30.950 (9.336)	9.661 (11.052)	5632.241 (13,049.58)	2738.008 (11,139.05)

Source, authors. Standard deviation in parenthesis. Net monthly income and rent adjusted using USD PPP 2020. Outliers removed using  $Q_3 + 3*(Q_3 - Q_1)$  formula.



**Fig. 4 Monthly comparisons of income distributions.** In **A**,  $F = 133.52$ ,  $\text{Prob.} > F = 0.0000$ . One-way Anova (Bonferroni). The boxplot shows the median (centre line), interquartile range (bounds of the box), and whiskers representing the data range. Outliers, depicted as gray points, lie beyond the whiskers. **B**, **C** show the  $t$  test analysis. Error bars at 95% interval. \* $p \leq 0.05$ , \*\* $p \leq 0.01$ , \*\*\* $p \leq 0.001$ , \*\*\*\* $p \leq 0.0001$ , ns (not significant  $p > 0.05$ ). Source, authors.

UAE emirates. Finally, the UAE emirates and Mexico had the newest homes and largest household size, on average.

Two out of the 15 pairwise comparisons were not statistically significant at the 95% confidence interval: the Republic of Ireland and UAE and Dubai vis-à-vis Abu Dhabi had comparable mean gross monthly incomes. Additionally, we compared the monthly income distribution, which is fully illustrated in Fig. 4.

#### Household interviews and site visits

For this method, we explored three vulnerable groups representative of each country, including Gypsies and Travellers in Northern Ireland ( $n = 41$ ), slum-dwellers living in informal settlements in the MCMA ( $n = 51$ ) and low-income migrants residing in

labour camps in the Abu Dhabi ( $n = 46$ ), (we elaborate on each group in the sections below). Given the systematic exclusion of transport and energy planning from these groups and recent papers<sup>112,113</sup> depicting persistent inequalities among different city contexts, we decided it was extremely important to conduct direct interviews with each group. In total, we conducted 138 household interviews, which lasted between 15 and 60 min. All interviews were recorded and fully transcribed, translated (in the case of Mexico) and coded. In terms of coding, our techniques of data analysis were inductive. That is, the authors carried out all interviews; there was no necessity for inter-coder agreement (given transcripts were not exhaustive or that long), and we adopted an empirical method that was not guided by any specific conceptual framework to avoid potentially biasing the results. Our

interview guidebook and questions are presented in the Supplementary Methods.

Our first case study centred on Gypsies and Travellers in Northern Ireland; we focused on this group because the health outcomes experienced by Gypsies and Travellers are among the most impoverished of any European demographic. They are frequently confronted with the uncertainty of accommodation and often find themselves living in conditions that are hazardous to their health, with dire consequences to their well-being<sup>114,115</sup>. Due to their exposure to extreme poverty, ill-health, exclusion from civil and political rights, and continual discrimination and harassment, they are arguably the most vulnerable minority group in Europe<sup>109</sup>. Despite experiencing frequent instances of discrimination and harassment, Gypsies and Travellers have not been able to attain many of the safeguards that are granted to other minority communities in practice. Moreover, the progress that has been made in enhancing the status or living conditions of Gypsies and Travellers in recent times has been undermined over the last two decades by both economic constraints and rising xenophobia within English society<sup>116</sup>.

Slums are characterised as a settlement where their inhabitants have inadequate housing and lack access to essential services. Moreover, slums are frequently not addressed nor recognized by the public authorities as an equal or integral part of the city<sup>117</sup>. UN-HABITAT defines a slum as “one or a group of individuals living under the same roof in an urban area, lacking in one or more of the following five amenities”: (i) durable housing, (ii) sufficient living area, (iii) access to improved water, (iv) access to improved sanitation facilities, (v) Secure tenure<sup>118</sup>. More than 25% of Mexico’s urban population resides in informal settlements, of which 60% are classified as poor or moderately poor and display different levels of social diversity and deprivation<sup>119</sup>. While informal settlements may aid in upward mobility, in the MCMA, slum dwellers lack access to fundamental services; even Roy et al. have characterized MCMA’s expansion as “highly unproductive, deepening inequality, and increasing pollution levels.” Meanwhile, Furszyfer and Sovacool note that slum-dwellers in the MCMA represent one of the most vulnerable groups in the region and are often exposed to racism, discrimination, social segregation, violence and extreme poverty<sup>20</sup>.

In the GCC region, migrant accommodations are often referred to as ‘labour camps’<sup>120</sup>. These camps typically house between six and eight individuals per room, although the numbers may vary widely<sup>121</sup>. Regulations have been put in place across GCC countries to improve the living conditions of residents in these camps, including limits on the number of people per room<sup>122</sup>. Labour camps are usually situated on the outskirts of cities or in marginal areas such as industrial zones<sup>123</sup>. Research notes that situating these facilities out of public view is motivated by concerns about cultural security, which reflect class, gender, and racial anxieties prevalent in the hosting societies<sup>122</sup>. Labour camp residents are perhaps the most vulnerable group in the UAE society; this group face constant discrimination and segregation, has limited political rights, and experiences constant violations of their human rights.

Throughout September and October 2021, we conducted 41 *household and community interviews* summarized in Supplementary Table 3 with Gypsies and Travellers. Half of our respondents identified as Irish travellers, while the others were half-Roman or Romani-Gypsies. Some respondents were sedentary or static and/or living in housing, whereas others were nomadic, travelling at least half the time each year. Our visits also consisted of various residency types and living conditions (including informal trailer parks, halting sites, formal Traveller’s sites and caravan parks). Some participants lived in tents or caravans (a trailer), and others in fixed houses called block houses or chalets as Supplementary Fig. 3 illustrates. As Supplementary Fig. 3 shows that the visits included a mix of

abandoned, serviced and unauthorized sites, and; a combination of ethnic groups (some of Romanian or Roma descent, others from English or Irish descent); a mix of fixed/static units and nomadic, mobile caravans; and a mix of urban and rural areas. This enabled us to observe living conditions, mobility, and energy practices and facilitated the collection of visual evidence (photographs) used throughout the manuscript.

Throughout November and December 2021, the research team conducted 51 household interviews with slum-dwellers of Texcoco, Nezahualcoyotl, Ecatepec Teotihuacan, and Chimalhuacan summarized in Supplementary Table 4 and illustrated in Supplementary Fig. 4. All interviews were conducted in Spanish and then translated to English by the authors of this research (one of the authors is a native Spanish speaker). Nearly more than half of our participants currently live in informal settlements, whereas the rest accepted that they initially settled there illegally, but their circumstances have changed and are legally established now.

In March 2022, the research team conducted 46 *household and community interviews* in five labour camps situated in different locations of the UAE, namely Mussafah Industrial Zone, Mafraq Industrial Area, Al Raha Village and Mohammed Bin Zayed City, with the participants’ descriptions summarized in Supplementary Table 5.

As Supplementary Fig. 5 depicts, our labour camp selection included a mix of residency types and living conditions, such as ‘luxurious labour camps’ which are close to entertainment and shopping facilities far removed from the city—to arguably discourage residents from entering the city in the first place<sup>124</sup>, and female camps—which access to them is extremely difficult, and perhaps is the group whose working and living conditions are the least known<sup>120</sup>.

We got explicit permission to use these images by the respondents themselves or by their parents in the instance they were children. Our study did receive formal ethics approval from the Social Sciences & Arts Cross-Schools Research Ethics Committee at the University of Sussex, with Reference Number ER/DDF20/2.

### Focus groups with rural and urban participants

To triangulate the findings from the household interviews, site visits and surveys, we also conducted seven focus groups in the last quarter of 2021 and the first quarter of 2022 in the MCMA, the UAE and Northern Ireland. The Focus Groups were conducted through an online platform and managed by a separate market research company, Norstat. Except in the case of the MCMA, where focus groups were facilitated by Observatorio de Desarrollo Regional y Promoción Social A.c and the help of Dr Paul Furszyfer. Unlike in the UAE and Northern Ireland, the focus groups in the MCMA were conducted in person and in Spanish; these were later translated into English by the lead author of this research. Even though the focus groups were facilitated, recorded and fully transcribed by Norstat and Observatorio de Desarrollo Regional y Promoción Social, at least one member of the research team observed all of the focus groups. The focus groups lasted between 90 and 120 min each and comprised a combination of different demographic respondents, with their details summarized in Table 12. The focus groups followed a similar structure to the household interviews and survey; hence we centred on examining behaviours, struggles, expenditures and patterns of energy use and transport. In this space, we would also like to note that since the focus groups conducted in Mexico took place in person, we were able to extract more granular data regarding the employment status of our participants.

**Table 12.** Overview of participants from the focus groups by location, respondent number, gender, age group and employment status ( $N = 58$ ).

Location	Respondent number	Gender	Age group	Current employment status	Previous employment status
<b>(A) Focus group participants' general characteristics from Mexico (<math>n = 9</math>)</b>					
Rural	MCMAR01	Female	36–45	Looks after cars parked on the streets	Sold clothes on a street stall
Rural	MCMAR02	Female	18–24	Housewife	Peasant
Rural	MCMAR03	Female	25–35	Housewife	Student
Rural	MCMAR04	Male	18–24	Student	Worked on a street stall
Rural	MCMAR05	Male	18–24	Works delivering industrial materials	–
Rural	MCMAR06	Female	25–35	Student	Worked on a street stall
Rural	MCMAR07	Female	46–54	Looks after cars parked on the streets	Housewife
Rural	MCMAR08	Male	36–45	Works for a decentralized federal institution	Peasant
Rural	MCMAR09	Female	25–35	Student	–
<b>(B) Focus group participants' general characteristics from Mexico (<math>n = 9</math>)</b>					
Urban	MCMAU01	Male	18–24	Student	Student
Urban	MCMAU02	Male	25–35	Works for a clothing company	Student
Urban	MCMAU03	Female	25–35	Works as a manager for a small firm	Student
Urban	MCMAU04	Female	55–74	Housewife	–
Urban	MCMAU05	Male	55–74	Unemployed	Bus driver
Urban	MCMAU06	Female	25–35	Housewife	Student
Urban	MCMAU07	Female	18–24	Works for a social service agency	Student
Urban	MCMAU08	Male	25–35	Unemployed	Human resources manager in a medium firm
Urban	MCMAU09	Female	36–45	Own a small-medium enterprise	Works for the Federal government
Location	Respondent number	Gender	Age group	Current employment status	
<b>(C) Focus group participants' general characteristics from the UAE (<math>n = 8</math>)</b>					
Rural	UAER01	Female	36–45		Unemployed
Rural	UAER02	Female	26–35		Employed
Rural	UAER03	Female	26–35		Employed
Rural	UAER04	Male	26–35		Employed
Rural	UAER05	Male	26–35		Employed
Rural	UAER06	Male	26–35		Employed
Rural	UAER07	Female	18–24		Employed
Rural	UAER08	Female	26–35		Employed
<b>(D) Focus group participants' general characteristics from the UAE (<math>n = 8</math>)</b>					
Urban	UAEU01	Male	26–35		Employed
Urban	UAEU02	Male	26–35		Employed
Urban	UAEU03	Female	36–46		Employed
Urban	UAEU04	Male	18–24		Employed
Urban	UAEU05	Female	18–24		Unemployed
Urban	UAEU06	Female	46–54		Employed
Urban	UAEU07	Female	26–35		Employed
Urban	UAEU08	Male	26–35		Employed
<b>(E) Focus group participants' general characteristics from Northern Ireland (<math>n = 5</math>)</b>					
Urban	FGUNI01	Male	26–35		Unemployed
Urban	FGUNI02	Male	36–46		Employed
Urban	FGUNI03	Female	36–46		Employed
Urban	FGUNI04	Female	26–35		Employed
Urban	FGUNI05	Male	26–35		Employed
<b>(F) Focus group participants' general characteristics from Northern Ireland (<math>n = 10</math>)</b>					
Urban	A-FGUNI01	Male	36–45		Employed
Urban	A-FGUNI02	Male	36–45		Employed
Urban	A-FGUNI03	Male	55–74		Employed
Urban	A-FGUNI04	Female	46–54		Employed
Rural	A-FGRNI05	Female	36–45		Employed

**Table 12** continued

Location	Respondent number	Gender	Age group	Current employment status
Rural	A-FGRNI06	Male	55–74	Retired
Urban	A-FGUNI06	Female	46–54	Employed
Rural	A-FGRNI07	Male	46–54	Employed
Urban	A-FGUNI08	Male	36–45	Employed
Urban	A-FGUNI08	MAle	55–74	Retired
<b>(G) Focus group participants' general characteristics from Northern Ireland (n = 9)</b>				
Urban	NIR&UFG01	Female	36–46	Employed
Urban	NIR&UFG02	Female	26–35	Employed
Urban	NIR&UFG03	Male	55–74	Employed
Urban	NIR&UFG04	Male	26–35	Employed
Urban	NIR&UFG05	Male	55–74	Retired
Rural	NIR&UFG06	Male	46–54	Unemployed
Rural	NIR&UFG07	Male	46–54	Unemployed
Rural	NIR&UFG08	Female	36–46	Employed
Rural	NIR&UFG09	Female	55–74	Retired

## DATA AVAILABILITY

Due to the ethical concerns of sharing qualitative data gathered from respondents from vulnerable groups, the interviews and focus groups, transcripts cannot be made available.

Received: 2 December 2022; Accepted: 15 June 2023;  
Published online: 30 June 2023

## REFERENCES

- World Bank. Poverty and shared prosperity 2022: correcting course. <https://doi.org/10.1596/978-1-4648-1893-6> (2022).
- United Nations. Addressing poverty. Academic impact. <https://www.un.org/en/academic-impact/addressing-poverty> (2023).
- OHCHR. Impact of the COVID-19 on vulnerable groups and groups at risk - causes, outcomes and recommendations. [https://serbia.un.org/sites/default/files/2021-02/LNOBanaliza\\_ENG\\_web.pdf](https://serbia.un.org/sites/default/files/2021-02/LNOBanaliza_ENG_web.pdf) (2020).
- Get the Sustainable Development Goals back on track. *Nature* **577**, 7–8 (2020).
- Bank for Reconstruction and Development/The World Bank. 2022 Tracking SDG7 report. [https://trackingsdg7.esmap.org/data/files/download-documents/sdg7-report2022-full\\_report.pdf](https://trackingsdg7.esmap.org/data/files/download-documents/sdg7-report2022-full_report.pdf) (2022).
- WHO. WHO publishes new global data on the use of clean and polluting fuels for cooking by fuel type. News Release. <https://www.who.int/news/item/20-01-2022-who-publishes-new-global-data-on-the-use-of-clean-and-polluting-fuels-for-cooking-by-fuel-type> (2022).
- IEA. SDG7: data and projections. <https://www.iea.org/reports/sdg7-data-and-projections> (2022).
- Alvaredo, F., Chancel, L., Piketti, T., Saenz, E. & Zucman, G. World inequality report. <https://wir2018.wid.world/files/download/wir2018-summary-english.pdf> (2018).
- Steinberger, J. K., Krausmann, F. & Eisenmenger, N. Global patterns of materials use: a socioeconomic and geophysical analysis. *Ecol. Econ.* **69**, 1148–1158 (2010).
- Nielsen, K. S., Nicholas, K. A., Creutzig, F., Dietz, T. & Stern, P. C. The role of high-socioeconomic-status people in locking in or rapidly reducing energy-driven greenhouse gas emissions. *Nat. Energy* **6**, 1001–1016 (2021).
- Bruckner, B., Hubacek, K., Shan, Y., Zhong, H. & Feng, K. Impacts of poverty alleviation on national and global carbon emissions. *Nat. Sustain.* **5**, 311–320 (2022).
- Sovacool, B. K. & Furszyfer, D. D. "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 (2022).
- Carley, S. & Konisky, D. M. The justice and equity implications of the clean energy transition. *Nat. Energy* **5**, 569–577 (2020).
- Ivanova, D. & Middlemiss, L. Characterizing the energy use of disabled people in the European Union towards inclusion in the energy transition. *Nat. Energy* **6**, 1188–1197 (2021).
- Memmott, T., Carley, S., Graff, M. & Konisky, D. M. Sociodemographic disparities in energy insecurity among low-income households before and during the COVID-19 pandemic. *Nat. Energy* **6**, 186–193 (2021).
- Longden, T. et al. Energy insecurity during temperature extremes in remote Australia. *Nat. Energy* **7**, 43–54 (2022).
- Wackernagel, M. et al. The importance of resource security for poverty eradication. *Nat. Sustain.* **4**, 731–738 (2021).
- Ricciardi, V. et al. A scoping review of research funding for small-scale farmers in water scarce regions. *Nat. Sustain.* **3**, 836–844 (2020).
- Sovacool, B. K., Heffron, R. J., McCauley, D. & Goldthau, A. Energy decisions reframed as justice and ethical concerns. *Nat. Energy* **1**, 16024 (2016).
- Furszyfer, D. D. & Sovacool, B. K. Of cooks, crooks and slum-dwellers: exploring the lived experience of energy and mobility poverty in Mexico's informal settlements. *World Dev.* **161**, 106093 (2023).
- Baker, K. J., Mould, R. & Restrck, S. Rethink fuel poverty as a complex problem. *Nat. Energy* **3**, 610–612 (2018).
- Brockway, A. M., Conde, J. & Callaway, D. Inequitable access to distributed energy resources due to grid infrastructure limits in California. *Nat. Energy* **6**, 892–903 (2021).
- Sunter, D. A., Castellanos, S. & Kammen, D. M. Disparities in rooftop photovoltaics deployment in the United States by race and ethnicity. *Nat. Sustain.* **2**, 71–76 (2019).
- O'Shaughnessy, E., Barbose, G., Wiser, R., Forrester, S. & Darghouth, N. The impact of policies and business models on income equity in rooftop solar adoption. *Nat. Energy* **6**, 84–91 (2021).
- White, L. V. & Sintov, N. D. Health and financial impacts of demand-side response measures differ across sociodemographic groups. *Nat. Energy* **5**, 50–60 (2020).
- Tunstall, R. et al. The links between housing and poverty: an evidence review. <https://www.jrf.org.uk/report/links-between-housing-and-poverty> (2013).
- Simcock, N., Frankowski, J. & Bouzarovski, S. Rendered invisible: institutional misrecognition and the reproduction of energy poverty. *Geoforum* **124**, 1–9 (2020).
- Cong, S., Nock, D., Qiu, Y. L. & Xing, B. Unveiling hidden energy poverty using the energy equity gap. *Nat. Commun.* **13**, 2456 (2022).
- Sovacool, B. K. Fuel poverty, affordability, and energy justice in England: policy insights from the Warm Front Program. *Energy* **93 Part 1**, 361–371 (2015).
- Furszyfer, J., Furszyfer, D. D., Sovacool, B. K. & Griffiths, S. The demographics of energy and mobility poverty: assessing equity and justice in Ireland, Mexico, and the United Arab Emirates. *Glob. Environ. Chang.* **81**, 102703 (2023).
- Upham, P., Sovacool, B. K. & Monyei, C. G. Energy and transport poverty amidst plenty: exploring just transition, lived experiences and policy implications in Iceland. *Renew. Sustain. Energy Rev.* **163**, 112533 (2022).
- Sovacool, B. K. *Energy, Poverty, and Development* (Routledge, 2014).
- Groth, S. Multimodal divide: reproduction of transport poverty in smart mobility trends. *Transp. Res. Part A Policy Pract.* **125**, 56–71 (2019).
- Churchill, S. A. & Smyth, R. Transport poverty and subjective wellbeing. *Transp. Res. Part A Policy Pract.* **124**, 40–54 (2019).



35. Lucas, K. & Jones, P. Social impacts and equity issues in transport: an introduction. *J. Transp. Geogr.* **21**, 1–3 (2012).
36. Department of Economic and Social Affairs. Global sustainable development report (GSDR) 2023. <https://sdgs.un.org/gsdrr> (2022).
37. Sustainable Mobility for All. SuM4All 2021 annual report. [https://www.sum4all.org/data/files/sum4allannualreport\\_041722\\_v10\\_web.pdf](https://www.sum4all.org/data/files/sum4allannualreport_041722_v10_web.pdf) (2022).
38. Gannon, C. A. & Liu, Z. Poverty and transport. <https://documents1.worldbank.org/curated/en/302611538245213278/pdf/Poverty-and-transport.pdf> (1997).
39. Benevenuto, R. & Caulfield, B. Poverty and transport in the global south: an overview. *Transp. Policy* **79**, 115–124 (2019).
40. Department of Economic and Social Affairs. Sustainable transport, sustainable development: interagency report. <https://www.un.org/en/desa/sustainable-transport-sustainable-development-interagency-report-second-global-sustainable> (2021).
41. Simcock, N. et al. Identifying double energy vulnerability: a systematic and narrative review of groups at-risk of energy and transport poverty in the global north. *Energy Res. Soc. Sci.* **82**, 102351 (2021).
42. Sovacool, B. K., Upham, P., Martiskainen, M., Jenkins, K. E. H. & Contreras, G. A. T. Policy prescriptions to address energy and transport poverty in the United Kingdom. *Nat. Energy* **8**, 273–283 (2023).
43. United Nations Human Settlements Programme. SDG indicator metadata. <https://unstats.un.org/sdgs/metadata/files/Metadata-11-02-01.pdf> (2021).
44. The World Bank and Sustainable Energy Sector Management Assistance Program. Multi tier framework; tracking progress towards sustainable energy goals. <https://mtfenergyaccess.esmap.org/methodology/electricity> (2015).
45. Rysankova, D., Portale, E. & Carletto, G. Measuring energy access introduction to the multi-tier framework introduction to the multi-tier framework. [https://www.seforall.org/sites/default/files/MTFpresentation\\_SE4ALL\\_April5.PDF](https://www.seforall.org/sites/default/files/MTFpresentation_SE4ALL_April5.PDF) (2016).
46. Martiskainen, M. et al. New dimensions of vulnerability to energy and transport poverty. *Joule* **5**, 3–7 (2021).
47. Upham, P. et al. Public support for decarbonization policies: between self-interest and social need for alleviating energy and transport poverty in the United Kingdom. *Energy Clim. Chang.* **4**, 100099 (2023).
48. Pelham, B., Hardin, C., Murray, D., Shimizu, M. & Vanello, J. A truly global, non-WEIRD examination of collectivism: the Global Collectivism Index (GCI). *Curr. Res. Ecol. Soc. Psychol.* **3**, 10030 (2022).
49. Sovacool, B. Who are the victims of low-carbon transitions? Towards a political ecology of climate change mitigation. *Energy Res. Soc. Sci.* **73**, 101916 (2021).
50. Heinrich, J., Heine, S. J. & Norenzayan, A. Most people are not WEIRD. *Nature* **466**, 29 (2010).
51. Hu, S. et al. A systematic review of building energy sufficiency towards energy and climate targets. *Renew. Sustain. Energy Rev.* **121**, 113316 (2023).
52. Carlisle, J. E., Kane, S. L., Solan, D. & Joe, J. C. Support for solar energy: examining sense of place and utility-scale development in California. *Energy Res. Soc. Sci.* **3**, 124–130 (2014).
53. Rudolph, D., Kirkegaard, J., Lyhne, I., Clausen, N.-E. & Kørnøv, L. Spoiled darkness? Sense of place and annoyance over obstruction lights from the world's largest wind turbine test centre in Denmark. *Energy Res. Soc. Sci.* **25**, 89–90 (2017).
54. Dugstad, A., Grimsrud, K., Kipperberg, G., Lindhjem, H. & Navrud, S. Place attachment and preferences for wind energy – a value-based approach. *Energy Res. Soc. Sci.* **100**, 103094 (2023).
55. Bergquist, P., Ansolabehere, S., Carley, S. & Konisky, D. Backyard voices: how sense of place shapes views of large-scale energy transmission infrastructure. *Energy Res. Soc. Sci.* **63**, 101396 (2020).
56. Mohr, A. & Smits, M. Sense of place in transitions: how the Hambach Forest Movement shaped the German coal phase-out. *Energy Res. Soc. Sci.* **87**, 102479 (2022).
57. Suchyta, M. Sense of place as a predictor of beliefs about energy development: a study in Pennsylvania's Marcellus Shale. *Energy Res. Soc. Sci.* **70**, 101635 (2020).
58. Groat, L. *Giving Places Meaning: Readings in Environmental Psychology* (Academic Press, 1995).
59. Feld, S. & Basso, K. H. *Senses of Place* (Santa Fe, 1996).
60. Sovacool, B. K., Hook, A., Martiskainen, M., Brock, A. & Turnheim, B. The decarbonisation divide: contextualizing landscapes of low-carbon exploitation and toxicity in Africa. *Glob. Environ. Chang.* **60**, 102028 (2020).
61. Sovacool, B. K. Expanding carbon removal to the Global South: thematic concerns on systems, justice, and climate governance. *Energy Clim. Chang.* **4**, 100103 (2023).
62. Soja, E. *Seeking Spatial Justice* (University of Minnesota Press, 2010).
63. Soja, E. The city and spatial justice. *Spat. Justice* **1**, 1–5 (2009).
64. AECM. Reliability. The Australian Energy Market Commission. <https://www.aemc.gov.au/energy-system/electricity/electricity-system/reliability> (2020).
65. Suryani, E., Hendrawan, R., EAdipraja, P., Wibisono, A. & Dewi, L. P. Modelling reliability of transportation systems to reduce traffic congestion. *J. Phys. Conf. Ser.* **1196**, 012029 (2019).
66. Dixit, M. & Sivakumar, A. Capturing the impact of individual characteristics on transport accessibility and equity analysis. *Transp. Res. Part D Transp. Environ.* **87**, 102473 (2020).
67. Chatterjee, K. et al. Access to transport and life opportunities. [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/831766/access\\_to\\_transport\\_report.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/831766/access_to_transport_report.pdf) (2019).
68. Gifi, A. *Nonlinear Multivariate Analysis* (Wiley Series in Probability and Statistics, 1991).
69. Leeuw, J. de & Mair, P. Gifi methods for optimal scaling in R: the package homals. *J. Stat. Softw.* **31**, 1–21 (2009).
70. Bradley, C., Canal, M., Smit, S. & Woetzel, J. Pixels of progress: a granular look at human development around the world. <https://www.mckinsey.com/mgi/our-research/Pixels-of-progress-introduction> (2022).
71. Benedek, D., Gemayel, E., Senhadji, A. & Tieman, A. A post-pandemic assessment of the sustainable development goals. <https://www.imf.org/en/Publications/Staff-Discussion-Notes/Issues/2021/04/27/A-Post-Pandemic-Assessment-of-the-Sustainable-Development-Goals-460076> (2021).
72. Fuldauer, L. I. et al. Targeting climate adaptation to safeguard and advance the Sustainable Development Goals. *Nat. Commun.* **13**, 3579 (2022).
73. Biermann, F. et al. Scientific evidence on the political impact of the Sustainable Development Goals. *Nat. Sustain.* **5**, 795–800 (2022).
74. Mercure, J.-F. et al. Reframing incentives for climate policy action. *Nat. Energy* **6**, 1133–1143 (2021).
75. Lenzen, M. et al. Implementing the material footprint to measure progress towards Sustainable Development Goals 8 and 12. *Nat. Sustain.* **5**, 157–166 (2021).
76. Hickel, J. et al. Degrowth can work — here's how science can help. *Nature* **612**, 400–403 (2022).
77. Keyßer, L. T. & Lenzen, M. 1.5 °C degrowth scenarios suggest the need for new mitigation pathways. *Nat. Commun.* **12**, 2676 (2021).
78. Dijkstra, L., Poelman, H. & Veneri, P. The EU-OECD definition of a functional urban area. <https://doi.org/10.1787/20737009> (2019).
79. FAO. Guidelines on defining rural areas and compiling indicators for development policy. <https://www.fao.org/3/ca6392en/ca6392en.pdf> (2018).
80. UN-HABITAT. State of the world's cities 2008/2009 - harmonious cities. <https://unhabitat.org/state-of-the-worlds-cities-20082009-harmonious-cities-2> (2009).
81. OECD. OECD economic surveys: Mexico 2019. <https://doi.org/10.1787/a536d00e-en> (2019).
82. IEA. Extended world energy balances (Edition 2018). <https://doi.org/10.1787/4bcaa5-en> (2018).
83. Fernandez, A., de, J. & Watson, J. Mexico's renewable energy innovation system: geothermal and solar photovoltaics case study. *Environ. Innov. Soc. Trans.* **43**, 200–219 (2022).
84. Scott, J. Redistributive impact and efficiency of Mexico's fiscal system. *Public Financ. Rev.* **42**, 368–390 (2013).
85. Rosas-Flores, J. A., Bakhat, M., Rosas-Flores, D. & Zayas, J. L. F. Distributional effects of subsidy removal and implementation of carbon taxes in Mexican households. *Energy Econ.* **61**, 21–28 (2017).
86. Mejía-Dorantes, L. & Villagrán, P. S. A review on the influence of barriers on gender equality to access the city: a synthesis approach of Mexico City and its Metropolitan Area. *Cities* **96**, 102439 (2020).
87. Crôtte, A., Noland, R. B. & Graham, D. J. An analysis of gasoline demand elasticities at the national and local levels in Mexico. *Energy Policy* **38**, 4445–4456 (2010).
88. Díaz, A. O. & Medlock, K. B. Price elasticity of demand for fuels by income level in Mexican households. *Energy Policy* **151**, 112132 (2021).
89. World Population Review. Country rankings/oil-producing countries. <https://worldpopulationreview.com/country-rankings/oil-producing-countries> (2022).
90. World Population Review. Oil producing countries 2022. <https://worldpopulationreview.com/country-rankings/oil-producing-countries> (2022).
91. Statistics Centre. National accounts: key figures. Statistic Centre Abu Dhabi. <https://www.scad.gov.ae/en/pages/statistics.aspx?topicid=37> (2019).
92. The System of National Accounts. National accounts. Government of Dubai. <https://www.dsc.gov.ae/en-us/Themes/Pages/National-Accounts.aspx?Theme=24> (2021).
93. GMI. United Arab Emirates population Statistics. Infographics. <https://www.globalmediainsight.com/blog/uae-population-statistics/#emirates> (2022).
94. Sgouridis, S., Griffiths, S., Kennedy, S. & Khalid, A. A sustainable energy transition strategy for the United Arab Emirates: evaluation of options using an Integrated Energy Model. *Energy Strateg.* **2**, 8–18 (2013).
95. Sgouridis, S. et al. RE-mapping the UAE's energy transition: an economy-wide assessment of renewable energy options and their policy implications. *Renew. Sustain. Energy Rev.* **55**, 1166–1180 (2016).
96. Our World in Data. Energy use per person, 2021. <https://ourworldindata.org/grapher/per-capita-energy-use> (2021).
97. AlGhamdi, A. Data insight: GCC residential electricity tariffs. <https://www.kapsarc.org/research/publications/gcc-residential-electricity-tariffs/> (2020).

98. Boersma, T. & Griffiths, S. Reforming energy subsidies: initial lessons from the United Arab Emirates. <https://www.brookings.edu/research/reforming-energy-subsidies-initial-lessons-from-the-united-arab-emirates/> (2016).
99. Eveloy, V. & Ahmed, W. Evaluation of low-carbon multi-energy options for the future UAE energy system. *Sustain. Energy Technol. Assess.* **53**, 102584 (2022).
100. Hinson, S. & Bolton, P. Fuel poverty. <https://researchbriefings.files.parliament.uk/documents/CBP-8730/CBP-8730.pdf> (2022).
101. Haase, D. & Gálová, V. The economic, social and territorial situation of Northern Ireland. [https://www.europarl.europa.eu/RegData/etudes/IDAN/2018/617459/IPOL\\_IDA\(2018\)617459\\_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/IDAN/2018/617459/IPOL_IDA(2018)617459_EN.pdf) (2018).
102. Mohan, G., Longo, A. & Kee, F. The effect of area based urban regeneration policies on fuel poverty: evidence from a natural experiment in Northern Ireland. *Energy Policy* **114**, 609–618 (2018).
103. Muinzer, T. L. Conceptualising the energy constitution: lessons from Northern Ireland. *Energy Policy* **140**, 111408 (2020).
104. Walker, R., Liddell, C., McKenzie, P., Morris, C. & Lagdon, S. Fuel poverty in Northern Ireland: humanizing the plight of vulnerable households. *Energy Res. Soc. Sci.* **4**, 89–99 (2014).
105. The Housing Executive. Warm home discount scheme. Affordable warmth scheme. <https://www.nihe.gov.uk/Housing-Help/Affordable-Warmth-Boiler-Replacement/Affordable-Warmth-Scheme> (2021).
106. Department of Economy. Electricity consumption and renewable generation in Northern Ireland: year ending December 2021. <https://www.economy-ni.gov.uk/news/electricity-consumption-and-renewable-generation-northern-ireland-year-ending-december-2021> (2022).
107. IEA. Ireland profile. Countries and profile. <https://www.iea.org/countries/ireland> (2022).
108. IEA. Energy policies for IEA countries. [https://iea.blob.core.windows.net/assets/07adb8b6-0ed5-45bd-b9a0-3e397575fefc/Energy\\_Policies\\_of\\_IEA\\_Countries\\_Ireland\\_2019\\_Review.pdf](https://iea.blob.core.windows.net/assets/07adb8b6-0ed5-45bd-b9a0-3e397575fefc/Energy_Policies_of_IEA_Countries_Ireland_2019_Review.pdf) (2019).
109. O'Malley, S., Roantree, B. & Curtis, J. Carbon taxes, poverty and compensation options. [https://www.esri.ie/system/files/publications/SUSTAT98\\_0.pdf](https://www.esri.ie/system/files/publications/SUSTAT98_0.pdf) (2020).
110. Lawlor, D. & Visser, A. Energy poverty in Ireland. [https://data.oireachtas.ie/ie/oireachtas/libraryResearch/2022/2022-03-04\\_IRs-note-energy-poverty-in-ireland\\_en.pdf](https://data.oireachtas.ie/ie/oireachtas/libraryResearch/2022/2022-03-04_IRs-note-energy-poverty-in-ireland_en.pdf) (2022).
111. Lenzi, C. & Perucca, G. Economic inequalities and discontent in European cities. *npj Urban Sustain.* **3**, 26 (2023).
112. Caragliu, A. & Del Bo, C. F. Smart cities and the urban digital divide. *npj Urban Sustain.* **3**, 43 (2023).
113. Greenfields, M. & Brindley, M. Impact of insecure accommodation and the living environment on Gypsies' and Travellers' health. [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/490846/NIHB\\_-\\_Gypsy\\_and\\_Traveller\\_health\\_accs.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/490846/NIHB_-_Gypsy_and_Traveller_health_accs.pdf) (2016).
114. Equality Commission for Northern Ireland. Outlining minimum standards for traveller accommodation. [https://www.equalityni.org/ECNI/media/ECNI/Publications/DeliveringEquality/Traveller\\_Accommodation-Outlining-Minimum-Standards.pdf](https://www.equalityni.org/ECNI/media/ECNI/Publications/DeliveringEquality/Traveller_Accommodation-Outlining-Minimum-Standards.pdf) (2009).
115. Van Cleemput, P., Parry, G., Thomas, K., Peters, J. & Cooper, C. Health-related beliefs and experiences of Gypsies and Travellers: a qualitative study. *J. Epidemiol. Community Health* **61**, 205–210 (2007).
116. Richardson, J. & Ryder, A. *Gypsies and Travellers: Empowerment and Inclusion in British Society* (The Policy Press, 2012).
117. UN-HABITAT. *Report of Expert Group Meeting on Urban Indicators: Secure Tenure, Slums and Global Sample of Cities* (UN-HABITAT, 2002).
118. UN-HABITAT. *The Challenge of Slums: Global Report on Human Settlements 2003*. (UN-HABITAT, 2003).
119. Roy, D., Bernal, D. & Lees, M. An exploratory factor analysis model for slum severity index in Mexico City. *Urban Stud.* **57**, 789–805 (2019).
120. Ewers, M. C., Diop, A. & Le, K. T. Migrant worker well-being and its determinants: the case of Qatar. *Soc. Indicators Res.* **152**, 137–163 (2020).
121. Reber, L. The cramped and crowded room: the search for a sense of belonging and emotional wellbeing among temporary low-wage migrant workers. *Emot. Sp. Soc.* **40**, 108808 (2021).
122. Gardner, A. M. Labor camps in the Gulf States. [https://soundideas.pugetsound.edu/cgi/viewcontent.cgi?referer=&httpsredir=1&article=1104&context=faculty\\_pubs](https://soundideas.pugetsound.edu/cgi/viewcontent.cgi?referer=&httpsredir=1&article=1104&context=faculty_pubs) (2010).
123. McQue, K. 'I am starving': the migrant workers abandoned by Dubai employers. *The Guardian* (3 September 2020).
124. Elsheshtawy, Y. Transitory sites: mapping Dubai's 'Forgotten' urban spaces. *Int. J. Urban Reg. Res.* **32**, 968–988 (2008).

## ACKNOWLEDGEMENTS

The authors gratefully acknowledge financial support from UK Research and Innovation through the Centre for Research into Energy Demand Solutions, grant reference number EP/R035288/1, as well as Khalifa University of Science and Technology "High Impact Grant." From Northern Ireland, we also thank Caroline Coleman, Lisa Hogg, and Roisin Brady from Craigavon Traveller's Support; Gerard Jervis and Stephen Semple from the Northern Ireland Housing Executive; and Debbie Cowan from the Department of Justice for Northern Ireland for helping facilitate our site visits and community interviews, along with the help of two community members Mark Donahue and Barbara Purcell. From the UAE, we earnestly thank journalist Katie McQue for providing valuable guidance and advice prior to conducting this research. From Mexico City, we equally would like to thank Vicente Vargas, Mauricio Ruiz and Daniel Antonio Garcia from Observatorio de Desarrollo Regional y Promoción Social A.c for helping facilitate our site visits and community interviews, along with the help of two community members, Arturo Gutierrez and Angel Martin Sanchez. We also want to thank Paul Furszyfer for providing the facilities to conduct the two focus groups in Mexico City. Finally, we give many thanks to all interviewees and focus group participants. All opinions and findings expressed in the study are the authors' own and do not represent any of the funders or institutions from above.

## AUTHORS CONTRIBUTIONS

D.D.F.D.R.: conceptualization, methodology, formal analysis, investigation, writing—original draft, writing—review and editing. B.K.S.: conceptualization, methodology, formal analysis, investigation, writing—original draft, writing—review & editing, supervision, project administration, funding acquisition. S.G.: conceptualization, methodology, formal analysis, investigation, writing—original draft, writing—review & editing. A.F.: writing—review & editing. J.F.D.R.: methodology, formal analysis, writing—original draft, writing—review & editing.

## COMPETING INTERESTS

The authors declare no competing interests.

## ADDITIONAL INFORMATION

**Supplementary information** The online version contains supplementary material available at <https://doi.org/10.1038/s42949-023-00121-0>.

**Correspondence** and requests for materials should be addressed to Dylan D. Furszyfer Del Rio.

**Reprints and permission information** is available at <http://www.nature.com/reprints>

**Publisher's note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.

© The Author(s) 2023, last corrected publication 2023