Environmental Impact Assessment Review 120 (2026) 108440

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

journal homepage: www.elsevier.com/locate/eiar

Reducing inequality is not antithetical to solving the climate crisis: An analysis of disposable income shares and carbon emissions for Canada's provinces

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ARTICLE INFO

Keywords:
Climate change
Carbon emissions
Income inequality
Inequality
Political economy
Sustainability
Climate mitigation

ABSTRACT

The authors conduct a comprehensive analysis of the relationship between carbon emissions and multiple characteristics of income inequality for the Canadian provinces for the 1999 to 2023 period. Particular attention is given to how disposable income shares for different groups affect province-level emissions. The analysis yields multiple findings of substantive relevance. First, the income share of the top quintile has a nontrivial positive effect on emissions in both the short-run and the long-run. This effect is found to be statistically asymmetrical, where a unit decrease in the income share has a proportionally larger effect on decreasing emissions than a unit increase does in increasing carbon emissions. Second, greater shares of disposable income going towards groups below the top quintile have negative short-run and long-run effects on carbon emissions, and these effects are statistically symmetrical. Finally, the effects of all income share measures are statistically equivalent for emissions from different sectors, robust to various model specifications, and not sensitive to the inclusion of different economic and demographic controls. Overall, the results highlight the climate mitigation potential of reducing income inequality in particular ways, and calls into question analytical arguments suggesting that addressing inequality is antithetical to solving the climate crisis.

1. Introduction

Research on the role of income inequality in shaping carbon emissions is a foundational and growing area of inquiry within the anthropogenic drivers of climate change research community (Dietz et al., 2020; Jorgenson et al., 2024; Rosa and Dietz, 2012). While much research focuses on this relationship at the global (Brucknew et al., 2022; Chancel, 2022; Hubacek et al., 2017) and national levels (Huang, 2024; Jorgenson et al., 2016; Wang et al., 2023; Zheng et al., 2023), empirical work on income inequality and emissions that uses regression modeling techniques to analyze panel data is becoming increasingly common at lower levels of aggregation, such as sub-nationally (Adua, 2022; Fitzgerald, 2022; Jorgenson et al., 2017, 2025; Zhang and Zhao, 2014) and even at the facility level (Grant et al., 2026). The scaling down of this empirical work highlights its importance and substantive reach. At the same time, researchers underscore the necessity in taking a more nuanced approach on both conceptual and measurement grounds. Varying analytical perspectives highlight how and why different attributes of income inequality might be associated with increases or decreases in emissions, and such distinctions call for the use of a range of measures of income inequality characteristics for valid hypotheses testing (Givens et al., 2023; Dietz, 2023).

The purpose of this study is to make multiple contributions to the income inequality and carbon emissions research literature. We scale down to the sub-national level, and focus on the relationship between a range of income distribution characteristics and carbon emissions for Canada's ten provinces. Answering the call of recent published commentaries, reviews, and syntheses of the research literature (Givens et al., 2023; Jorgenson et al., 2024; Nielsen et al., 2021), we pay particular attention to how income shares below the top of the income distribution might affect province-level emissions, as doing so allows for assessing the arguments of analytical perspectives that have received very little attention in recent empirical work. This is the most noteworthy and unique contribution of the present study. Furthermore, a

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https://doi.org/10.1016/j.eiar.2026.108440
Received 18 February 2026; Received in revised form 8 March 2026; Accepted 17 March 2026
Available online 7 April 2026

focus on Canada is far beyond trivial (Das et al., 2026). For the year 2023, which is the most current year in which data are currently available, Canada ranked 12th among the world's nations for consumption-based emissions and 11th for territorial-based emissions.[1] Like others, we suggest a focus on province-level emissions is critical, given the variation across Canada's provinces in carbon emissions and inequality, and the power and potential institutional resources provinces have in regulating emissions and implementing measures that could help reduce income inequality (Jorgenson et al., 2025).

Two widely engaged analytical perspectives suggest that a higher concentration of income towards the top of the distribution is likely to be associated with higher levels and growth in carbon emissions and other forms of pollution. The first argues that those towards the top of the income distribution are more likely to be investors in carbon-intensive industries, actual owners of carbon-polluting firms, serve on the boards of highly emitting corporations, reside in larger living spaces and own multiple dwellings, consume excessive goods and services with substantial environmental impacts, and participate frequently in expensive carbon-intensive activities, such as air travel in first class or in private aircrafts (Boyce, 1994; Dietz, 2023; Nielsen et al., 2021). Those towards the top of the income distribution are also likely to utilize their vast economic resources to gain disproportionate influence in climate, energy, and other areas of environmental policy and politics more generally, as they are more likely to benefit financially from carbon-polluting economic activities (Atkinson, 2015; Cushing et al., 2015; Downey, 2015; Malm, 2016; Schor and Jorgenson, 2019).

The second perspective argues that a higher concentration of income towards the top of the distribution causes heightened status competition, which leads to increased emissions and other environmental impacts associated with consumption. In this context, individuals and households in lower income categories increase their spending to emulate the widely promoted and culturally desirable high carbon lifestyles of higher income groups. Classically, this is referred to as the "Veblen effect", and increasingly in contemporary contexts referred to as the "influencer effect" (Frank, 2020; Nielsen et al., 2021; Schor, 1998; Veblen, 1934).

Recent empirical research on anthropogenic carbon emissions at both national and sub-national levels have focused on testing these two perspectives using measures of income concentration (i.e., income shares) at the top of the distribution, with the findings generally supportive of their arguments, revealing positive associations between emissions and such income inequality characteristics (e.g., Das et al., 2026; Fitzgerald, 2022; Huang, 2024; Jorgenson et al., 2025). These particular studies, however, have neglected to explicitly assess the potential effects of income shares on emissions for groups below the top of the income distribution. While the two preceding analytical perspectives largely focus on the carbon impacts of the top of the income distribution, it might be reasonable to infer that they would expect a higher concentration of income shares below the top of the distribution to have null effects or perhaps modest negative effects on emissions at best.

Other analytical perspectives focus to a greater degree on the potential climate impacts of larger income shares being held by individuals and groups below the top of the income distribution, which is generally indicative of lower levels of income inequality. For example, one perspective, grounded in conventional economic reasoning, focuses on a set of relationships suggesting that increased inequality is emission reducing. At the center of this approach is the position that the "marginal propensity to emit" is negatively associated with income level, indicating that reducing carbon emissions is at loggerheads with improving economic equality. More specifically, when the relationship between income and environmental impact is concave, meaning that impacts rise with income to a point and then decline, a redistribution of income from higher income groups to lower income groups will likely result in overall higher levels of carbon emissions and other environmental harms (Heil and Selden, 1999; Jakob et al., 2014; Ravallion et al., 2000; Seriño and Klasen, 2015). In this context, consumption demand is a primary factor determining the marginal propensity to emit.

In a different yet related vein, from a Keynesian perspective, lower-income households consume more than higher-income households for each dollar of additional income, suggesting that the "marginal propensity to consume" declines with income (Jorgenson et al., 2017). Here, greater income shares going to lower income groups yield a higher level of overall consumption demand and, therefore, increased carbon emissions. Combined, these related perspectives suggest two potential pathways through which higher shares of income going to non-high-income groups may increase overall emissions. First, groups with relatively lower incomes have a higher propensity to emit for each unit of additional income. Second, relatively lower income groups have a higher propensity to consume from each unit of additional income.

Building on prior research (e.g., Jorgenson et al., 2025), in the present study we evaluate the arguments of these competing analytical frameworks, with a particular focus on income shares below the top of the distribution. To do so, we estimate models of the short-run and long-run effects of the disposable income shares of the top quintile as well as combinations of the bottom four quintiles on carbon emissions for Canada's provinces for the 1999 to 2023 period. Analyzing the top quintile is consistent with other recent studies, while analyzing the bottom four quintiles allows us to assess the arguments of the analytical perspectives that have received far less empirical attention in recent research. We also assess if the effects of the various disposable income share measures are statistically equivalent for province-level emissions from different sectors, and if the effects are statistically symmetrical, meaning that positive and negative changes in an independent variable differentially affect the dependent variable. We turn now to the Data and Methods section, which describes the analyzed sample and data, as well as the various statistical modeling techniques that we use to conduct the analysis.

2. Data and methods

2.1. Data

With a total of 250 observations, the analyzed dataset consists of twenty-five yearly observations from 1999 to 2023 for each of the ten provinces in Canada (Alberta, British Columbia, Manitoba, New Brunswick, Newfoundland and Labrador, Nova Scotia, Ontario, Prince Edward Island, Quebec, Saskatchewan). These are the years in which provincial-level data are currently available for both the dependent variable and the key independent variables. In line with prior Canadian sub-national research on anthropogenic drivers of emissions (Boyce and He, 2022; Jorgenson et al., 2025), the territory jurisdictions are excluded from the present study because their political structures differ from that of the provinces. Further, data availability for the primary independent variables is relatively limited for the territories, compared to the provinces.

The primary dependent variable is anthropogenic Total Carbon Dioxide (CO_2) Emissions, measured in kilotons (kt). We also estimate stacked regression models (see description below) for emissions from the overall energy sector compared to emissions from all other sectors combined (i.e., non-energy emissions). Energy sector emissions consist of those from (1) stationary and (2) transport fuel combustion activities as well as (3) fugitive emissions from the fossil fuel industry. Stationary fuel combustion emission sources include use of fossil fuels by the electricity generating industry, the oil and gas industry, manufacturing industry, and the residential and commercial sectors. Emissions from transport fuel combustion include domestic aviation, road transportation, railways, domestic marine, off-road vehicle use and pipelines. Fugitive emissions associated with the fossil fuel industry are the intentional (flaring) or unintentional releases (leaks or accidents)

[1] Based on data obtained from https://globalcarbonatlas.org/emissions/carbon-emissions/.

resulting from production, processing, transmission, and storage of fuels. Non-energy emissions consist of those from (1) industrial processes and product use, (2) agriculture, (3) waste, and (4) land use, land-use change and forestry.[2] These emissions data are publicly available from Canada's Official Greenhouse Gas Inventory (https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html).

The primary independent variables of interest are disposable income shares, including income share of the 5th quintile, income share of the bottom 4 quintiles, income share of the bottom 3 quintiles, income share of the bottom 2 quintiles, and income share of the 1st quintile. These variables are measured as percentages, where the sum of all quintiles for a given province for a given year would be 100. Income share refers to the distribution of household disposable income across income quintiles within each province. Household disposable income represents the total income available to the household sector for consumption and saving after accounting for taxes and transfers (Statistics Canada, 2025) and is measured in millions of Canadian dollars. The quintiles for income shares are constructed using equivalized household disposable income, which adjusts for household size and composition according to the OECD equivalence scale. These data are obtained from Statistics Canada (2025).

Supplementary Fig. 1 through Supplementary Fig. 6 plot out the data for the primary dependent variable and the primary independent variables, which highlight notable differences between provinces and changes within provinces through time.

Additional independent variables, which are also obtained from Statistics Canada (2025), include Total Population, GDP Per Capita (chained 2012 dollars), and Energy as % GDP. These far-reaching economic and demographic measures capture a range of the characteristics of the provinces and are among the most common controls in the anthropogenic drivers research (Dietz et al., 2020; Jorgenson et al., 2024; Rosa and Dietz, 2012). Given the overall limited sample size for the study (e.g., $N = 250$), we keep the number of control variables in reported models to a relative minimum. Univariate descriptive statistics for all variables included in the reported analysis are provided in the table in the Supplementary information, and the full dataset is available from the lead author upon request.

2.2. General modeling approach

All models are estimated using Stata (version 19), and all Stata code used for the reported analysis is available from the lead author upon request. Consistent with much other research on the anthropogenic drivers of CO_2 emissions, all nonbinary variables are transformed into logarithmic form, meaning the models estimate elasticity coefficients where the coefficient for the independent variable is the estimated net percentage change in the dependent variable associated with a 1% increase in the independent variable.

All reported models are estimated with the xtreg, fe command, and include both province-specific and year-specific fixed effects. Given the relatively small number of cases (10 provinces) and moderate size of T (25 yearly observations per province), hc2 clustered robust standard errors are estimated with the xtreg models (Bell and McCaffrey, 2002; StataCorp, 2025). The hc2 standard errors tend to produce more conservative confidence intervals than other standard error approaches, leading to more conservative hypothesis testing where we are less likely to falsely reject the null hypothesis (StataCorp, 2025). The xtreg, fe command uses the within estimator to account for province-level fixed effects, and temporal fixed effects are derived from the inclusion of year-specific dummy variables (Allison, 2009).

The estimated models are dynamic, meaning they include the lagged dependent variable as a control and are thus a simple autoregressive distributed lag model, commonly denoted as an ARDL (1,0) model. Panel data are often autoregressive, meaning the data tend to be correlated over time, and excluding the lag of the dependent variable from the model will result in omitted variable bias if the outcome variable is truly a function of their past value (Pickup, 2015). Including the lagged dependent variable also allows for the estimation of both short-run and long-run effects of independent variables.

The general equation for the models reported in Table 1 is as follows:

$$\begin{aligned} CO_2Emissions_{i,t} &= \lambda_1 CO_2Emissions_{i,t-1} + \beta_1 Income\ Share\ of \ldots Quintile(s)_{i,t} \\ &+ \beta_2 Total\ Population_{i,t} + \beta_3 GDP\ per\ capita_{i,t} \\ &+ \beta_4 Energy\ as\%GDP_{i,t} + \alpha_i + u_t + \varepsilon_{i,t}. \end{aligned}$$

The short-run estimated effects are β_1 to β_4, and long-run effects are estimated by dividing each short-run estimate by 1-λ_1. The long-run effects are calculated using the community-contributed lreff command in Stata (Thombs, 2022a), which serves as a wrapper for the nlcom command that computes standard errors using the delta method. The short-run estimates correspond to the immediate change in emissions, while the long-run effects estimate the total change in emissions over time. For β_1, *Income Share of … Quintile(s)* refers to the independent variable of interest in each estimated model (i.e., income share of 5th quintile, income share of bottom 4 quintiles, income share of bottom 3 quintiles, income share of bottom 2 quintiles, income share of 1st quintile).

2.3. Testing the simultaneous effects of income shares on energy and non-energy emissions

Consistent with other recent research, we use a stacked regression analysis, reported in Table 2 and Table 3, to test whether the effects of income inequality are different for energy and non-energy CO_2 emissions (Jorgenson et al., 2025). “Stacking” is a procedure that appends the two samples of data together, which doubles the number observations used in the analysis (Mize et al., 2019). A new dependent variable is generated that equals the value of energy emissions in the first half of the data and equals the value of non-energy emissions in the second half. Independent variables are also generated for each sample. A useful characteristic of this approach is that the coefficients and standard errors are equal to the non-stacked estimates, and a simple Wald test can be performed to test whether the effects are equivalent.

2.4. Asymmetrical analysis

For the asymmetrical analysis reported in Table 4 and Table 5, we follow the standard approach to modeling asymmetry by including the positive and negative partial sums of each income share measure in the models (Thombs, 2022b; Thombs et al., 2022; York, 2012). $x_{i,t}$ is decomposed as $x_{i,t} = x_{i,0} + x^+_{i,t} + x^-_{i,t}$, where $x^+_{i,t}$ and $x^-_{i,t}$ are partial sums around a threshold of zero:

$$x^+_{i,t} = \sum_{j=1}^{t} \Delta x^+_{i,t} = \sum_{j=1}^{t} \max\left(\Delta x^+_{i,t}, 0\right)$$

$$x^-_{i,t} = \sum_{j=1}^{t} \Delta x^-_{i,t} = \sum_{j=1}^{t} \min\left(\Delta x^-_{i,t}, 0\right)$$

In other words, two series are generated that estimate the running totals of the positive ($x^+_{i,t}$) and negative ($x^-_{i,t}$) changes in $x_{i,t}$. A Wald test is then used to test whether the coefficients of the two sums are equal. If they are statistically different then there is evidence of asymmetry. The partial sums are generated in Stata 19 using the community contributed

[2] Based on IPCC categorizations, which these data are structured with, energy sector emissions account for the lion's share of emissions for every province. In the analyzed dataset, they account for between 86.9% (Ontario) and 99.1% (Prince Edward Island) of province-level emissions in 1999, and between 85.5% (Quebec) and 99.4% (Newfoundland and Labrador) in 2023.

Table 1
Coefficients for the regression of CO_2 emissions for Canada Provinces.

	Model 1	Model 2	Model 3	Model 4	Model 5
Inc Share 5Q	0.116* (0.046) [0.011 to 0.222]				
Inc Share Bot 4Q		−0.193* (0.070) [−0.352 to −0.034]			
Inc Share Bot 3Q			−0.126* (0.050) [−0.240 to −0.012]		
Inc Share Bot 2Q				−0.075* (0.028) [−0.139 to −0.011]	
Inc Share 1Q					−0.047** (0.010) [−0.071 to −0.023]
L-R Effect	0.644** (0.222) [0.209 to 1.078]	−1.093** (0.370) [−1.820 to −0.366]	−0.713*** (0.217) [−1.140 to −0.286]	−0.460** (0.152) [−0.759 to −0.162]	−0.297** (0.097) [−0.488 to −0.106]
Total Pop	0.404** (0.111) [0.154 to 0.654]	0.373** (0.111) [0.122 to 0.624]	0.386** (0.111) [0.134 to 0.637]	0.388** (0.101) [0.159 to 0.616]	0.385** (0.118) [0.118 to 0.652]
GDP PC	0.188^ (0.090) [−0.016 to 0.392]	0.175^ (0.089) [−0.028 to 0.378]	0.169 (0.098) [−0.052 to 0.390]	0.182^ (0.097) [−0.036 to 0.401]	0.156 (0.086) [−0.038 to 0.350]
Energy / GDP	0.038^ (0.020) [−0.008 to 0.085]	0.041^ (0.021) [−0.007 to 0.089]	0.039^ (0.021) [−0.009 to 0.086]	0.032 (0.020) [−0.014 to 0.078]	0.037^ (0.019) [−0.007 to 0.081]
Lagged CO_2	0.819*** (0.050) [0.707 to 0.932]	0.823*** (0.046) [0.718 to 0.928]	0.823*** (0.050) [0.710 to 0.936]	0.837*** (0.047) [0.730 to 0.944]	0.840*** (0.051) [0.725 to 0.956]
R-sq within	0.904	0.903	0.904	0.903	0.903
CIPS Statistic	−4.670**	−4.367**	−4.773**	−4.981**	−4.909**

Notes: Inc Share 5Q = Income Share of 5th Quintile; Inc Share Bot 4Q = Income Share of Bottom 4 Quintiles; Inc Share Bot 3Q = Income Share of Bottom 3 Quintiles; Inc Share Bot 2Q = Income Share of Bottom 2 Quintiles; Inc Share 1Q = Income Share of 1st Quintile; L-R Effect = Long-Run Effect for Income Share Measure; Total Pop = Total Population: GDP PC = GDP Per Capita; Energy / GDP = Energy as % GDP; Lagged CO_2 = Lagged CO_2 Emissions; models estimated with xtreg fe in Stata 19 (hc2 clustered robust standard errors); N = 250, with 25 annual observations (1999-2023) per province; ***p < 0.001 **p<.01 *p<.05 ^p<.10 (two-tailed); standard errors in parentheses; 95% confidence intervals in brackets; all models include unreported province-specific and year-specific fixed effects; non-binary variables are in logarithmic form; long-run effects estimated with Thombs' user-generated lreff command; CIPS statistics estimated with xtcips command.

Table 2
Stacked regression of energy and non-energy CO_2 emissions for Canada Provinces (short-run effects).

	Inc Share 5Q	Inc Share Bot 4Q	Inc Share Bot 3Q	Inc Share Bot 2Q	Inc Share 1Q
Coefficient for Energy Emissions	0.125* (0.046) [0.010 to 0.239]	−0.210* (0.069) [−0.383 to −0.036]	−0.135* (0.051) [−0.263 to −0.006]	−0.080* (0.029) [−0.155 to −0.006]	−0.052** (0.010) [−0.077 to −0.026]
Coefficient for Non-Energy Emissions	0.127 (0.168) [−0.328 to 0.582]	−0.193 (0.309) [−1.018 to 0.632]	−0.120 (0.169) [−0.574 to 0.333]	−0.107 (0.099) [−0.378 to 0.165]	−0.041 (0.055) [−0.185 to 0.102]
Wald Test	0.01	0.01	0.01	0.10	0.05

Notes: Inc Share 5Q = Income Share of 5th Quintile; Inc Share Bot 4Q = Income Share of Bottom 4 Quintiles; Inc Share Bot 3Q = Income Share of Bottom 3 Quintiles; Inc Share Bot 2Q = Income Share of Bottom 2 Quintiles; Inc Share 1Q = Income Share of 1st Quintile; models estimated with xtreg fe in Stata 19 (hc2 clustered robust standard errors); N =500, with 25 annual observations (1999-2023) per province for each emissions outcome; ***p < 0.001 **p<.01 *p<.05 ^p<.10 (two-tailed); standard errors in parentheses; 95% confidence intervals in brackets; all models include unreported province-specific and year-specific fixed effects; non-binary variables are in logarithmic form; models control for Total Population, GDP Per Capita, Energy as % GDP, and Lagged Carbon Emissions; Wald Tests are not statistically significant.

Table 3
Stacked regression of energy and non-energy CO_2 emissions for Canada Provinces (long-run effects).

	Inc Share 5Q	Inc Share Bot 4Q	Inc Share Bot 3Q	Inc Share Bot 2Q	Inc Share 1Q
Coefficient for Energy Emissions	0.654** (0.209) [0.245 to 1.063]	−1.118** (0.345) [−1.795 to −0.441]	−0.717*** (0.205) [−1.118 to −0.316]	−0.463** (0.144) [−0.745 to −0.182]	−0.305** (0.092) [−0.486 to −0.123]
Coefficient for Non-Energy Emissions	0.413 (0.559) [−0.683 to 1.509]	−0.633 (1.027) [−2.647 to 1.380]	−.1.159*** (0.591) [−1.556 to −0.762]	−0.651** (0.332) [−1.003 to −0.299]	−0.137 (0.175) [−0.480 to 0.206]
Wald Test	0.34	0.36	0.44	0.23	0.94

Notes: Inc Share 5Q = Income Share of 5th Quintile; Inc Share Bot 4Q = Income Share of Bottom 4 Quintiles; Inc Share Bot 3Q = Income Share of Bottom 3 Quintiles; Inc Share Bot 2Q = Income Share of Bottom 2 Quintiles; Inc Share 1Q = Income Share of 1st Quintile; models estimated with xtreg fe in Stata 19 (hc2 clustered robust standard errors); N =500, with 25 annual observations (1999-2023) per province for each emissions outcome; ***p < 0.001 **p<.01 *p<.05 ^p<.10 (two-tailed); standard errors in parentheses; 95% confidence intervals in brackets; all models include unreported province-specific and year-specific fixed effects; non-binary variables are in logarithmic form; models control for Total Population, GDP Per Capita, Energy as % GDP, and Lagged Carbon Emissions; long-run effects estimated with Thombs' user-generated lreff command; Wald Tests are not statistically significant.

Table 4
Asymmetric regression of CO_2 emissions for Canada Provinces (short-run effects).

	Model 1	Model 2	Model 3	Model 4	Model 5
Inc Share 5Q (+)	0.106*				
	(0.043)				
	[0.009 to 0.203]				
Inc Share 5Q (−)	0.240**				
	(0.058)				
	[0.109 to 0.371]				
Inc Share Bot 4Q (+)		−0.335*			
		(0.125)			
		[−0.617 to −0.053]			
Inc Share Bot 4Q (−)		−0.187*			
		(0.071)			
		[−0.347 to −0.027]			
Inc Share Bot 3Q (+)			−0.177^		
			(0.088)		
			[−0.377 to 0.022]		
Inc Share Bot 3Q (−)			−0.114^		
			(0.055)		
			[−0.239 to 0.012]		
Inc Share Bot 2Q (+)				−0.032	
				(0.045)	
				[−0.135 to 0.071]	
Inc Share Bot 2Q (−)				−0.089^	
				(0.040)	
				[−0.179 to 0.002]	
Inc Share 1Q (+)					−0.037^
					(0.019)
					[−0.081 to 0.006]
Inc Share 1Q (−)					−0.050*
					(0.017)
					[−0.090 to −0.011]
Wald Test	4.22^	2.00	0.47	0.74	0.19

Notes: Inc Share 5Q = Income Share of 5th Quintile; Inc Share Bot 4Q = Income Share of Bottom 4 Quintiles; Inc Share Bot 3Q = Income Share of Bottom 3 Quintiles; Inc Share Bot 2Q = Income Share of Bottom 2 Quintiles; Inc Share 1Q = Income Share of 1st Quintile; models estimated with xtreg fe in Stata 19 (hc2 clustered robust standard errors); N = 250, with 25 annual observations (1999-2023) per province; ***p < 0.001 **p<.01 *p<.05 ^p<.10 (two-tailed); standard errors in parentheses; 95% confidence intervals in brackets; all models include unreported province-specific and year-specific fixed effects; non-binary variables are in logarithmic form; models control for Total Population, GDP Per Capita, Energy as % GDP, and Lagged Carbon Emissions; Wald Test is statistically significant for only Model 1.

xtasysum command (Thombs, 2022c).

3. Results

Table 1 reports five models of total emissions where each includes one of the disposable income share measures as the primary independent variable of interest. All models include total population, GDP per capita, energy as % GDP, and lagged emissions as controls, along with the province-specific and year-specific fixed effects. The high within R-squared values (all above 0.900) are largely due to the lagged emissions control, as an estimated model with just this control yields an R-squared within value of 0.835. The long-run effects of the income share measures are reported for each model as well. As a reminder, elasticity coefficients are reported, where the coefficient for an independent variable is the estimated net percentage change in the dependent variable associated with a 1% increase in the independent variable.

Across each model, both the short-run and long-run effects of the disposable income share measure are statistically significant, with the effects of income share of the 5th quintile being positive, and all other income share effects being negative. In particular, for Model 1, a 1 % increase in the income share of the 5th quintile leads to a 0.116% immediate increase in total emissions (95% C.I. = 0.011 to 0.222), and a 0.644% increase in the long run (95% C.I. = 0.209 to 1.078). For Model 2, a 1 % increase in the income share of the bottom 4 quintiles leads to a 0.193% immediate decrease in total emissions (95% C.I. = −0.352 to −0.034), and a 1.093% decrease in the long run (95% C.I. = −1.820 to −0.366). It is important to note that income share of the top quintile and income share of the bottom 4 quintiles, when summed for a given province in a given year, would equal 100%. Thus, when the value increases for one of these two measures, it proportionally decreases for the other measure.

Turning to Model 3, a 1 % increase in the income share of the bottom 3 quintiles leads to a 0.126% immediate decrease in total emissions (95% C.I. = −0.240 to −0.012), and a 0.713% decrease in the long run (95% C.I. = −1.140 to −0.286). For Model 4, a 1 % increase in the income share of the bottom 2 quintiles leads to a 0.075% immediate decrease in total emissions (95% C.I. = −0.139 to −0.011), and a 0.460% decrease in the long run (95C.I. = −0.759 to −0.162). And for the fifth and final model, a 1 % increase in the income share of the 1st quintile leads to a 0.047% immediate decrease in total emissions (95% C.I. = −0.071 to −0.023), and a 0.297% decrease in the long run (95% C.I. = −0.488 to −0.106).

Regarding the controls, total population has a positive short-run effect on emissions in all models, while the short-run effect of GDP per capita is positive and marginally statistically significant in all but Models 3 and 5, while energy as % GDP has a positive and marginally statistically significant short-run effect on emissions in all but Model 4. As expected, the estimated coefficient for lagged emissions is positive and statistically significant, with the point estimates being above 0.800 in each model (all 95% C.I.s falling somewhere between 0.707 and 0.956).

We use the common procedure within the panel data methods literature to test whether the residuals for each model are stationary (Thombs, 2022d). If the residuals are not stationary, then we likely have spurious long-run relationships. We test for residual stationarity using Pesaran's (2007) panel unit root test, which is implemented with the xtcips command (Burdisso and Sangiácomo, 2016). In Table 1, this is reported as the CIPS statistic, where the null hypothesis is homogenous non-stationary. All CIPS values are statistically significant, rejecting the null. Therefore, we find that all of the residuals are stationary.

Table 5
Asymmetric regression of CO_2 emissions for Canada Provinces (long-run effects).

	Model 1	Model 2	Model 3	Model 4	Model 5
Inc Share 5Q (+)	0.506* (0.246) [0.024 to 0.988]				
Inc Share 5Q (−)	1.148*** (0.335) [0.492 to 1.804]				
Inc Share Bot 4Q (+)		−2.022* (0.831) [−3.652 to −0.392]			
Inc Share Bot 4Q (−)		−1.127** (0.433) [−1.975 to −0.278]			
Inc Share Bot 3Q (+)			−1.090* (0.536) [−2.140 to −0.040]		
Inc Share Bot 3Q (−)			−0.698** (0.265) [−1.129 to −0.178]		
Inc Share Bot 2Q (+)				−0.166 (0.244) [−0.644 to 0.312]	
Inc Share Bot 2Q (−)				−0.459*** (0.124) [−0.702 to −0.216]	
Inc Share 1Q (+)					−0.223^ (0.115) [−0.449 to 0.003]
Inc Share 1Q (−)					−0.302** (0.104) [−0.506 to −0.097]
Wald Test	4.38*	1.77	0.44	0.93	0.19

Notes: Inc Share 5Q = Income Share of 5th Quintile; Inc Share Bot 4Q = Income Share of Bottom 4 Quintiles; Inc Share Bot 3Q = Income Share of Bottom 3 Quintiles; Inc Share Bot 2Q = Income Share of Bottom 2 Quintiles; Inc Share 1Q = Income Share of 1st Quintile; models estimated with xtreg fe in Stata 19 (hc2 clustered robust standard errors); N = 250, with 25 annual observations (1999-2023) per province; ***p < 0.001 **p<.01 *p<.05 ^p<.10 (two-tailed); standard errors in parentheses; 95% confidence intervals in brackets;all models include unreported province-specific and year-specific fixed effects; non-binary variables are in logarithmic form; models control for Total Population, GDP Per Capita, Energy as % GDP, and Lagged Carbon Emissions; long-run effects estimated with Thombs' user-generated lreff command; Wald Test is statistically significant for only Model 1.

As a series of robustness checks available from the lead author upon request, we re-estimate all models in Table 1 using the wild cluster bootstrap approach (wildbootstrap fe command) and with Prais-Winsten regression with panel-corrected standard errors (xtpcse command). For the wildbootstrap fe models we specify normal error weights, symmetric *p*-values, and 1000 replications. Wild cluster bootstrap is an additional approach that is considered more preferable when there are relatively few clusters (Mackinnon et al., 2023). The Prais-Winsten regression models estimate panel-corrected standard errors, allowing for disturbances that are heteroskedastic and contemporaneously correlated across panels (Beck, 2001). The results for both the Wild cluster bootstrap and Prais-Winsten regression models are entirely consistent with the reported findings. As a sensitivity analysis, we estimate models, full results available upon request, that include additional controls for manufacturing as % GDP, agriculture as % GDP, services as % GDP, and non-dependent population (percent of population aged 15 to 64). None of these additional controls have significant effects on carbon emissions, and their inclusion does not change the reported findings of interest.

To provide more nuance to the long-run effects in Models 1 through 5 in Table 1, Figs. 1 through 5 illustrate the percentage change in emissions over a two-decade period resulting from a 1% increase in the relevant disposable income share measure.[3] The cumulative effect (i.e., the long-run effect) is the cumulative sum of the period effects (see also Jorgenson et al., 2025; Thombs, 2023). For ease of comparison, the figures are scaled equally.

Fig. 1 illustrates the percentage change in emissions resulting from a 1% increase in the share of disposable income going to the 5th quintile. As the figure shows, the largest increase in emissions occurs in the immediate time period (0.116, i.e., the short-run effect), which is labeled as year zero. By the end of two decades following the immediate time period, 99.3% of the total long-run effect occurs (0.639).

Figs. 2 through 5 illustrate the percentage change in emissions resulting from a 1% increase in the income share of the bottom 4 quintiles, income share of the bottom 3 quintiles, income share of the bottom 2 quintiles, and income share of the 1st quintile. For Fig. 2, which focuses on the effect of the income share of the bottom 4 quintiles, the largest decrease in emissions occurs in the immediate time period, and by the end of two decades following the immediate time period, 99.2% of the total long-run effect occurs. Turning to Fig. 3, which focuses on the effect of the income share of the bottom 3 quintiles, consistent with the prior figure, the largest decrease in emissions occurs in the immediate time period. By the end of two decades following the

[3] We use the community contributed lrplot program to create the figures, which simulates the effects by taking draws from a multivariate normal distribution where the means of each variable and the variance-covariance matrix are the coefficients from the estimated regression model (Thombs, 2023). The program then solves the equation for each period associated with a 1% increase in the income share measure variable in the initial time period. The first period is equal to the simulated regression coefficient, and the remaining periods are equal to the simulated autoregressive coefficient multiplied by the estimated value from the previous period.

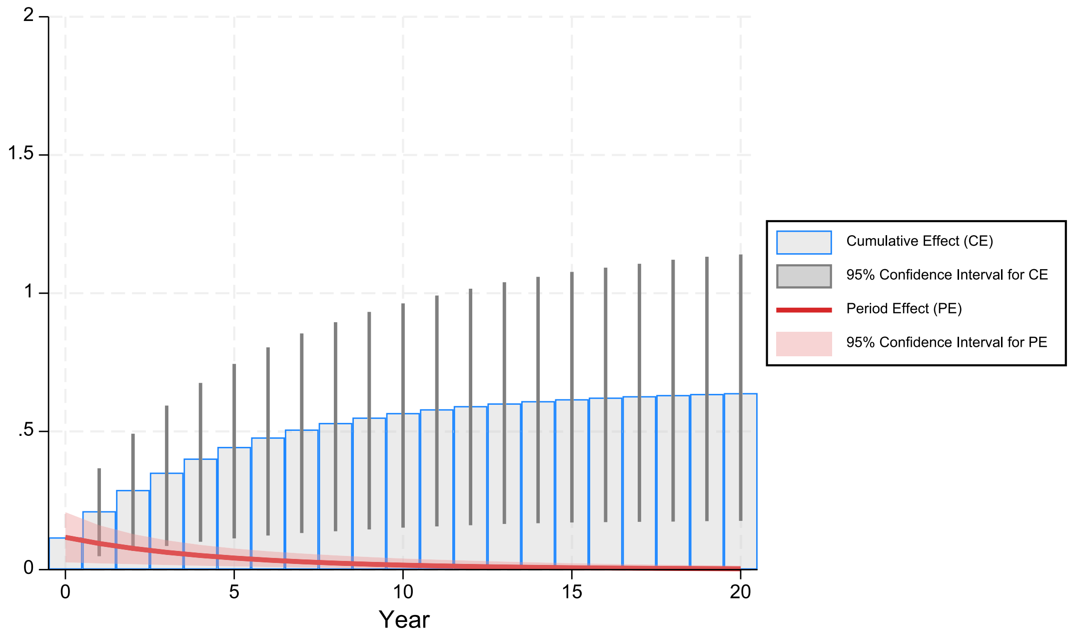

Fig. 1. The Long-Run Effect of the Income Share of the 5th Quintile on Total CO_2 Emissions.

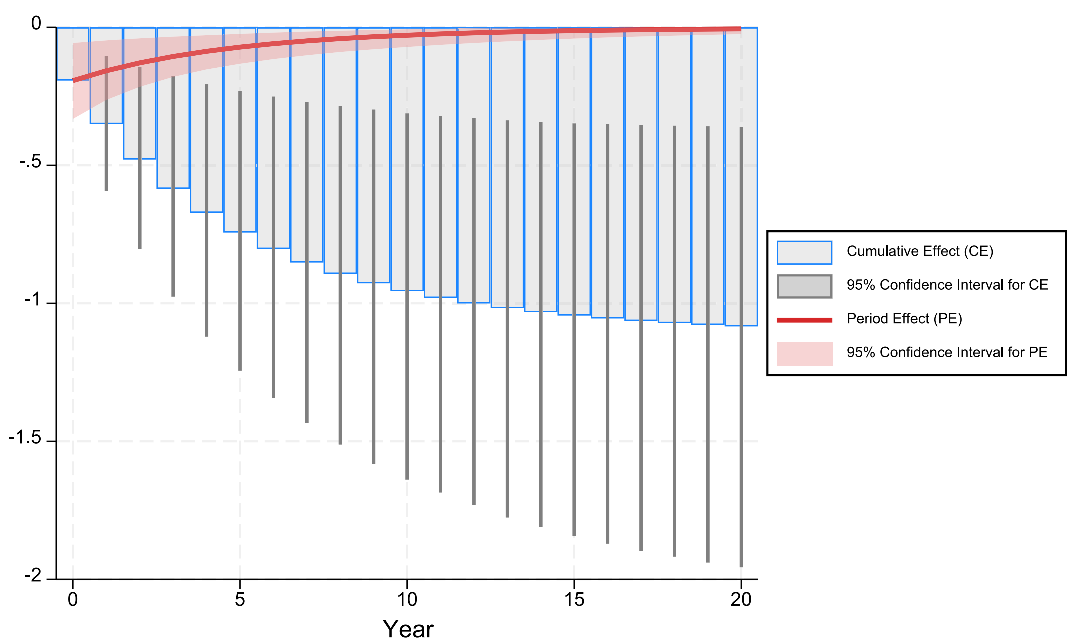

Fig. 2. The Long-Run Effect of the Income Share of the Bottom 4 Quintiles on Total CO_2 Emissions.

immediate time period, 96.9% of the total long-run effect occurs.

Fig. 4 focuses on the effect of the income share of the bottom 2 quintiles, and continues the pattern of the largest decrease in emissions occurring in the immediate time period, while 97.2% of the total long-run effect occurs by the end of two decades following the immediate time period. Income share of the 1st quintile is the focus of Fig. 5. As expected, the largest decrease in emissions occurs in the immediate time period, and 99.9% of the total long-run effect occurs by the end of two decades following the immediate time period.

Next, we use stacked regression analysis to test whether the effects of the income share measures are different for emissions from the overall energy sector relative to emissions from all other sectors combined. The findings are presented in Table 2 (short-run effects) and Table 3 (long-run effects). The results of the Wald tests (all not statistically significant) indicate that the short-run and long-run effects of each income share measure are statistically equivalent for energy and non-energy emissions.[4] In an additional analysis available from the lead author upon request, estimated seemingly unrelated regression models lead to the same conclusions.

Finally, we assess if the short-run and long-run effects of the disposable income share measures on province-level emissions are asymmetrical, meaning that positive and negative changes in an independent variable differentially affect the dependent variable. Without

[4] While we are unable to conduct a test of whether the residuals are non-stationary in the stacked regression models, given that there are repeated time values within each panel, CIPS tests from their individual regressions suggest the residuals of each are indeed stationary.

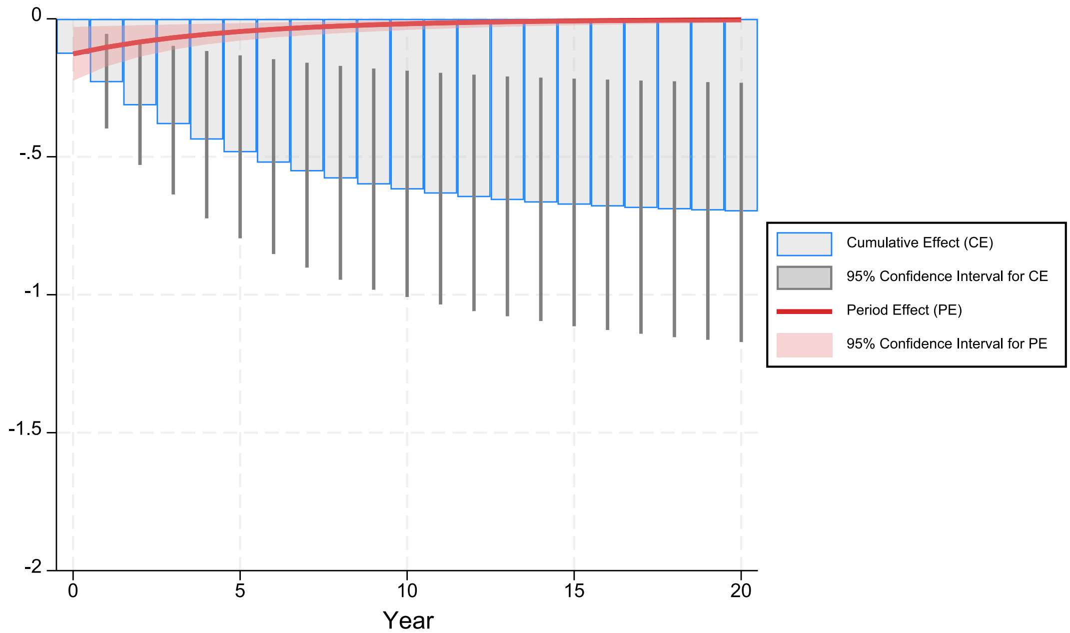

Fig. 3. The Long-Run Effect of the Income Share of the Bottom 3 Quintiles on Total CO_2 Emissions.

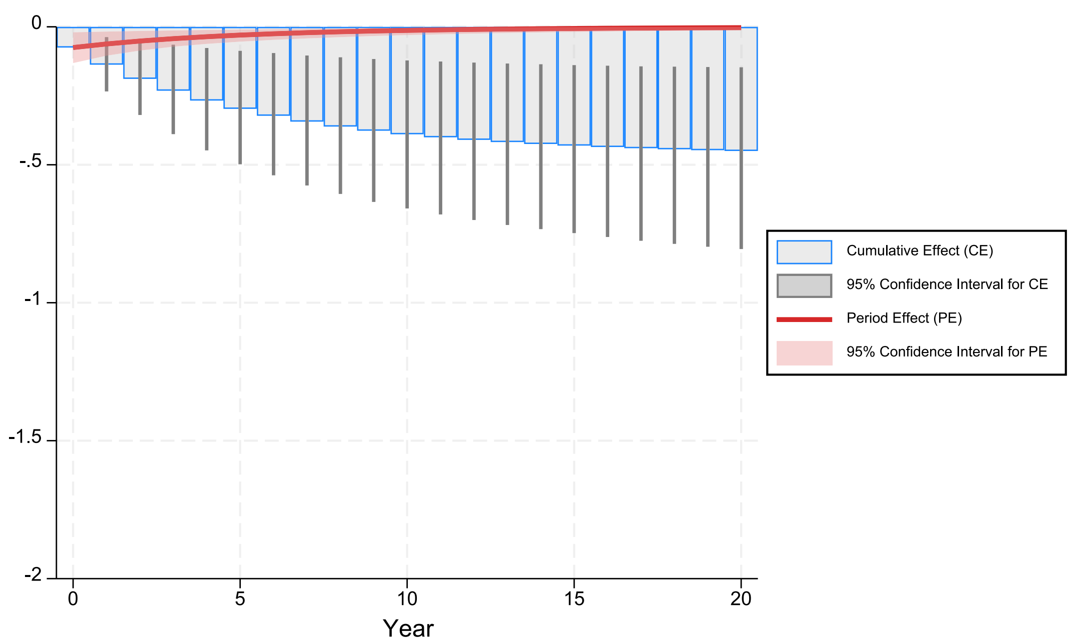

Fig. 4. The Long-Run Effect of the Income Share of the Bottom 2 Quintiles on Total CO_2 Emissions.

question, modeling for potential asymmetry in their short-run and long-run effects is important on climate mitigation and potential solutions grounds. As described in the Methods section, we follow the standard approach to modeling asymmetry by including the positive and negative partial sums of each income share measure in the models. The findings are presented in Table 4 (short-run effects) and Table 5 (long-run effects).

With the exception of income share of the 5th quintile, the results of the Wald tests are not statistically significant, indicating that there is no asymmetry in the short-run or long-run effects of the income share measures. In other words, an increase and a decrease in the income share of the bottom 4, bottom 3, and bottom 2 quintiles, as well as the income share of the 1st quintile, result in the same proportional change in total CO_2 emissions. Therefore, the initial estimated short-run and long-run effects reported in Table 1 for these particular measures are symmetrical and can be interpreted as the effect of an increase or decrease in the respective disposable income share on emissions.

For the income share of the 5th quintile, the Wald statistic is marginally statistically significant for short-run effects on emissions (Table 4), and statistically significant for long-run effects (Table 5). The short-run and long-run effects of the negative partial sums are statistically significant and larger than the for the positive partial sums, which are also both statistically significant. These results suggest that a unit decrease in the income share of the 5th quintile has a proportionally larger effect on decreasing emissions than a unit increase does on increasing CO_2 emissions, both in the short-run and the long-run.

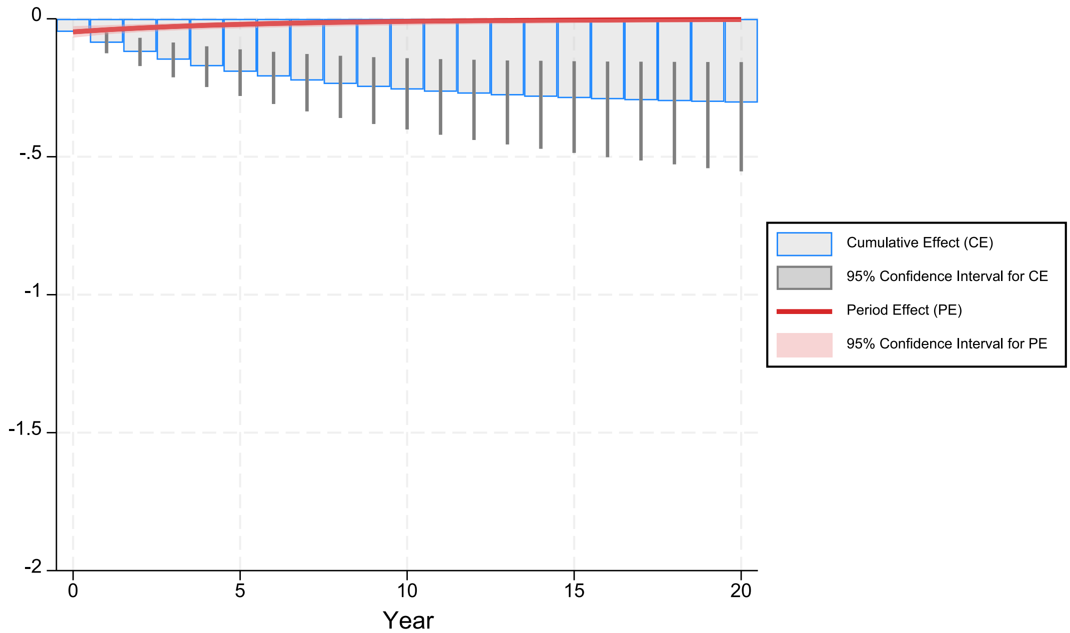

Fig. 5. The Long-Run Effect of the Income Share of the 1st Quintile on Total CO_2 Emissions.

4. Conclusion

The purpose of this study was to help advance the income inequality and carbon emissions research literature. Scaling down to the sub-national level, and building on prior work (Jorgenson et al., 2025), we focused on various income distribution characteristics and carbon emissions for Canada's ten provinces from 1999 to 2023, with particular attention given to how income shares for different groups, and especially income shares below the top quintile, might affect province-level emissions. The analysis yielded multiple findings of substantive relevance.

Consistent with other recent sub-national, national, and cross-national studies (e.g., Das et al., 2026; Fitzgerald, 2022; Huang, 2024; Jorgenson et al., 2017, 2025), we find that the disposable income share of the top quintile has a nontrivial positive effect on emissions in both the short-run and the long-run. These findings lend further support to the analytical perspectives that focus on how and why a higher concentration of income shares towards the top of the income distribution increase carbon emissions and other environmental harms (Boyce, 1994; Downey, 2015; Nielsen et al., 2021). Further, we find that both the short-run and long-run effect is statistically asymmetrical, where a one unit decrease in the income share of the top quintile has a proportionally lager effect on decreasing emissions than a one unit increase income share does in increasing carbon emissions. While some prior studies observe this form of statistical asymmetry in the estimated effects of economic growth on emissions (Shahiduzzaman and Allan, 2015; Sheldon, 2017), which in that context is referred to as contraction-leaning asymmetry (Huang and Jorgenson, 2018), it is unclear what underlying mechanisms would shape our findings here. Indeed, these results suggesting asymmetry in effects of income shares to the top quintile are notable on climate mitigation and solutions grounds, highlighting that reducing this characteristic of income inequality has the potential to help limit growth in anthropogenic emissions in nontrivial ways. How and why this asymmetry occurs is beyond the scope of the present analysis and warrants future investigation.

Additional findings reveal that greater shares of disposable income going towards groups below the top quintile have negative short-run and long-run effects on carbon emissions, and these effects are statistically symmetrical. This applies to income shares for the bottom 4, 3, 2, and 1st quintiles. While these particular empirical relationships have received very little, if any, attention in prior sub-national research, the results challenge the arguments of the analytical perspectives regarding the marginal propensity to emit and the marginal propensity to consume, which ultimately suggest that a redistribution of income from higher-income groups to lower-income groups will likely result in overall higher levels of emissions (Jakob et al., 2014; Ravallion et al., 2000; Seriño and Klasen, 2015). Since these analytical perspectives largely focus on the potential effects of larger income shares being held by individuals and groups below the top of the income distribution, we suggest our choice in modeled predictors is well suited to test their overall arguments. Prior studies claiming to yield results that support such arguments, or those that report null findings, commonly use the Gini coefficient as the key predictor of income inequality (e.g., Soysa and Indra., 2025; Ghazouani and Beldi, 2022; Uddin et al., 2020). By design, however, the Gini coefficient does not capture with specificity where inequality actually occurs within the distribution (Givens et al., 2023; Grant et al. 2026; Jorgenson et al., 2024).

While the results generally contradict the overall arguments of the analytical perspectives suggesting that emissions will increase if there is a redistribution of income from higher-income groups to lower-income groups, at least in the Canadian sub-national context, what might explain our findings regarding the negative effects of greater income shares to the bottom quintiles? We briefly offer two additional potential explanations.[5] First, it could be, at least partly, that a redistribution of income shares from the top group to lower-income groups operate as a type of substitution effect, given that the carbon impacts of over-consumption by higher-income groups could greatly outweigh the much smaller carbon impacts of lower-income consumers. Second, as a type of structural effect, when the income shares increase for lower-income groups, the additional income might be directed towards less carbon-intensive consumption, such as service-oriented consumption, along with investments in more efficient and environmentally friendly material goods, such as heat pumps and other energy efficient household items (e.g., induction ranges, tankless water heaters) and household insulation, as well as electric vehicles that are available at relatively more affordable prices. If and the extent to which these might be actual mechanisms and pathways that help shape our findings requires

[5] We thank an anonymous reviewer for suggesting we note these potential mechanisms.

nuanced analyses beyond the scope of the present study.

Overall, the statistically asymmetrical effect of the income shares of the top quintile, where a unit decrease has a proportionally larger short-run and long-run effect of reducing emissions than a unit increase does in increasing emissions, coupled with the statistically symmetrical short-run and long-run negative effects of income shares for the bottom 4 quintiles, highlights the climate mitigation potential of reducing income inequality in particular ways. And the effects of all income share measures are statistically equivalent for emissions from different sectors, robust to various model specifications, and not sensitive to the inclusion of different economic and demographic controls.

While this research makes multiple contributions, it also has limitations that should be addressed in future analyses. Foremost, while we find notable evidence of disposable income shares for the top quintile increasing emissions and income shares of the bottom 4 quintiles decreasing emissions, given current data availability constraints, the reported analysis does not capture the underlying mechanisms shaping these complex socioenvironmental relationships for Canada's provinces. In future work we plan to conduct in-depth case studies to better identify and understand the underlying mechanisms, such as the potential substitution and structural effects briefly noted above, and other conditions within and across provinces that shape the robust associations between emissions and the various income share measures we observe in the reported statistical analysis. Further, it is unclear if our findings, especially those considering the negative effects of the income shares of the bottom four quintiles, are widely generalizable outside of Canada. Indeed, while other analyses yield results similar to ours regarding the positive effect of the income share of the top quintile on carbon emissions, if and how income shares of the bottom four quintiles shape emissions in other geographic and structural contexts are unanswered empirical questions. We hope that the present study will encourage others to pursue such queries in future research, especially subnationally for highly emitting nations such as China and the United States, as doing so has significant mitigation policy implications, as well as determining if these relationships are similar within and across nations throughout the world.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eiar.2026.108440.

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.

Acknowledgements

This work was supported by the Social Sciences and Humanities Research Council of Canada [grant number AWD-032861 SSHRC 2025]. The authors thank the anonymous reviewers and the handling editor for their helpful suggestions and support.

Data availability

Data will be made available on request.

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