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Energy poverty in Canada: Prevalence, social and spatial distribution, and implications for research and policy

Mylene Riva [a,*], Sophie Kingunza Makasi [a], Philippe Dufresne [a], Kimberley O'Sullivan [b], Megan Toth [a]

[a] Canada Research Chair in Housing Community and Health, Institute for Health and Social Policy and Department of Geography, McGill University, Burnside Hall Room 705, 805 Sherbrooke St. W., Montreal, Quebec H3A 0B9, Canada
[b] He Kāinga Oranga/Housing and Health Research Programme, Department of Public Health, University of Otago, Wellington, PO Box 7343, Wellington South 6242, New Zealand

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ABSTRACT

Canada is one of the largest energy producers in the world and one of the largest consumers of energy. A cold climate, dispersed population, affordable energy prices, and high standards of living contribute to Canada's high energy intensity. Yet, some 6% to 19% of Canadian households are experiencing energy poverty. Relying on data from the 2017 Survey of Household Spending, this study explores the social and spatial distribution of energy poverty across Canada. Energy poverty is measured at the household level, using expenditure-based indicators computed before and after housing costs. Logistic regression models are applied to examine the association between energy poverty and factors related to household composition, dwelling characteristics, urban/rural location, and province of residence. The odds of energy poverty are significantly higher for one-person, lone-parent, and older households, and for households with someone living with a long-term illness or disability. Energy poverty is significantly higher for households living in duplex or row housing, in single-detached and in mobile houses, in dwellings built prior to 1960, and in dwellings requiring major repairs. In comparison to homeowners with a mortgage, energy poverty is significantly higher for renters in urban centers. There are geographical patterns, with the odds of energy poverty almost twice as high for households in Atlantic provinces and in rural areas. These findings demonstrate that energy poverty is patterned across a social gradient in Canada and that it varies across space. The implications of the results for research and policy are discussed.

1. Introduction

Globally, Canada is one of the largest energy producers and one of the largest consumers of energy. A cold climate (with generally warm summers in southern latitudes), dispersed population, affordable energy prices, and high standards of living contribute to Canada's high energy intensity [1]. Nevertheless, results reported in this paper show that some 6% to 19% of Canadian households are living in energy poverty. Despite this high prevalence putting Canada on par with countries where reducing energy poverty is on the policy agenda, there is a dearth of academic research on the prevalence and on the social and spatial distribution of energy poverty in the country, and no research investigating the health and well-being impacts of exposure to energy poverty. Using data from a representative pan-Canadian population survey, this study reports on the prevalence of energy poverty in Canada and on its social and spatial patterning. Results are discussed for their implications for policy. Avenues for future research are suggested.

1.1. Background

Energy poverty happens when "*a household experiences inadequate levels of essential energy services in the home*" [2] (p.879), where energy services are those functions performed using energy, such as heating, cooling, lighting, cooking, washing, etc. [3]. While energy poverty relates to household factors such as low income, occupancy, and the needs and practices of household members, it is also caused by factors external to the household including the energy inefficiency of the dwelling and of appliances, the type of energy supply, and its cost. The capital

* Corresponding author.
E-mail addresses: mylene.riva@mcgill.ca (M. Riva), sophie.kingunzamakasi@mail.mcgill.ca (S. Kingunza Makasi), philippe.dufresne4@mcgill.ca (P. Dufresne), kimberley.osullivan@otago.ac.nz (K. O'Sullivan), megan.toth@mcgill.ca (M. Toth).

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expenditure needed to improve the energy efficiency of the dwelling is what distinguishes energy poverty from poverty: while increased incomes can lift households out of poverty, it may not lift them out of energy poverty if they still cannot afford, or have no control over (in the case of renters), improving the energy efficiency of their dwelling [4]. Thus, while related, energy poverty is not just a problem of low income.

Energy poverty is usually measured using self-reported and expenditure-based indicators [5]. Direct measurements (e.g., temperature readings) are also used but more rarely because of technical limitations. Self-reported indicators are based on household members' assessment of indoor thermal comfort and housing conditions, such as the presence of a leaking roof, damp walls, or rotten windows, their ability (to pay) to keep the dwelling adequately warm (or cool), and difficulty to pay utility bills. Such indicators are regularly collected in national surveys in several countries but less so in Canada. Expenditure-based indicators consider energy costs and household income and use thresholds to categorize households in energy poverty. One common metric classifies households as energy poor if they spend more than 10% of their income on energy. This metric originates from the work of Brenda Boardman in England in the early 1990's when the median *required* share of energy cost to household income was then around 5% [6]. This initial modelling of energy poverty focussed on the *need* of households to spend more than 10% of their income to meet energy-related residential demand, rather than actual spending. The 10% cut-off thus represented, at that time, twice the national median share of energy cost to household income (hereafter 2M) – that is a "high share of energy expenditure to income", which is another metric commonly used to quantify energy poverty. Since 2013, the Low Income High Cost (LIHC) measure has been used in England and elsewhere to categorize households as energy poor when their income after required energy costs falls below the poverty line and the share of their income spent on energy is above the national median [7]. This measure calculates the required energy expenditure based on energy needs for the dwelling (using data from the English House Condition Survey) – rather than using actual energy expenditure. The distinction is important since actual spending tends to underestimate actual rates. Indeed, across different countries, households in energy poverty have been found to reduce their energy use in order to reduce spending [8–12]. Yet, data needed to model energy needs are scarce outside of England, and the application of the LIHC measure is complex [13,14].

Studies have shown how the choice of indicators to measure energy poverty can influence the identification of target populations and localities for intervention [15,16]. As per the 2M measures, about 19% of households in the UK and over 20% of those in Sweden and Finland were considered energy poor in 2015 [17]. While expenditure-based indicators are perceived as providing objective and quantifiable estimates of energy poverty, they are criticized for their limitations in reflecting households' energy needs as well as their demographic, social, and economic circumstances. Using as an indicator the "inability to pay to keep the home adequately warm", the prevalence of energy poverty ranges from less than 2% in Nordic countries to 8% in the UK, and to over 20% in Portugal, Greece, and Cyprus [17]. While a strength of self-reported indicators is their potential to capture wider dimensions of energy poverty such as social exclusion and material deprivation [2], they are prone to measurement biases. To account for variation in the choice of indicators, some authors argue for the use of multidimensional indices of energy poverty combining expenditure-based and self-reported measures (see, for example, [18]).

Energy poverty is socially patterned. Low-income households are disproportionately impacted as they tend to live in older and poorly insulated dwellings which require more energy to reach an adequate livable temperature [19]. Their financial situation limits the possibilities of renovating or retrofitting their dwellings to improve energy efficiency and reduce energy costs. Research also suggests that energy poverty varies by gender, household composition, tenure, and socioeconomic status [20–23], and that it is unequally distributed across space [16,24]. Energy poverty is generally higher in rural areas where houses tend to be bigger and thus more expensive to heat, and where transmission and distribution charges are higher. Energy poverty also varies over time because of yearly fluctuation in the needs for energy services, changes in needs across life course, and households' trajectories into, and out of, energy poverty [25]. Ultimately, exposure to energy poverty can compromise health. International evidence shows that exposure to energy poverty is associated with an exacerbation of certain chronic diseases, poorer mental health outcomes, and an increased risk of cardiovascular and respiratory diseases, hospitalizations, and mortality [26–30].

1.2. Energy and energy poverty in Canada

In Canada, natural gas and electricity are the most common types of energy used (Fig. 1). However, the main source of energy consumption differs across provinces. For example, natural gas represents a greater share of household energy consumption in Ontario, Saskatchewan, Alberta and British Columbia, while electricity is the main source of energy used by households in Quebec, New Brunswick, and Newfoundland and Labrador. For Prince Edward Island and Nova Scotia, heating oil accounts for a larger proportion of household energy consumption. Each province has jurisdiction over its energy systems. Therefore, there is not one, but diverse residential energy systems in Canada, with varying prices for electricity, natural gas and oil across the provinces. When considering the abundance and reliability of energy resources, Canada ranks high in terms of energy security [31]. From the users' perspective however, access to essential energy services in the home is compromised for many.

According to the 10% of income expenditure on energy threshold, 8% of Canadian households were energy poor in 2013 (based on data from the 2013 Survey of Household Spending) [32]. British Columbia had the lowest prevalence at 5%, while Atlantic Canada had the highest at 21% [32]. According to the 2M measure applied to data from the 2016 Canadian Census, about 20% of Canadian households and over 30% of households in Atlantic Canada are energy poor. While the prevalence of energy poverty is higher in the Atlantic provinces, the absolute numbers are highest in Ontario where over one million households are estimated to be energy poor [33].

The Canadian Housing Survey, conducted for the first time in 2018, is the only survey asking respondents to report on energy poverty-related variables. According to the survey, between 76% and 70% of respondents are satisfied (or very satisfied) with their ability to maintain a comfortable temperature in their dwelling during the winter and the summer, respectively. About 62% reported being satisfied with the energy efficiency of their dwelling [34]. Satisfaction is higher among home owners compared to renters, and in small and rural communities compared to metropolitan areas [28]. These figures thus indicate that anywhere between 24% and 36% of Canadians are not satisfied with their ability to maintain comfortable indoor temperatures nor with the energy efficiency of their dwelling. Using data from the 2011 Survey of Household Spending, Rezaei identified risk factors associated with energy poverty, measured using the 2M indicator [35]. In models adjusted for household income and housing costs, the risk of energy poverty was observed to be higher for larger households, for those living in larger, single-detached and older dwellings, and in dwellings in need of major repairs. Energy poverty was also observed to be higher and among older renters and rural dwellers [35]. These results, however, are potentially limited by multicollinearity (e.g., adjustments for household size and composition) and over-adjustment (models are adjusted for household income before tax when household income after tax is the denominator of the dependent variable).

Building on this work and using more recent data from the Survey of Household Spending, the current study measures the prevalence of energy poverty in Canada by comparing and contrasting two expenditure-based indicators: the 10% threshold and the twice the national median

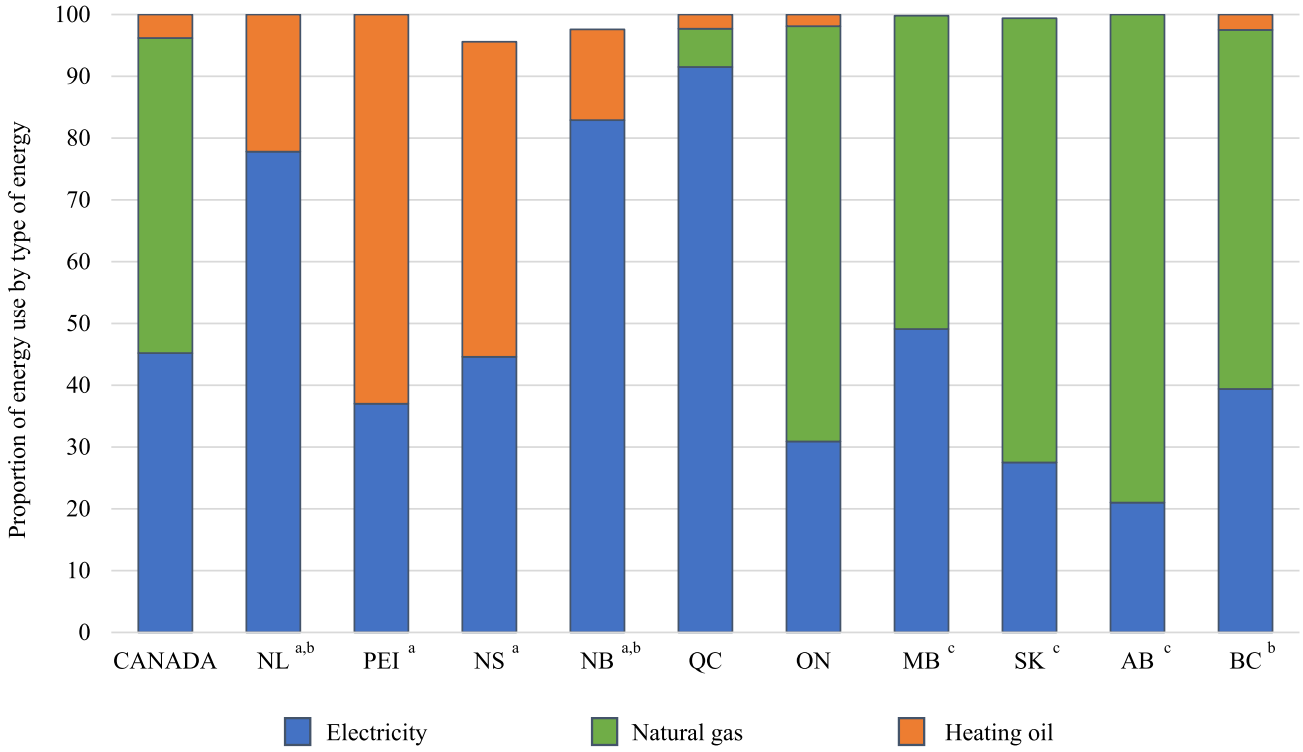

Fig. 1. Household energy consumption, Canada and provinces, 2015. Source: Statistics Canada. Table 25-10-0060-01 Household energy consumption, Canada and provinces. Data are from the 2015 Households and the Environment Survey. Available at https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=2510006001.
NL: Newfoundland and Labrador; PEI: Prince Edward Island; NS: Nova Scotia; NB: New Brunswick; QC: Quebec; ON: Ontario; MB: Manitoba; SK: Saskatchewan; AB: Alberta; BC: British Columbia.
[a] Figures for natural gas consumption too unreliable to be published.
[b] Figures for heating oil consumption to interpret with caution.
[c] Figures for heating oil consumption too unreliable to be published.

share of energy cost to household income. We then investigate variation in energy poverty by household composition, dwelling conditions, socioeconomic characteristics of survey respondents, and geography – focussing on variation across provinces and along the urban–rural continuum. We further explore whether risk factors associated with energy poverty differ between urban and rural areas.

2. Materials and methods

2.1. Data

Data are from the 2017 Survey of Household Spending (SHS), an annual survey conducted by Statistics Canada [36], and the latest version of the survey available for analysis. The target population corresponds to the population of the 10 provinces (n = 17,792) and of the three territorial capitals (n = 929). Residents of institutions, collective dwellings (retirement homes and long-term care facilities, school residences, work camps, etc.), members of the Canadian Forces living in military camps, and First Nations communities (reserves) are excluded from the sampling frame [36].

Households are selected to participate in the SHS using a two-stage sampling design. Clusters of geographic areas are first selected. Then, within each cluster, dwellings meeting the inclusion criteria are selected. From the selected dwellings, those inhabited by members of the target population constitute the sample of households. Within households, one member is identified as the 'reference person' – the one who is mainly responsible for the financial management of the household (so not necessarily the one paying all, or a larger portion, of the bills). When household members equally share the responsibility, one of the members is selected as the reference person. Data collection is conducted from January to December using an individual questionnaire that collects detailed information on household expenditures, as well as information on dwelling characteristics, household equipment, and socioeconomic characteristics (a subset of participants also complete a diary of daily expenditures) [36]. Because the target population of the SHS in the territories is not representative of the distribution of the population (characterized largely by small, remote First Nations and Inuit communities), our study is limited to the 10 provinces.

2.2. Measures

2.2.1. Energy poverty

Expenditure-based measures of energy poverty were computed. In the SHS, respondents reported the amount of their last payments for electricity, for natural gas, and for other fuel (heating oil, propane for heating and cooking, wood and other fuel for heating and cooking). The information provided for each of electricity, natural gas, and other fuel is adjusted so that the costs cover 12months and is summed to obtain the annual energy spending for the household. Data on household income and income taxes are from Individual Tax Return files from the Canada Revenue Agency and linked to the SHS by the Social Data Linkage Environment of Statistics Canada (participants have to consent for their income data to be linked to the SHS file).

Ratios of energy cost (sum of expenditures for electricity, natural gas, and other fuel) to annual household income after tax were computed before and after housing costs since households' capacity to pay for energy will depend on their disposable income, after housing costs [37]. Housing costs include rent, mortgage and property taxes, and condominium fees. From these ratios, four indicators of energy poverty were computed: households spending more than 10% of their annual after-tax

household income on energy-related costs i) before and ii) after housing costs; and households spending more than twice the national median share of energy-related costs to annual household income after tax (2M; the national median share is 3%) iii) before and iv) after housing costs. Analyses were restricted to households with energy costs greater than 0 (11.7% of households whose energy costs were = 0, e.g. for whom energy bills are included in their rent, were excluded from the analyses); with energy costs lower than annual household income after tax (0.2% households are excluded); and with an annual household income greater than $1,000 (0.5% households were excluded). For indicators considering housing costs, analyses are further restricted to households with annual energy costs lower than annual household income after tax (0.3% households are excluded). However, we should be clear that both the 10% absolute and 2M relative thresholds that we use are both based on actual energy expenditure, rather than an in-depth calculation that estimates the required energy expenditure accounting for factors such as housing quality, outdoor temperature, and price of electricity [2,38]. To be comparable to previous Canadian reports on energy poverty [32,33,35], we did not adjust household income and energy expenditures for household size and composition. We return to this in the discussion.

2.2.2. Housing conditions

The selection of housing conditions measures was guided by previous research [35,39], and characterize household composition and dwelling characteristics. Household composition comprises information on household type (a couple with, or without, children; lone-parent family; one-person household; etc.); age structure (presence of children and youth aged $\leq$ 14 years; presence of adults aged $\geq$ 65 years); and whether any household member has a long-term illness or disability. Quintiles of household income after tax were created for descriptive purposes. With regard to dwelling characteristics, we considered dwelling type (single-detached, apartment, etc.), period of construction, repairs needed (maintenance only, minor repairs, or major repairs), and tenure (owned with, or without, a mortgage, or rented).

2.2.3. Demographics of the reference person answering the survey

Age, sex, marital status, highest educational attainment, and work status were considered.

2.2.4. Geography

The spatial distribution of energy poverty is examined across provinces and along the urban/rural continuum. In the SHS, participants are classified according to the population size of the area of residence [36]. Population centres represent areas with a population $\geq$1,000 and a density of $\geq$400 people per km^2. Population centres are classified as small, medium, or large. Small population centers have a population ranging between 1,000 and 29,999; medium centers have a population ranging from 30,000 to 99,999; and large centers have a population of $\geq$100,000. All areas outside population centres are considered rural. To ensure sufficient sample sizes for the analysis, participants were categorized as living in rural areas, in small/medium centers, or in large population centers.

2.3. Statistical analysis

Descriptive and chi-square statistics are used to examine the prevalence of energy poverty and its variation by household composition, dwelling characteristics, socioeconomic characteristics of the main respondent, and geography. Because the sampling frame of the study is at the household level, and energy poverty is also measured at the household level, logistic regression is applied to investigate the association between energy poverty and household-level conditions and geography (respondents' characteristics are not considered in regression models). All variables were modelled simultaneously (household size is not included in the models given the correlation with household type). Analyses are further stratified by rurality to assess whether housing conditions associated with energy poverty vary across the urban/rural continuum. All analyses are conducted using survey and bootstrap weights in Stata/SE. Analyses were performed at the McGill-Concordia Research Data Centre (RDC), a secure physical environment available to accredited researchers to access anonymized microdata for research purposes. Descriptive results are estimated as counts and transformed into percentages before being released from the RDC. Estimates with a count lower than 5 or with a coefficient of variation greater than 33.3% are not released.

3. Results

As per the 10% threshold computed before and after housing costs, respectively 6.2% and 10.4% households are in energy poverty (Fig. 2). With the 2M measure, the prevalence of energy poverty is much higher at 18.1% and 19.2%, before and after housing costs, respectively. There is variation by provinces, with the highest prevalence of energy poverty observed in the Atlantic provinces (Newfoundland and Labrador, Prince Edward Island, Nova Scotia, and New Brunswick), followed by Ontario and Saskatchewan. Compared to urban centers, energy poverty is considerably higher in rural areas, where the prevalence surpasses 30% according to the 2M indicators (ranging between 13% and 19% when using the 10% measure before and after housing costs, respectively). Overall, while there is little difference in the prevalence estimates of energy poverty when measured using the 2M indicators before and after housing costs, differences are larger for the 10% indicator when housing costs are considered.

Table 1 presents the prevalence of households in energy poverty vs. those who are not, by household composition and dwelling characteristics. Overall, patterns are similar across most indicators of energy poverty. The prevalence of energy poverty is higher for one-person households, for households where at least one person is aged 65 years or older, and for households where at least one person is living with a long-term illness or disability. With regards to dwelling characteristics, energy poverty is higher for those living in detached dwellings, in dwellings built prior to 1960, and in dwellings requiring major repairs. Considering tenure, energy poverty measured before housing costs is higher among homeowners without a mortgage; however, the pattern is less clear when housing costs are considered. The distribution of energy poverty across quintiles of household income after tax shows that, while the risk of experiencing energy poverty is overrepresented in households in the two lowest quintiles, not all low-income households are experiencing energy poverty. It appears that the 10% threshold is more sensitive to adjustments for housing costs, in that differences before and after adjustments are generally larger for the 10% than the 2M thresholds. The 10% threshold seems to pick up more people in lower income groups, whereas the 2M classifies more households as experiencing energy poverty in higher income quintiles.

The distribution in the prevalence of energy poverty by the socioeconomic demographics of the household's reference person is displayed in Table 2. Results compare the proportion of reference persons in energy poverty vs. those who are not, by their socioeconomic conditions. Patterns are similar across all indicators. Significantly greater risk of energy poverty was identified when the reference person is a woman; is in an older age group (especially 65 years and over); is single or separated, divorced, or widowed; has a lower educational level (less than high school diploma); or did not work the week before the survey.

Results of logistic regressions for all four indicators of energy poverty are in Table 3. While associations are, overall, stronger when energy poverty indicators are computed before rather than after housing costs, trends in the associations are mostly similar across all four indicators. However, there are exceptions. For conciseness, we focus here on results for energy poverty measured using the 2M indicator after housing costs. Compared to nuclear family households (couple with children), the odds of living in energy poverty are over four times higher for people living

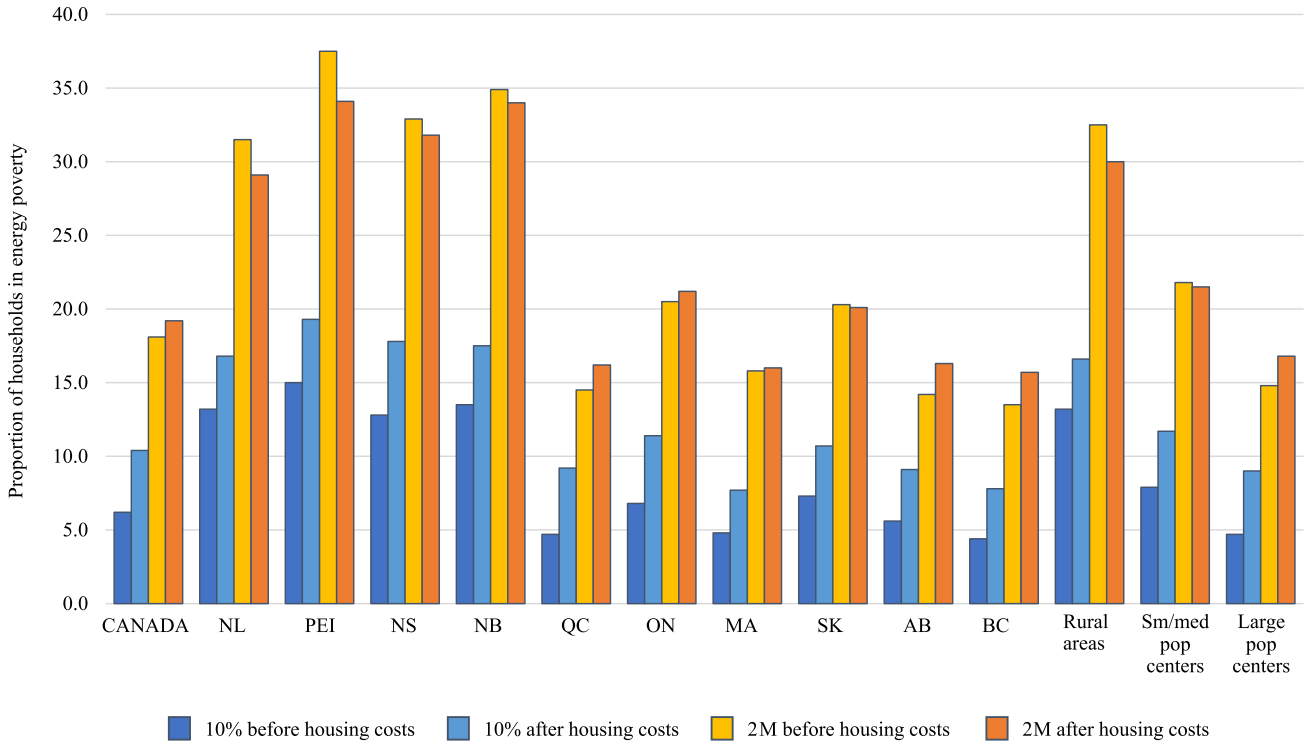

Fig. 2. Proportion of households in energy poverty, by different indicators and by province, 2017 Survey of Household Spending.
NL: Newfoundland and Labrador; PEI: Prince Edward Island; NS: Nova Scotia; NB: New Brunswick; QC: Quebec; ON: Ontario; MB: Manitoba; SK: Saskatchewan; AB: Alberta; BC: British Columbia.

alone (one-person household), and more than twice as high for single-parent families. The odds are also significantly higher for households with at least one member living with a long-term illness or disability and for households with at least one member aged 65 years and older. To note, the increased odds of energy poverty among older households are only apparent when energy poverty is measured using the 2M threshold, and not the 10% threshold. Compared to people living in apartments, energy poverty is significantly higher for those living in a duplex or row housing, in single-detached houses or mobile homes. Energy poverty is also higher for people living in dwellings built prior to 1960 and in dwellings requiring major repairs. In comparison to homeowners with a mortgage, renters are at increase risk of energy poverty, whereas homeowners without a mortgage are at lower risk. There are clear geographical patterns in the distribution of energy poverty across Canada, with the odds being higher in rural areas compared to large population centers, and in all Atlantic provinces and in Ontario in comparison to British Columbia (where the prevalence of energy poverty is the lowest).

When investigating housing conditions associated with energy poverty across rural, small/medium and large urban centers (Table 4 for the 10% and 2M measures after housing costs), results are, overall, similar to those obtained for the full models. But there are differences. In rural areas, the odds of energy poverty are especially high for one-person and lone-parent households, for households with someone living with a long-term disability or illness, and for households living in single-detached dwellings and in dwellings built prior to 1960. There is no significant variation in rural energy poverty by tenure, repairs needed, or province. For households in small/medium and large population centers, the risk of energy poverty is more pronounced for households with older adults, those living in all dwelling types compared to apartments, and in Atlantic provinces. The need for major repairs is only significantly associated with energy poverty in small/medium population centres. With regard to tenure, while the odds of energy poverty are significantly lower for homeowners without a mortgage, the risk of energy poverty is higher for renters in large urban centers.

4. Discussion

Our findings indicate that energy poverty is prevalent in Canada, affecting between 6% and 19% of households nationally, depending on the measure used. The prevalence of energy poverty is even greater in the Atlantic provinces, where almost one in three households is considered energy poor. Given the recent economic and social consequences of the COVID-19 pandemic as well as stay-at-home measures, the prevalence of energy poverty is likely to have increased in the past year [40–42].

Measurements of the national prevalence of energy poverty are sensitive to the indicator used (10% vs. 2M thresholds) and to consideration of housing costs. Generally, the prevalence of energy poverty almost doubles when energy poverty is measured using a relative (2M) vs. an absolute (10%) threshold. Likewise, there are differences when the share of energy cost to household income is computed after accounting for housing costs (rent, mortgage, etc.). This is particularly true in economies where housing costs are allocated a significant portion of income or have risen rapidly in comparison to incomes. Indeed, correcting for housing costs removes the effect of differences in housing costs that are not related to the quality of the dwelling, like location [14]. This is likely why our results show higher prevalence of energy poverty when measured after housing costs in provinces where the average house price is higher, i.e., in British Columbia, Ontario, Alberta, and Quebec. The variation in results according to the indicator applied to measure energy poverty reinforce previous arguments that researchers and decision-makers should rely on multiple indicators to identify target populations and localities for energy poverty reduction interventions [14].

Furthermore, results demonstrate a clear social patterning of energy poverty in Canada. This is consistent previous Canadian reports using earlier data from the Survey of Household Spending [35] and with

Table 1
Energy poverty by household composition and dwellings characteristics, 2017 Survey of Household Spending.

	10% before housing costs		10% after housing costs		2M before housing costs		2M after housing costs	
	No (%)	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)
HOUSEHOLD COMPOSITION AND INCOME								
Household type	$p < 0.001$		$p < 0.001$		$p < 0.001$		$p < 0.001$	
One-person	22.5	53.9	21.1	45.8	20.9	40.8	19.8	40.0
Couple, no kids	30.5	19.5	31.3	21.1	30.5	26.7[c]	31.7	24.4
Couple with kids	29.4	10.3[a]	30.1	15.4	30.8	16.1	31.0	18.0
Lone-parent	5.5	8.7[a,c]	5.4	8.4[a,c]	5.0	8.8	5.1	8.1
Other	12.1	7.6[a]	12.1	9.2	12.8	7.7	12.3	9.6[c]
Children 0-14y	$p < 0.001$		$p < 0.001$		$p < 0.001$		$p < 0.001$	
No	76.2	86.2[c]	76.1	80.9	75.4	83.4	75.7	80.3[c]
Yes	23.8	13.8	23.9	19.1	24.6	16.6	24.3	19.7
Adult(s) ≥ 65y	$p = 0.004$		$p = 0.030$		$p < 0.001$		$p < 0.001$	
No	71.3	63.0[c]	70.9	64.8	73.2	59.8	72.1	62.7
Yes	28.7	37.0	29.1	35.2[c]	26.8	40.2	27.9	37.3
Person with long term illness/disability	$p < 0.001$		$p < 0.001$		$p < 0.001$		$p < 0.001$	
No	94.2	87.1[c]	94.6	86.0	95.1	87.8[c]	95.1	87.9[c]
Yes	5.8	12.9[a]	5.4	14.0	4.9	12.2	4.9	12.1
Household income after tax	$p < 0.001$		$p < 0.001$		$p < 0.001$		$p < 0.001$	
Q1 (low)	11.8	73.4	9.0	56.3	9.2	45.1	7.1	42.6
Q2	19.5	20.7[c]	18.5	30.6	16.4	33.7	16.6	33.2
Q3	21.8	5.4[a]	22.4	11.2	21.9	15.7	22.2	17.2
Q4-Q5 (high)	[b]		50.0	2.0[a]	52.5	5.5	54.0	7.0
DWELLING CHARACTERISTICS								
Dwelling type	$p = 0.002$		$p = 0.038$		$p < 0.001$		$p < 0.001$	
Single detached	60.8	70.8[c]	61.5	65.8[c]	59.1	72.1	60.5	68.0
Double, row, duplex	16.4	14.1[c]	16.4	16.1[c]	16.6	14.7[c]	16.4	16.0[c]
Apartment	21.4	12.5[a]	20.7	15.8	23.2	10.6	21.8	13.7
Mobile home	1.3	2.6[a,c]	1.4	2.3[a,c]	1.2	2.6[a]	1.3	2.3[a,c]
Tenure	$p < 0.001$		0.003		$p < 0.001$		$p = 0.209$	
Owned, mortgage	41.8	28.1	41.5	37.3	42.8	32.6	41.6	38.8[c]
Owned, no mortgage	32.9	46.9	34.7	31.6	31.3	44.7	34.3	34.8[c]
Rented	25.3	25.0[c]	23.9	31.0	25.9	22.7[c]	24.2	26.4[c]
Period of construction	$p < 0.001$		$p < 0.001$		$p < 0.001$		$p < 0.001$	
1960 or before	22.9	31.5	22.8	30.3[c]	21.8	30.9	22.1	29.8
1961 to 1980	27.3	30.4[c]	27.3	29.1	26.4	32.1	26.8	30.3
1981 or after	49.8	38.0	49.9	40.7	51.7	37.0	51.1	39.9
Repairs needed	$p < 0.001$		$p < 0.001$		$p < 0.001$		$p < 0.001$	
Regular maintenance	70.7	63.7[c]	70.9	63.3	71.7	63.8	71.5	64.1
Minor repairs	22.0	22.3[c]	22.0	23.1[c]	21.4	25.2[c]	21.7	24.1[c]
Major repairs	7.3	14.0	7.1	13.6[c]	7.0	11.0	6.8	11.8

[a] Estimates with coefficients of variation between 16.6% and 33.3%; estimates should be interpreted with caution.
[b] Estimates with coefficients of variation higher than 33.3%; estimates are unreliable.
[c] Confidence intervals of the estimates are overlapping, indicating the difference is not statistically significant.

international studies. International evidence demonstrates that specific populations such as older adults living alone, single-parent families, people with fewer years of education, and those who are unemployed and/or receiving social assistance are at increased risk of experiencing energy poverty [20–23]. In our study, a heightened risk of energy poverty is also observed for one-person and lone-parent households, but also for households with older adults and with someone living with a long-term illness or disability. Our results support previous research demonstrating a gendered experience of energy poverty, where women tend to be at greater risk of energy poverty as a result of (among other factors) gendered household practices (domestic responsibilities, caring for children) and lower participation in the economy [22,23,43–46]. Results of the distribution of energy poverty across household income quintiles clearly demonstrates that, while energy poverty is strongly correlated with households' disposable income, it is not only indicative of lower incomes. The choice of energy poverty measure is an important consideration when identifying target populations for energy poverty interventions in Canada, especially for capturing households composed of older adults, who are more vulnerable to exposure to energy poverty [29].

With regard to dwelling characteristics, in comparison to apartments, energy poverty is higher in all dwelling types, which likely reflects costs associated with heating larger areas. In apartments, the reduced exposure to outdoor walls, floors, roofs, and windows contributes to lower energy requirements per apartment household [47]. As observed elsewhere [38,48,49], energy poverty is significantly higher among renters in comparison to homeowners (with a mortgage), and especially for renters in large population centers. This likely reflects renters' lower control over their dwelling and heating system and their limited ability to bring modifications to improve energy efficiency of the dwelling because of their tenure status [45]. Energy poverty is also higher for households living in older dwellings (built prior to 1960) and in houses requiring major repairs, which likely reflects the lower energy efficiency of these dwellings.

There is a strong geographical pattern in the distribution of energy poverty across Canada, with higher prevalence of households in energy poverty in the Atlantic Canada and in rural areas. In Atlantic provinces, heating oil and biomass is used more frequently as a main heating sources compared to the rest of Canada [50]. Atlantic Canada is also characterized by lower median household income and a larger share of the population aged 65 years and older, who potentially increase their energy use to keep the home at comfortable temperatures. Finally, more than 40% of the population in Atlantic provinces lives in rural areas, where the cost of electricity distribution is often higher and where houses are often larger and therefore more expensive to heat [33].

Housing conditions associated with energy poverty differ between population centers and rural areas. In rural areas, household composition variables are most consistently associated with energy poverty,

Table 2
Energy poverty by demographics of the reference person answering the survey, 2017 Survey of Household Spending.

	10% before housing costs		10% after housing costs		2M before housing costs		2M after housing costs	
	No (%)	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)
Age	$p < 0.001$		$p < 0.001$		$p < 0.001$		$p < 0.001$	
<30y	8.9	7.8[a,b]	8.4	7.8	9.4	6.1	8.7	7.2[b]
30-39y	18.1	9.2[a]	17.9	14.5	18.7	12.0	18.4	14.0
40-54y	29.9	23.1	30.2	23.8	31.1	22.1	30.8	23.9
55-64y	19.7	25.7[b]	19.8	21.9[b]	19.4	23.0[b]	19.6	21.6[b]
≥65y	23.5	34.1	23.6	32.1[b]	21.3	36.9	22.4	33.3
Sex	$p = 0.045$		$p = 0.015$		$p = 0.001$		$p < 0.001$	
Men	50.6	42.8[b]	50.8	43.3	51.6	43.3	51.5	44.0
Women	49.4	57.2[b]	49.2	56.7[b]	48.4	56.7	48.5	56.0
Marital status	$p < 0.001$		$p < 0.001$		$p < 0.001$		$p < 0.001$	
Married/common-law	65.2	31.5	66.9	39.3	67.2	44.8	68.4	45.7
Single, never married	16.0	24.0	15.1	21.3[b]	15.9	19.4[b]	14.9	19.5
Separated, widowed or divorced	18.7	44.5	18.0	39.4	16.9	35.8	16.7	34.9
Highest level of education	$p < 0.001$		$p < 0.001$		$p < 0.001$		$p < 0.001$	
Less than high school	11.1	25.0	10.6	23.8	9.4	23.5	9.5	22.0
High school or equiv.	20.4	22.0[b]	20.3	22.1[b]	20.0	23.0[b]	19.8	23.3[b]
Postsec., <university	32.6	35.3[b]	32.6	34.7[b]	32.4	34.6[b]	32.4	34.7[b]
University completed	35.9	17.7	36.5	19.4	38.3	18.9	38.2	20.0
Employed	$p < 0.001$		$p < 0.001$		$p < 0.001$		$p < 0.001$	
No	38.5	64.8	37.4	60.0[b]	35.4	61.7	35.7	57.1
Yes	61.5	35.2	62.6	40.0[b]	64.6	38.3	64.3	42.9

[a] Estimates with coefficients of variation between 16.6% and 33.3%; estimates should be interpreted with caution.
[b] Confidence intervals of the estimates are overlapping, indicating the difference is not statistically significant.

compared to dwelling characteristics. Issues with sample size are at play here, as evidenced in the large confidence intervals for some of the estimates, especially for dwelling type which is more uniform across rural areas than in other population centers. There are slight differences in association between housing conditions and the indicator of energy poverty used; future studies should explore in greater depth spatial variation in various energy poverty metrics between, and within, rural and urban areas. Households with at least one person with a long-term illness or disability appear to be more at risk of energy poverty in rural areas and large urban centers, compared to households in small/medium population centers. For households located in small, medium, and large population centers, energy poverty further varies by province. For non-rural households, this may suggest that variability in energy poverty is more influenced by variation in energy costs between provinces. In large urban centers, renters are at increased risk of energy poverty. These results call for more research to explore the geography of energy poverty at smaller geographical scales in Canada in order to identify target populations and localities for intervention.

4.1. Limitations and avenues for future research

Our study has some limitations. Since we conducted secondary data analysis, we were limited by the data available in the SHS to measure energy poverty and risk factors. We applied two expenditure-based measures of energy poverty, the 10% and the 2M thresholds. Expenditure-based indicators have been criticized for the arbitrariness of the threshold and sensitivity to fluctuations in energy prices [51,52] and income measures, and because they do not account for a household's specific energy needs [2,8,53]. The metrics we have chosen may also fail to capture cases of energy poverty where households drastically reduce their energy consumption below levels required to meet their needs [54]. In our study, about 12% of households were excluded because they reported no energy cost, likely representing a situation where households have the cost of their utilities included in their rent. As a consequence, by excluding these households from the analysis, the prevalence of energy poverty might be underestimated.

More research is needed conceptualize and operationalize indicators of energy poverty that are relevant to the Canadian context and to monitor trends over time. For example, metrics that equivalize income and energy use for household size and composition should be considered. While equivalization scales exist for household income, equivalizing energy use is less straightforward [13,14]. Nevertheless, income equivalization scales are not without limitations. For example, the OECD equivalence scale which is commonly used, was last modified in 1994 and is meant to provide a common scale for international comparison. Therefore, it is not sensitive to regional variations [14], including variation in the cost of living – which is important to consider in a large country like Canada and in a country where the energy supply and cost vary significantly between provinces. In addition, consideration should be given to modelling energy needs rather than only actual spending and to developing indicators that are able to capture cases of hidden energy poverty or cases where households overspend on energy [54]. Informed by international research and policy [38,42,55–59] self-reported indicators of energy poverty (and security) should be validated, adapted, or developed for the Canadian context. Ultimately, the complex reality of energy poverty calls for the use of different indicators in order to capture the diversity of experiences and intensities of energy poverty rather than the development and adoption of one single metric [14].

In a large country like Canada, the urban design is profoundly influenced by the use of the automobile. Because transportation accounts for an important share of household energy consumption and related costs, future studies should consider fuel expenditures for transportation. Some households may in fact experience a 'double energy vulnerability,' being exposed to both domestic- and transportation-related energy poverty [60–62]. This is important to consider because studies have shown that, in some cases, energy poverty related to transportation may increase the risk of domestic energy poverty [61]. It is possible that households, and especially those in *peri*-urban regions, may decide to modify their domestic energy use rather than reduce their vehicle fuel consumption, as they might be dependent on their car to go to work [61]. Households experiencing this double energy vulnerability tend to be located in remote rural areas characterized by poor public transportation services and with fewer energy infrastructures [61]. Given that our analysis shows that households in rural areas have higher

Table 3
Association between energy poverty, household composition, dwelling characteristics, and geography, 2017 Survey of Household Spending.

	10% before housing costs OR (95%CI)	10% after housing costs OR (95%CI)	2M before housing costs OR (95%CI)	2M after housing costs OR (95%CI)
HOUSEHOLD COMPOSITION				
Household type				
Couple with kids	1.00	1.00	1.00	1.00
One-person	**8.57 (5.34, 13.75)**	**5.69 (4.05, 7.99)**	**4.81 (3.69, 6.27)**	**4.65 (3.61, 6.00)**
Couple no kids	*1.63 (1.00, 2.68)*	**1.41 (1.02, 1.96)**	**1.43 (1.11, 1.83)**	**1.33 (1.04, 1.70)**
Lone-parent	**4.25 (2.43, 7.45)**	**2.83 (1.81, 4.42)**	**3.28 (2.33, 4.61)**	**2.63 (1.85, 3.73)**
Other	*1.72 (0.95, 3.13)*	1.23 (0.80, 1.89)	0.92 (0.66, 1.29)	1.09 (0.80, 1.48)
Adults ≥ 65y				
No	1.00	1.00	1.00	1.00
Yes	0.88 (0.64, 1.20)	*1.27 (0.99, 1.62)*	**1.39 (1.14, 1.69)**	**1.48 (1.23, 1.78)**
Person with long term illness/disability				
No	1.00	1.00	1.00	1.00
Yes	**2.42 (1.53, 3.84)**	**2.89 (2.05, 4.07)**	**3.11 (2.29, 4.22)**	**2.84 (2.12, 3.81)**
DWELLING CHARACTERISTICS				
Dwelling type				
Apartment	1.00	1.00	1.00	1.00
Single detached	**3.96 (2.37, 6.61)**	**4.06 (2.64, 6.24)**	**5.43 (3.82, 7.70)**	**4.26 (3.07, 5.91)**
Double, row, duplex	**2.58 (1.46, 4.58)**	**2.58 (1.72, 3.85)**	**3.41 (2.38, 4.87)**	**2.82 (2.03, 3.91)**
Mobile home	**3.55 (1.65, 7.62)**	**4.30 (2.28, 8.13)**	**6.42 (3.69, 11.18)**	**4.85 (2.94, 8.01)**
Tenure				
Owned, mortgage	1.00	1.00	1.00	1.00
Owned, no mortgage	**1.49 (1.05, 2.13)**	**0.63 (0.48, 0.82)**	1.18 (0.95, 1.47)	**0.65 (0.53, 0.79)**
Rented	**1.84 (1.23, 2.74)**	**1.89 (1.34, 2.66)**	**1.76 (1.31, 2.36)**	**1.60 (1.23, 2.08)**
Period of construction				
1981 or after	1.00	1.00	1.00	1.00
1961 to 1980	1.12 (0.82, 1.54)	1.00 (0.77, 1.29)	**1.36 (1.10, 1.68)**	1.16 (0.96, 1.40)
1960 or before	1.18 (0.84, 1.64)	1.08 (0.82, 1.42)	**1.41 (1.14, 1.75)**	**1.24 (1.00, 1.53)**
Repairs needed				
Regular maintenance	1.00	1.00	1.00	1.00
Minor repairs	0.94 (0.68, 1.30)	1.00 (0.79, 1.26)	1.14 (0.95, 1.38)	1.06 (0.89, 1.27)
Major repairs	1.37 (0.92, 2.03)	**1.48 (1.06, 2.06)**	1.19 (0.90, 1.56)	**1.36 (1.04, 1.77)**
GEOGRAPHY				
Urban/rural categorization				
Large pop. centers	1.00	1.00	1.00	1.00
Small-med pop. centers	*1.31 (0.96, 1.79)*	1.02 (0.78, 1.34)	1.19 (0.95, 1.49)	1.04 (0.84, 1.28)
Rural areas	**2.15 (1.53, 3.03)**	**1.53 (1.15, 2.04)**	**1.85 (1.50, 2.28)**	**1.59 (1.27, 1.98)**
Province				
BC	1.00	1.00	1.00	1.00
NL	**2.37 (1.51, 3.74)**	**1.89 (1.37, 2.63)**	**2.05 (1.59, 2.64)**	**1.69 (1.31, 2.17)**
PEI	**2.58 (1.56, 4.28)**	**2.09 (1.44, 3.04)**	**2.55 (1.84, 3.52)**	**1.98 (1.45, 2.68)**
NS	**2.34 (1.49, 3.65)**	**2.02 (1.50, 2.73)**	**2.33 (1.83, 2.97)**	**1.93 (1.52, 2.44)**
NB	**2.30 (1.47, 3.60)**	**1.90 (1.40, 2.57)**	**2.38 (1.87, 3.01)**	**2.08 (1.63, 2.66)**
QC	0.96 (0.61, 1.52)	1.11 (0.80, 1.54)	1.00 (0.79, 1.28)	0.95 (0.74, 1.21)
ON	**1.76 (1.10, 2.81)**	**1.58 (1.14, 2.19)**	**1.68 (1.32, 2.15)**	**1.43 (1.13, 1.82)**
MB	0.91 (0.53, 1.54)	0.86 (0.57, 1.29)	0.95 (0.72, 1.27)	0.85 (0.63, 1.13)
SK	1.22 (0.75, 1.98)	1.18 (0.84, 1.66)	1.14 (0.88, 1.48)	1.06 (0.83, 1.37)
AB	1.19 (0.73, 1.94)	1.07 (0.73, 1.58)	0.93 (0.70, 1.25)	0.93 (0.71, 1.22)

In bold: p-value < 0.05. In italics: p-value < 0.10.

rates of domestic energy poverty, it is worth investigating whether rural households are further disadvantaged by transportation costs. Already, findings from a 2016 report by the Fraser Institute showed that, as per the 10% measure, nationwide estimates of energy poverty rose from 7.9% to 19.4% when gasoline was included [32], which indicates that transportation costs are relevant to consider in measures of energy poverty in Canada.

While the SHS is designed to be representative of the Canadian population, generalizations of our findings are nonetheless limited. First, because participation in the SHS is voluntary, self-selection cannot be ruled out. There is often lower participation to population surveys from lower-income groups [63]. It is therefore possible that the prevalence of energy poverty is underestimated. With regard to applicability of our results for minority groups, our results are limited by the data available and the sampling frame of the SHS. The 2017 SHS does not contain information on ethnicity or immigration status – groups that may be particularly vulnerable to energy poverty [63]. Our study is limited to the 10 provinces, therefore excluding the territorial capitals where a higher proportion of Indigenous peoples live. Within provinces, the survey frame of the SHS excludes First Nation communities (reserves). Yet, Indigenous communities in Canada face a unique set of challenges related to housing and energy use. For example, housing needs are high [64] and many communities, including most Inuit communities in Northern Canada, are not connected to the main power grids and rely rather on local power plants fuelled by diesel [65], increasing the cost of energy. Many Indigenous communities have been displaced for large scale hydroelectricity developments; others are still not connected to the main power grids – a clear energy justice issue. More efforts are required to measure and address energy poverty and insecurity experienced by racial/ethnic, Indigenous and other minority groups across the country.

In-depth qualitative research should be carried out to understand how energy poverty influences the daily lives of Canadians, including for subgroups of the population who might be more vulnerable to the effects of energy poverty. While the SHS does not measure health per se, findings indicate an increased risk of energy poverty for households with someone living with a long-term illness or disability. Assessing whether energy poverty is a risk factor for the health and well-being of Canadians is a critical research gap to address. This is especially relevant since health risks associated with energy poverty are higher for those living alone, for

Table 4
Association between energy poverty, household composition, dwelling characteristics, by rurality, 2017 Survey of Household Spending.

	10% after housing costs			2M after housing costs		
	Rural OR (95%CI)	Small-medium pop. center OR (95%CI)	Large pop. centers OR (95%CI)	Rural OR (95%CI)	Small-medium pop. center OR (95%CI)	Large pop. centers OR (95%CI)
HOUSEHOLD COMPOSITION						
Household type						
Couple with kids	1.00	1.00	1.00	1.00	1.00	1.00
One-person	**6.74 (2.83, 16.01)**	**5.59 (2.63, 11.86)**	**5.82 (3.71, 9.15)**	**5.02 (2.72, 9.26)**	**5.85 (3.46, 9.89)**	**4.41 (3.15, 6.18)**
Couple no kids	1.81 (0.81, 4.08)	0.94 (0.41, 2.12)	**1.55 (1.01, 2.37)**	1.47 (0.88, 2.47)	1.35 (0.77, 2.36)	*1.34 (0.97, 1.85)*
Lone-parent	**4.33 (1.48, 12.68)**	**3.50 (1.20, 10.19)**	**2.51 (1.38, 4.58)**	**2.95 (1.32, 6.59)**	**2.69 (1.25, 5.79)**	**2.58 (1.65, 4.03)**
Other	1.19 (0.36, 3.89)	0.65 (0.25, 1.70)	1.44 (0.84, 2.46)	1.43 (0.57, 3.57)	0.80 (0.36, 1.79)	1.13 (0.78, 1.64)
Adults ≥ 65y						
No	1.00	1.00	1.00	1.00	1.00	1.00
yes	1.37 (0.82, 2.31)	*1.58 (0.95, 2.63)*	1.15 (0.82, 1.62)	1.46 (*0.96, 2.23*)	**1.70 (1.14, 2.54)**	**1.42 (1.09, 1.84)**
Person with long term illness/disability						
No	1.00	1.00	1.00	1.00	1.00	1.00
Yes	**2.78 (1.15, 6.72)**	1.52 (0.64, 3.66)	**3.71 (2.44, 5.63)**	**4.36 (2.16, 8.81)**	1.76 (0.83, 3.76)	**3.16 (2.20, 4.55)**
DWELLING CHARACTERISTICS						
Dwelling type						
Apartment	1.00	1.00	1.00	1.00	1.00	1.00
Single detached	*4.71 (0.79, 27.94)*	**3.65 (1.35, 9.86)**	**4.37 (2.52, 7.58)**	**6.67 (1.32, 33.78)**	**5.65 (2.51, 12.69)**	**4.07 (2.75, 6.01)**
Double, row, duplex	4.93 (0.38, 63.23)	2.04 (0.82, 5.09)	**2.87 (1.75, 4.73)**	3.35 (0.42, 26.52)	**3.49 (1.56, 7.80)**	**2.74 (1.86, 4.04)**
Mobile home	4.38 (0.63, 30.30)	**5.71 (1.53, 21.41)**	2.02 (0.48, 8.54)	4.77 (*0.91, 25.07*)	**8.28 (2.63, 26.06)**	**5.14 (1.43,18.41)**
Tenure						
Owned, mortgage	1.00	1.00	1.00	1.00	1.00	1.00
Owned, no mortgage	0.93 (0.50, 1.75)	0.66 (0.36, 1.20)	**0.53 (0.37, 0.76)**	1.00 (0.64, 1.55)	**0.57 (0.37, 0.89)**	**0.60 (0.46, 0.79)**
Rented	*2.10 (0.87, 5.06)*	1.79 (0.72, 4.46)	**1.87 (1.24, 2.82)**	1.86 (0.81, 4.29)	*1.83 (0.98, 3.43)*	**1.53 (1.10, 2.11)**
Period of construction						
1981 or after	1.00	1.00	1.00	1.00	1.00	1.00
1961 to 1980	0.91 (0.51, 1.62)	1.07 (0.58, 1.99)	1.00 (0.71, 1.40)	1.08 (0.66, 1.77)	1.20 (0.76, 1.88)	1.16 (0.91, 1.48)
1960 or before	*1.81 (0.96, 3.41)*	1.37 (0.70, 2.68)	0.91 (0.63, 1.31)	**1.72 (1.05, 2.80)**	1.32 (0.82, 2.12)	1.14 (0.86, 1.51)
Repairs needed						
Regular maintenance	1.00	1.00	1.00	1.00	1.00	1.00
Minor repairs	0.78 (0.48, 1.27)	1.36 (0.79, 2.34)	0.96 (0.70, 1.30)	0.65 (*0.42, 1.01*)	*1.47 (0.96, 2.26)*	1.08 (0.86, 1.36)
Major repairs	1.15 (0.53, 2.48)	**3.24 (1.54, 6.81)**	1.21 (0.76, 1.92)	1.43 (0.85, 2.41)	**2.29 (1.20, 4.37)**	1.08 (0.74, 1.58)
GEOGRAPHY						
Province						
BC	1.00	1.00	1.00	1.00	1.00	1.00
NL	1.48 (0.67, 3.27)	**2.78 (1.38, 5.60)**	1.47 (0.86, 2.49)	1.51 (0.68, 3.38)	**2.75 (1.52, 4.97)**	1.32 (0.93, 1.89)
PEI	2.02 (0.86, 4.74)	*1.99 (0.95, 4.17)*	–	2.04 (0.87, 4.79)	**2.61 (1.47, 4.64)**	–
NS	1.48 (0.61, 3.56)	**2.74 (1.33, 5.66)**	**1.98 (1.29, 3.02)**	1.67 (0.74, 3.77)	**3.55 (1.91, 6.59)**	**1.66 (1.23, 2.25)**
NB	1.18 (0.52, 2.71)	**2.24 (1.13, 4.45)**	**2.28 (1.41, 3.69)**	1.70 (0.77, 3.73)	**2.81 (1.64, 4.81)**	**2.17 (1.49, 3.17)**
QC	0.84 (0.36, 2.01)	0.72 (0.31, 1.68)	1.33 (0.85, 2.09)	1.01 (0.45, 2.26)	1.04 (0.57, 1.89)	0.90 (0.66, 1.24)
ON	1.70 (0.59, 4.88)	1.62 (0.73, 3.57)	**1.56 (1.01, 2.39)**	1.48 (0.61, 3.60)	*1.81 (0.97, 3.37)*	*1.31 (0.98, 1.75)*
MB	0.74 (0.28, 1.95)	1.01 (0.44, 2.30)	0.82 (0.45, 1.50)	0.76 (0.31, 1.89)	1.28 (0.65, 2.54)	0.75 (0.51, 1.10)
SK	1.12 (0.49, 2.54)	0.63 (0.28, 1.42)	1.40 (0.84, 2.36)	1.54 (0.66, 3.59)	0.89 (0.49, 1.61)	0.95 (0.66, 1.39)
AB	1.38 (0.48, 3.96)	1.35 (0.51, 3.59)	0.82 (0.49, 1.38)	1.53 (0.58, 4.03)	1.32 (0.66, 2.65)	*0.71 (0.50, 1.01)*

In bold: p-value < 0.05. In italics: p-value < 0.10.
-: There are no large population centers in PEI.

older adults, and for those with pre-existing health conditions [27,39] – three groups identified as being at higher risk of experiencing energy poverty in our study. Demographic changes in the country further highlight the potential increasing risk of exposure to energy poverty. This calls for a better identification of sub-groups of the population that are more vulnerable to exposure to energy poverty. For example, the 2016 Canadian Census revealed that one-person households are the most common household type (at 28%), surpassing nuclear family households [66]. The prevalence of living alone is higher in older age groups (25% compared to 13% in the 35 to 64 age group). In addition, the proportion of the population aged 65 years and older (16.9%) is now larger than the proportion of children aged ≤14 years (16.6%) [66]. Furthermore, the ageing of the population is observed to be slower in large urban centers than in other regions in the country [66].

4.2. Policy implications

While identified as an issue in some provinces, targeting energy poverty is not on the national policy agenda in Canada. That said, there are efforts to target the drivers of energy poverty, namely residential energy efficiency retrofit programs and programs that support lower-income households. The federal government has advanced several initiatives to promote energy efficiency, including joining the Three Percent Club, which is a collaboration of governments and organizations committed to reaching 3% annual efficiency improvement [67]. To meet this goal, Canada will need to triple its current energy efficiency improvement [67]. As a step in this direction, the 2021 federal budget proposes to provide $4.4 billion to the Canada Mortgage and Housing Corporation (CMHC) to fund interest-free loans worth up to $40,000 to assist homeowners complete deep home retrofits [68].

Ultimately, provinces have jurisdiction over most energy matters, and many of the federal programs operate through the provinces or municipalities. For example, the Federation of Canadian Municipalities administers the Green Municipal Fund, which includes programs that provide funds to local housing providers to retrofit existing affordable housing units or to construct new energy efficient housing, and to municipalities to deliver energy financing programs to households [69]. The availability of energy efficiency programs varies widely between provinces. Most provinces administer programs that provide no-cost energy efficiency upgrades to low-income households. These programs vary in scope: some provide more minor upgrades, such as weather stripping, faucet aerators, LED light bulbs, and programmable

thermostats, while others include deeper retrofits like insulation, air sealing, or appliance upgrades. Most tend to follow a model of providing a free home energy assessment followed by free upgrades implemented by a program-approved contractor. Such programs provide an important response to energy poverty by directly improving the energy efficiency of the dwelling and helping to reduce monthly utility bills. However, they vary in their effectiveness and do not necessarily assist all households in energy poverty. For example, in some provinces, such programs are only available to homeowners. Considering that our analysis reveals that energy poverty is significantly higher for renters in comparison to homeowners, especially in urban centers, this represents a major limitation in the ability of existing programs to address energy poverty. While there are programs, such as the Green Municipal Fund, to support the retrofit or construction of energy efficient affordable housing in Canada, landlords may not be motivated to retrofit existing rental units because they believe tenants will refuse to pay the higher rents needed to finance improvements and yield a return on investment [48,70]. On the other side, tenants have limited capacity to modify their dwelling; they might not want to ask their landlords for energy improvements for fear of being evicted or having their rent increased [21,38,70], or because they don't want to invest in a dwelling they might only briefly occupy [70].

An additional concern is that, in all provinces, the maximum qualifying income to be eligible for the no-cost energy efficiency upgrade programs is low. For example, in Nova Scotia, the maximum qualifying income (after tax) for a single-person household is $26,365 [71], which is slightly higher than the national Low-Income Measure for a single-person household after tax (just over $22,000 [72]). Thus, these programs may only be capturing a portion of the population experiencing energy poverty. It is likely that there exists a "gap," where many households do not meet the low-income requirements to qualify but are still unable to afford the retrofits needed to sufficiently improve the efficiency of their dwelling and exit energy poverty. Finally, not all programs offer equally extensive or deep retrofits, such as wall insulation. This is concerning, as insulation appears to have a significant impact on the energy efficiency of the dwelling. Indeed, a community-based cluster randomised study in New Zealand reported that households that received a housing insulation upgrade including ceiling and a small level of floor insulation reduced their energy consumption to 81% of that of uninsulated houses [73].

Another important consideration in assessing how the provinces can address household energy poverty, or energy security, is utility disconnections. Even though most regions in Canada experience below-freezing temperatures in the winter, there is no national ban on winter utility disconnections. Utilities in many provinces do have policies suspending disconnections from electricity and/or from gas during winter months (see for example: Alberta [74]; Nova Scotia [75]; Québec [76]; and Ontario [77]), but this is not the case in all provinces or for all utilities, and policies are not always clear. One way to prevent utility disconnections is a one-time emergency assistance paid to help low-income customers with their utility bills. However, not all provinces offer such program and among those that do, the level of support varies and can be as low as a one-time payment of $100 [78,79]. While Canada is known for its cold winters, it also has warm summers. In addition to disconnection during winter months, a ban on disconnection of utilities during heatwaves should be considered. As climate change brings an increase in temperature and extreme weather events such as heatwaves, Canada might see a decrease over time in demand for heating and an increased demand for cooling. This was seen during heatwaves in the summer of 2018 in the province of Quebec and summer 2021 in British Columbia where spaces without air conditioning became life threatening for some vulnerable populations, such as older adults who have sensitive thermoregulatory systems and people with pre-existing health conditions [29]. Thus, similar to heating, cooling is becoming a basic necessity [80] and the ability of households to keep cool should be a focus of energy policy.

As Canada embarks on energy transition, attention should be paid to the equitable distribution of these efforts across the country. It will be important to ensure that energy prices are affordable, especially for vulnerable, low-income, and rural households that are currently experiencing energy poverty. Current schemes to support the development of renewable energy, often translate into rising energy tariffs [81]. When the increase in tariffs is applied uniformly across residential customers, those with lower incomes are disproportionately affected by the price change [81]. Such situations not only pose an additional barrier to achieving energy security but could also lead to backlash against the green energy transition if adequate support is not provided [82,83]. Canada, indeed as all countries and the global community as a whole, must achieve sustainable development and clean energy access for all in a just energy transition [84]. Paying attention to potential negative impacts across the full life cycle of energy transition policies is critical, as energy transition projects in some settings have created new, or entrenched existing, energy injustices [84].

4.3. Conclusion

Findings from our study demonstrate that, depending on the measure, between 6% and 19% of households were living in energy poverty in Canada in 2017. In Atlantic Canada, over 30% of households were identified as being in energy poverty. The Canadian prevalence of energy poverty is similar to, and for some provinces even greater than, the prevalence observed in Europe and New Zealand. Using the 2M measure, almost 20% of Canadian households are experiencing energy poverty. In comparison, 16% of the population of the EU experienced energy poverty (computed using the 2M indicator) in 2015 [17]. Despite this prevalence, Canada, much like the US [56] but unlike several European countries [85,86] has not formally recognized energy poverty as an issue. This is limiting effective responses.

The UN Sustainable Development Goal 7 aims to "ensure access to affordable, reliable, sustainable and modern energy for all" by 2030 [87]. Curbing energy poverty and improving energy security should be a preoccupation for Canada to attain its emission target [88,89]. To reduce energy poverty and increase energy security across the country, programs and policies should continue addressing the main drivers of energy poverty, i.e. dwellings' energy efficiency, energy prices, and low-incomes [53], while also targeting remedial programs and policies to households and communities that are most at risk. Our study identifies these as single-headed or lone-parent households, households with older adults or with someone with long-term health problems or disabilities, households in single-detached dwellings, renters in large population centers, and rural households. This study is among the first reporting on the prevalence of energy poverty in Canada. Results point to the need for a rigorous multidisciplinary research agenda to inform and implement programs and policies to mitigate energy poverty generally, and in the context of a changing climate especially.

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Declaration of Competing Interest

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

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