Evaluating exposure inequalities in air pollution health science: state of the science and current activities at Health Canada

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Upwind Downwind Conference,
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Hamilton

Health Canada Santé Canada

Canada

Outlines and Objectives

- Describe the **Right to a Healthy Environment** under CEPA and its relevance to air pollution
- Detail findings of two recent projects evaluating **national exposure inequalities**
- Highlight **other relevant work** related to environmental justice and air pollution at Health Canada

Right to a Healthy Environment under the *Canadian Environmental Protection Act, 1999* (CEPA)

The right to a healthy environment under CEPA

CEPA was amended in June 2023 to recognize, in the preamble, that every individual in Canada has a right to a healthy environment as provided under the Act and require the Government to develop an implementation framework

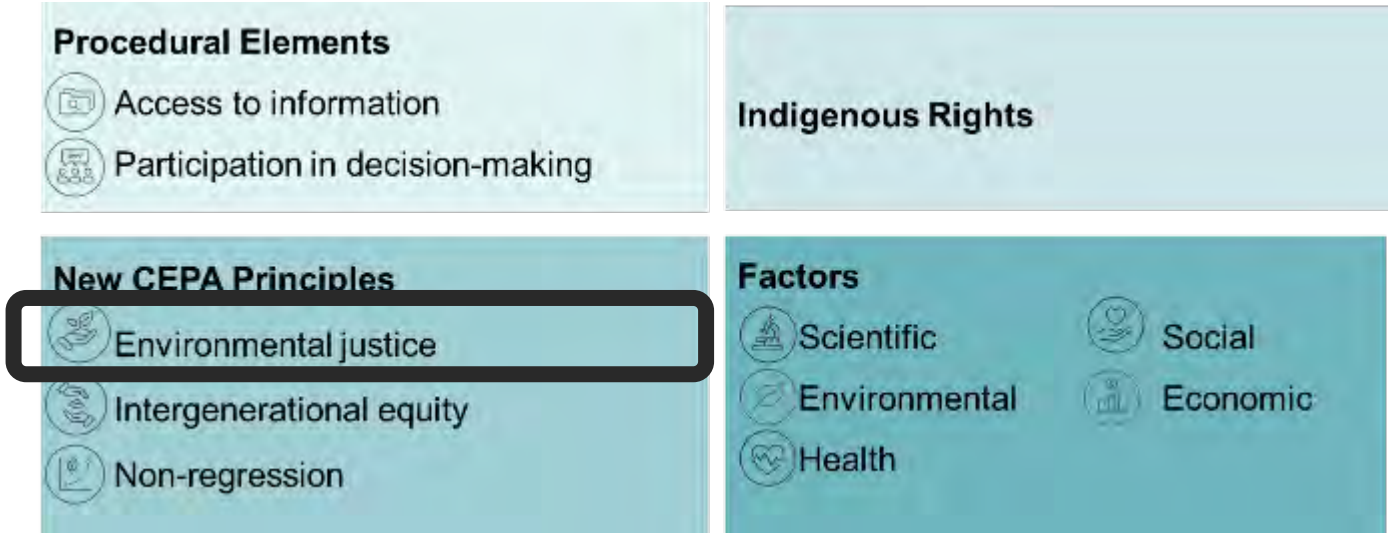
- In July 2025, the Government published the implementation framework to set out what the right to a healthy environment means **in the context of CEPA**, and how Health Canada and Environment and Climate Change Canada staff will fulfill their duty to protect this right and uphold 3 new principles in their work.

Check out the Implementation framework for the right to a healthy environment under the Canadian Environmental Protection Act, 1999 - Canada.ca

Right to A Healthy Environment under CEPA

Substantive elements

- The right of every individual in Canada to live in an environment that is protected from harmful substances, pollutants, and waste, and where actions taken under CEPA contribute to:
  - clean and healthy air and water
  - a sustainable climate
  - healthy ecosystems and biodiversity

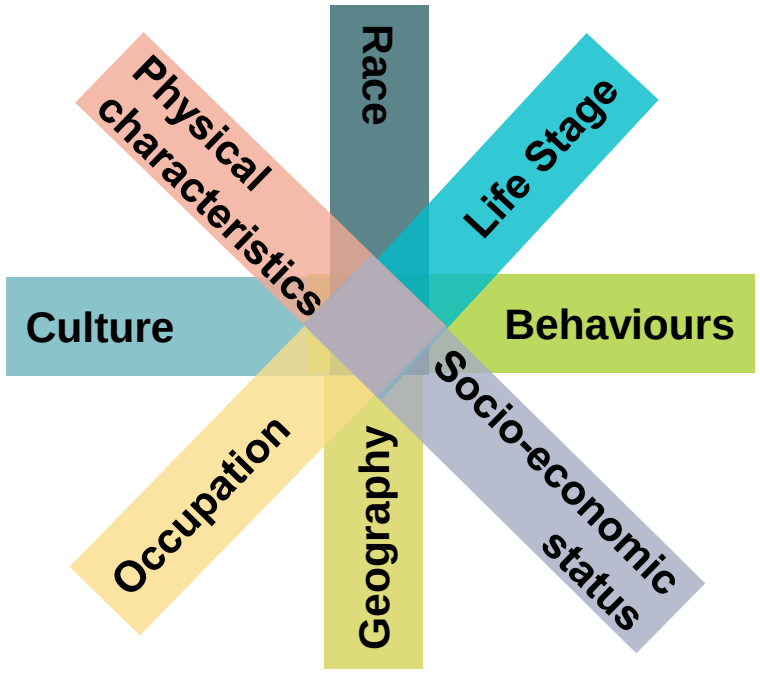


Ref: Environment and Climate Change Canada, 2025. Implementation Framework for the Right to a Healthy Environment under the Canadian Environmental Protection Act, 1999

Environmental Justice under CEPA

Seeks to advance the fair and equitable protection of all people in Canada from disproportionate environmental or health risks and to advance their equitable access to meaningful participation in decision-making under the Act.

Disproportionate impacts on populations can arise from greater exposure and/or greater susceptibility due to:



Ref: Environment and Climate Change Canada, 2025. Implementation Framework for the Right to a Healthy Environment under the Canadian Environmental Protection Act, 1999

Environmental Justice as it Relates to the Air Program:

Research & Monitoring:

- **Identifying populations who may be disproportionately impacted**
- **Collecting and sharing disaggregated data (i.e. exposure broken down by sex, race, age, community etc.)**

Risk Assessment:

- Identify if risks are present for communities with a disproportionate susceptibility or exposure

Risk Communication:

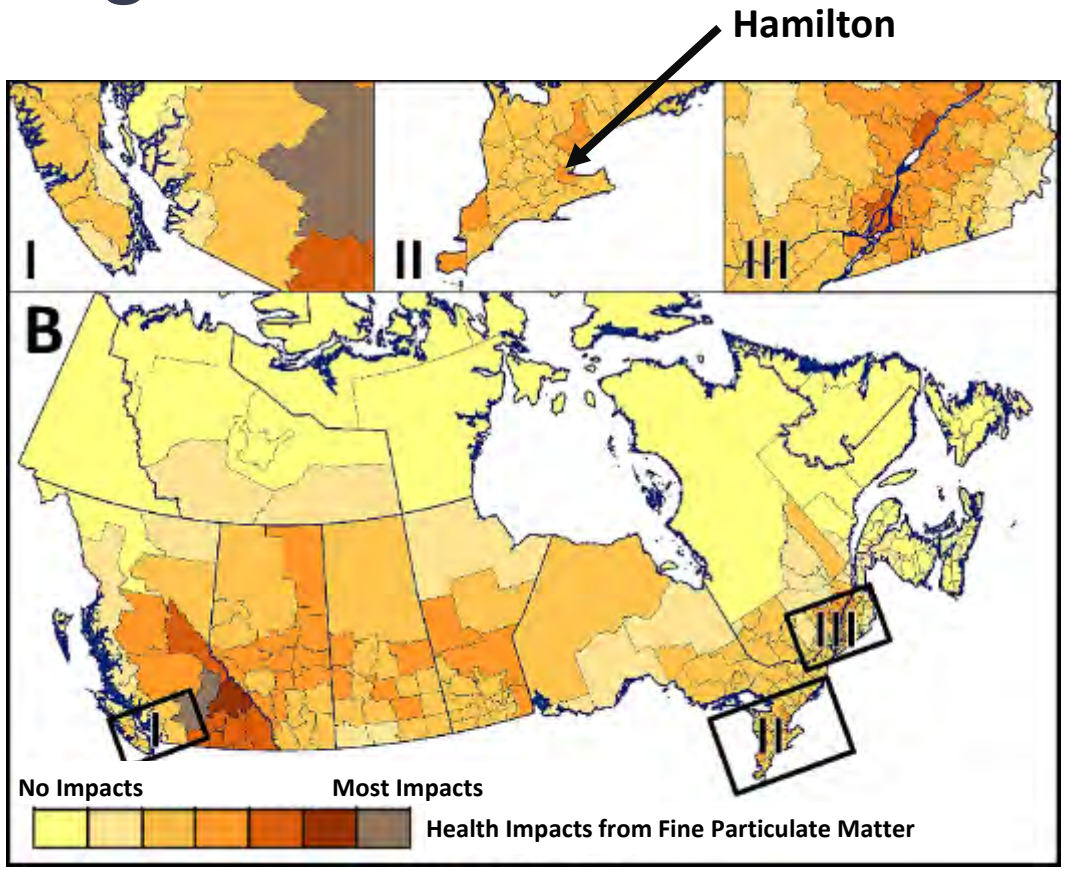
- Establishing outreach and risk communication strategies tailored for these populations
- Making efforts to include diverse voices in consultation and engagement activities.

Ref: Environment and Climate Change Canada, 2025. Implementation Framework for the Right to a Healthy Environment under the Canadian Environmental Protection Act, 1999

R2HE: Research and Monitoring

Basis for understanding disproportionate impact

- Sources of air pollution are distinct geographically
- Air pollution varies substantially within and between urban centres
- Population characteristics and susceptibility are not uniform across individual cities nor nationally



Ref: Fuller-Thomson et al., 2024

Evaluating exposure inequalities

National $PM_{2.5}$ Inequality under Multiple Exposure Models

ACS ES&T Air

Article

Variation in Fine Particulate Matter Exposure Models: Implications for Health, Equity, and Uncertainty Evaluation

Amanda J. Pappin,* Elysia G. Fuller-Thomson, Saeed Nadi, Hong Chen, Anas Alhusban, Y. Burak Oztaner, Amir Hakami, Nedka Pentcheva, Xihong Wang, Maxim Bulat, and Richard T. Burnett

Cite This: ACS EST Air 2026, 3, 681−696

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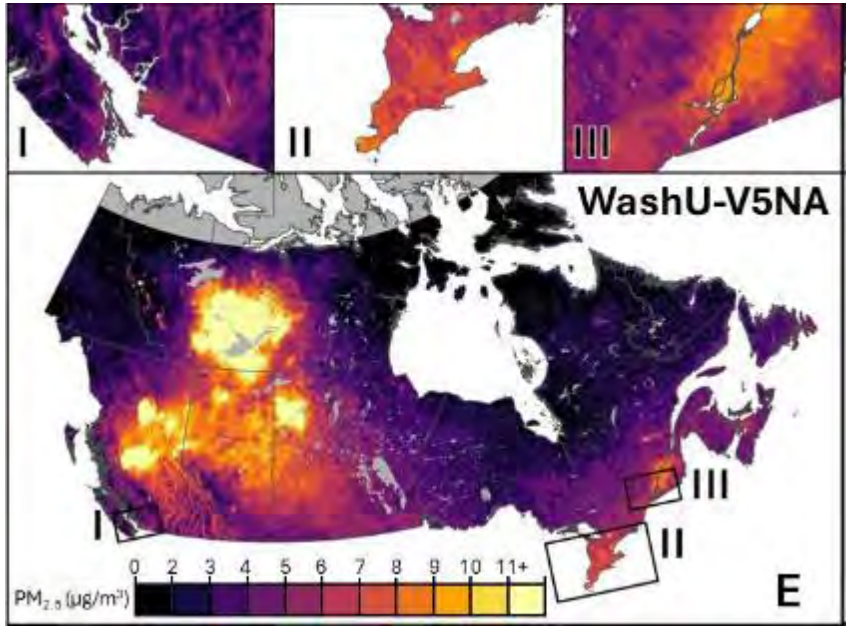
Methods

7 Exposure Models, 2002-2014



7 total models encompassing modern techniques:

- **Chemical Transport Modelling**
- **Machine Learning**
- **Satellite Information**

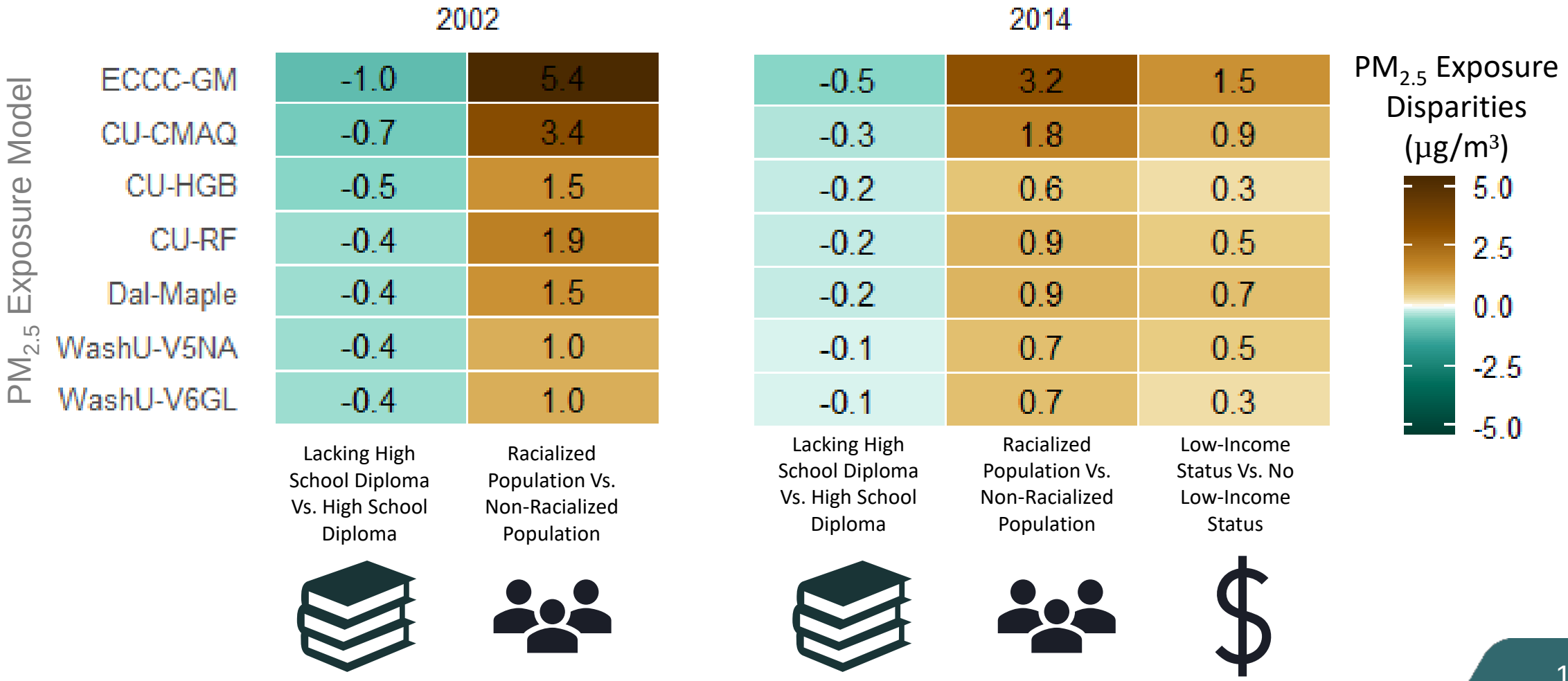
Three Measures of SES, Canadian Census

- Racialized Populations
- High School Education
- Low-Income Status

Disparities Assessed

Ref: Pappin et al., 2026

Results: $PM_{2.5}$ Disparities Across Exposure Model Type



Ref: Pappin et al., 2026

Key-Takeaways

- Consistent national $PM_{2.5}$ disparities no matter the choice of exposure model
- Trends hypothesized to be linked to urban-rural gradients
- Absolute disparities decreases, very slight decrease to relative disparities

Ref: Pappin et al., 2026

Analyses examining national nitrogen dioxide exposure inequalities

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Mathieu Rouleau[a]
Toyib Olaniyan[b]
Amanda Pappin[a]

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[b]Health Analysis and Modelling Division, Analytical Studies and Modelling Branch

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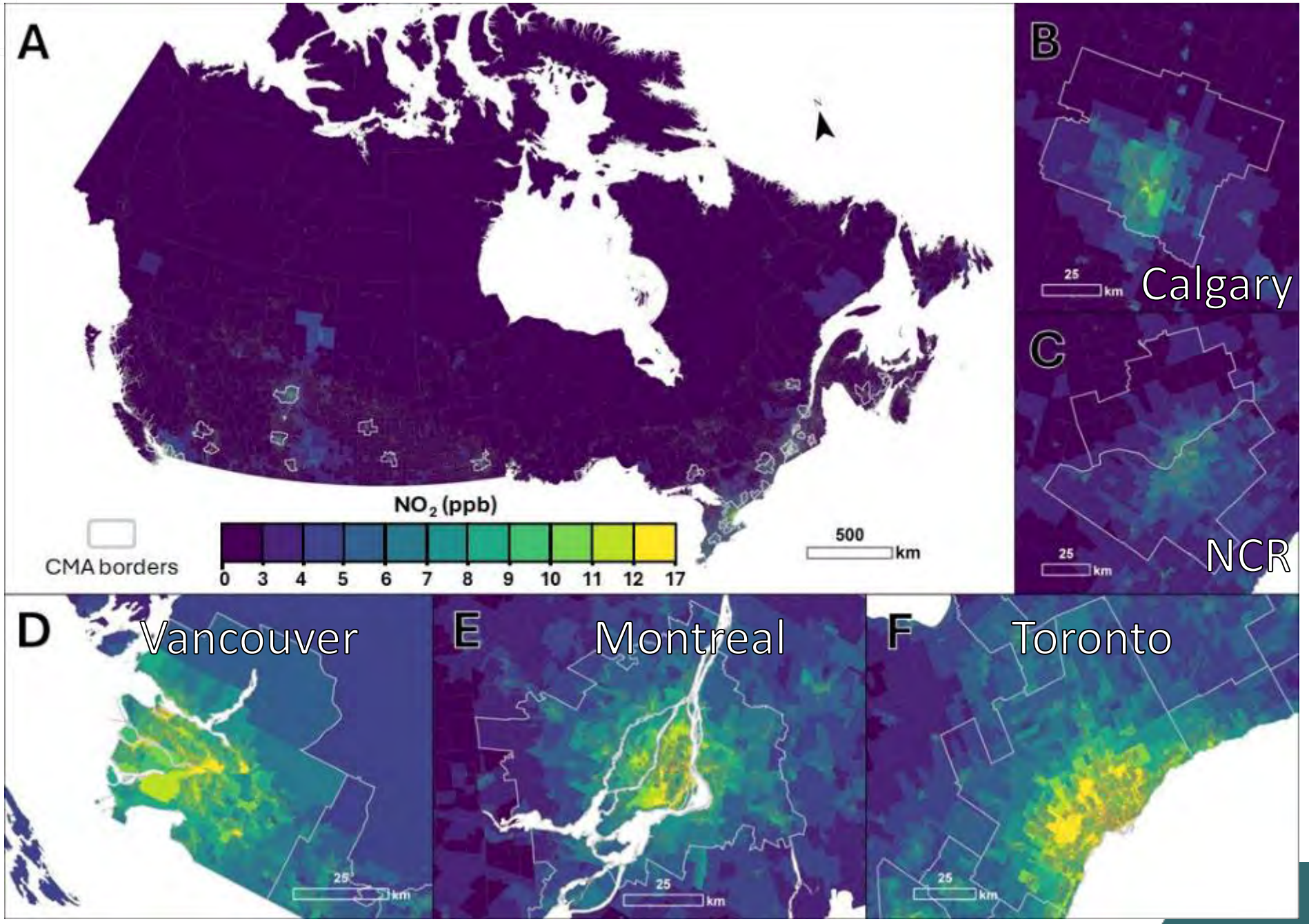
Data Source: 2019 Land-Use Regression Exposure Model



Ref: Fuller-Thomson et al. (in review)

Data Source:
Area-Level Socioeconomic Data

Specific SES Measures from 2021 Census

- Precedence within Canadian literature
- Six Measures:
  - % Age 14-
  - % Age 65+
  - % Indigenous
  - % < High School Education
  - % < Low-Income Cut-Off (LICO)
  - % Racialized Population

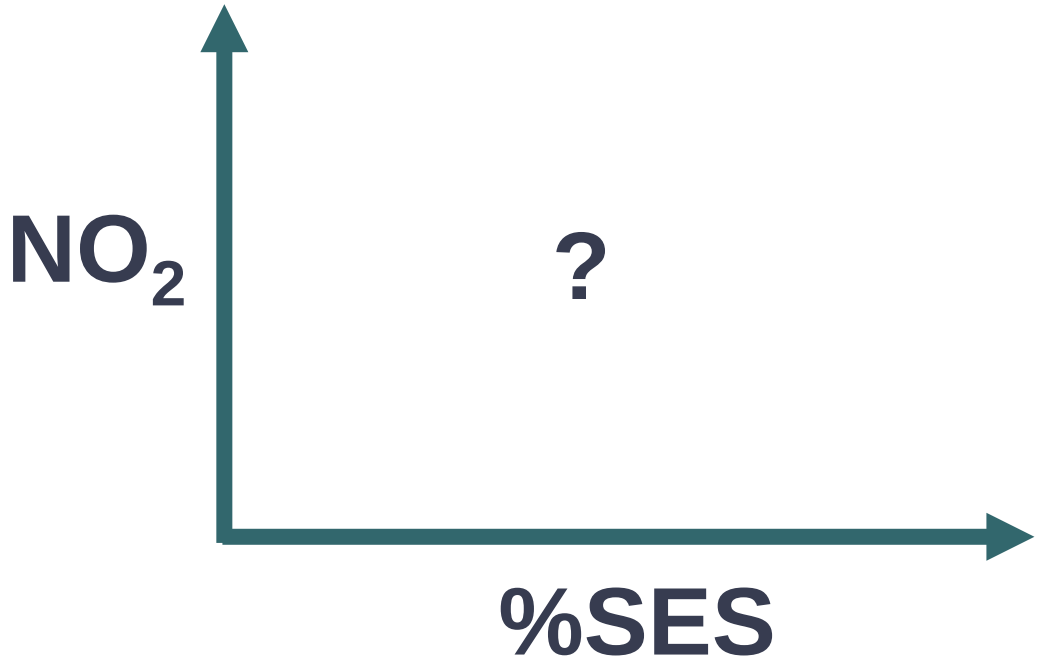
Canadian Index of Multiple Deprivation (CIMD) (2021)

- Commonly employed index of SES
- Statistics Canada product available freely
- Four dimensions

Ref: Fuller-Thomson et al. (in review)

GOAL:
Evaluate the association between area-based measures of socioeconomic status and NO_2 exposure

$$NO_2 \propto \%SES\ (?)$$



Ref: Fuller-Thomson et al. (in review)

Methodology: Statistical Regression

- Simultaneous Autoregressive Model (Spatial Lag) evaluates associations between SES and NO_2
  - Two modelling types: National + Stratified by Census Metropolitan Area
  - Separate models for census and CIMD
  - Accounts for common methodological concerns
  - Standardized by standard deviation to fairly compare SES

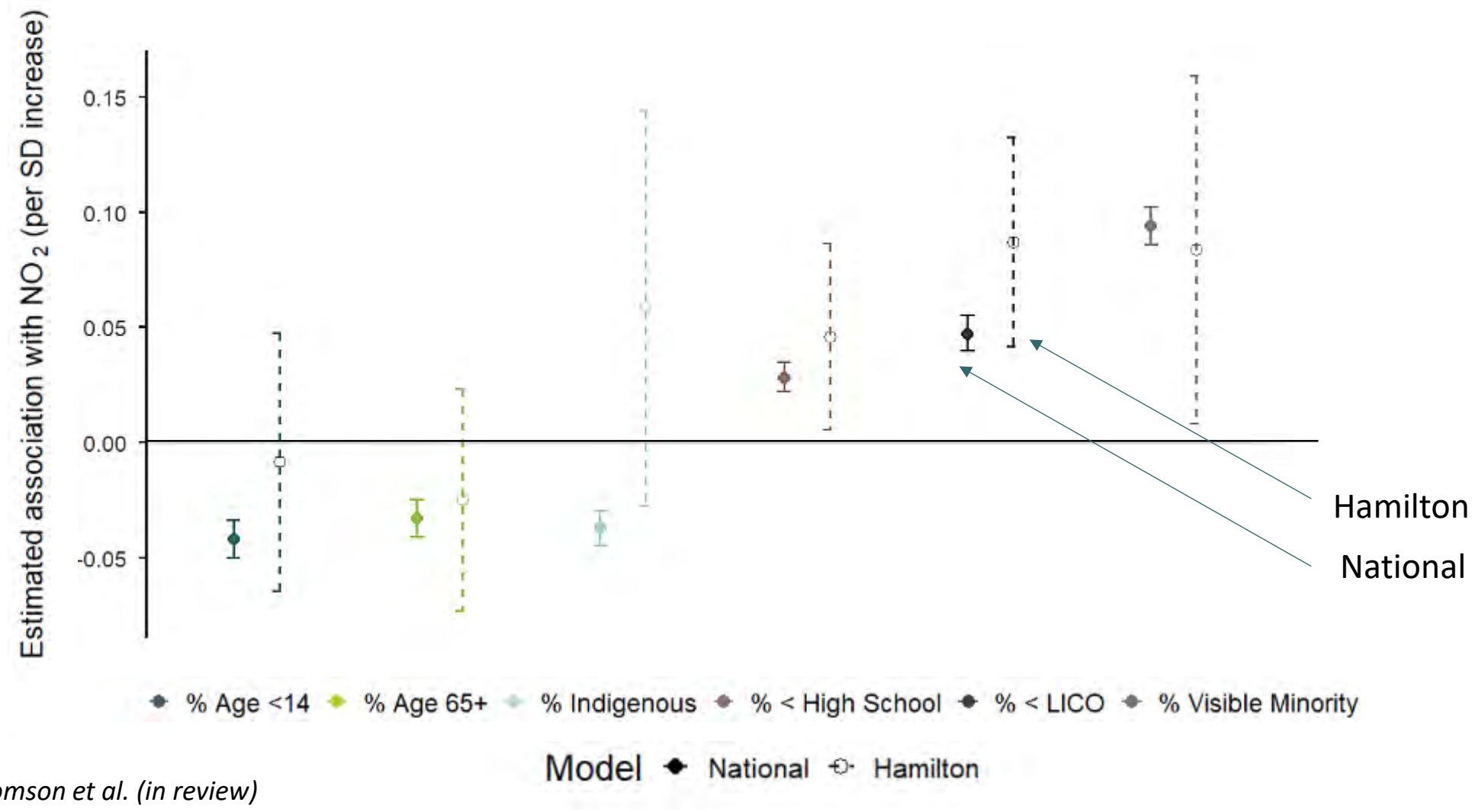
Results: Statistical Associations Between SES Census Variables and NO_2 Exposure

	SAR – Spatial Lag Model
% Age 14- (SD = 5.1%)	−
% Age 65+(SD = 9.8%)	−
% Indigenous (SD = 5.7%)	−
% < High School (SD = 8.4%)	+
% < LICO (SD = 5.2%)	+
% Racialized (SD = 25.6%)	+

+ Positive − Negative

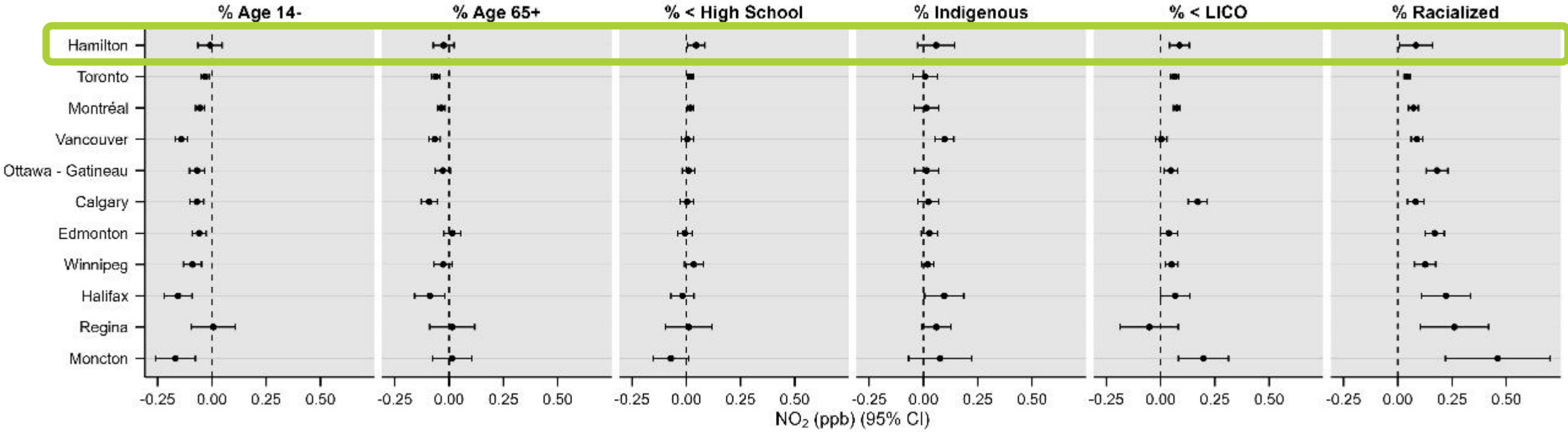
Ref: Fuller-Thomson et al. (in review)

Associations Between SES Census Variables and NO_2 exposure (SAR Model)



Ref: Fuller-Thomson et al. (in review)

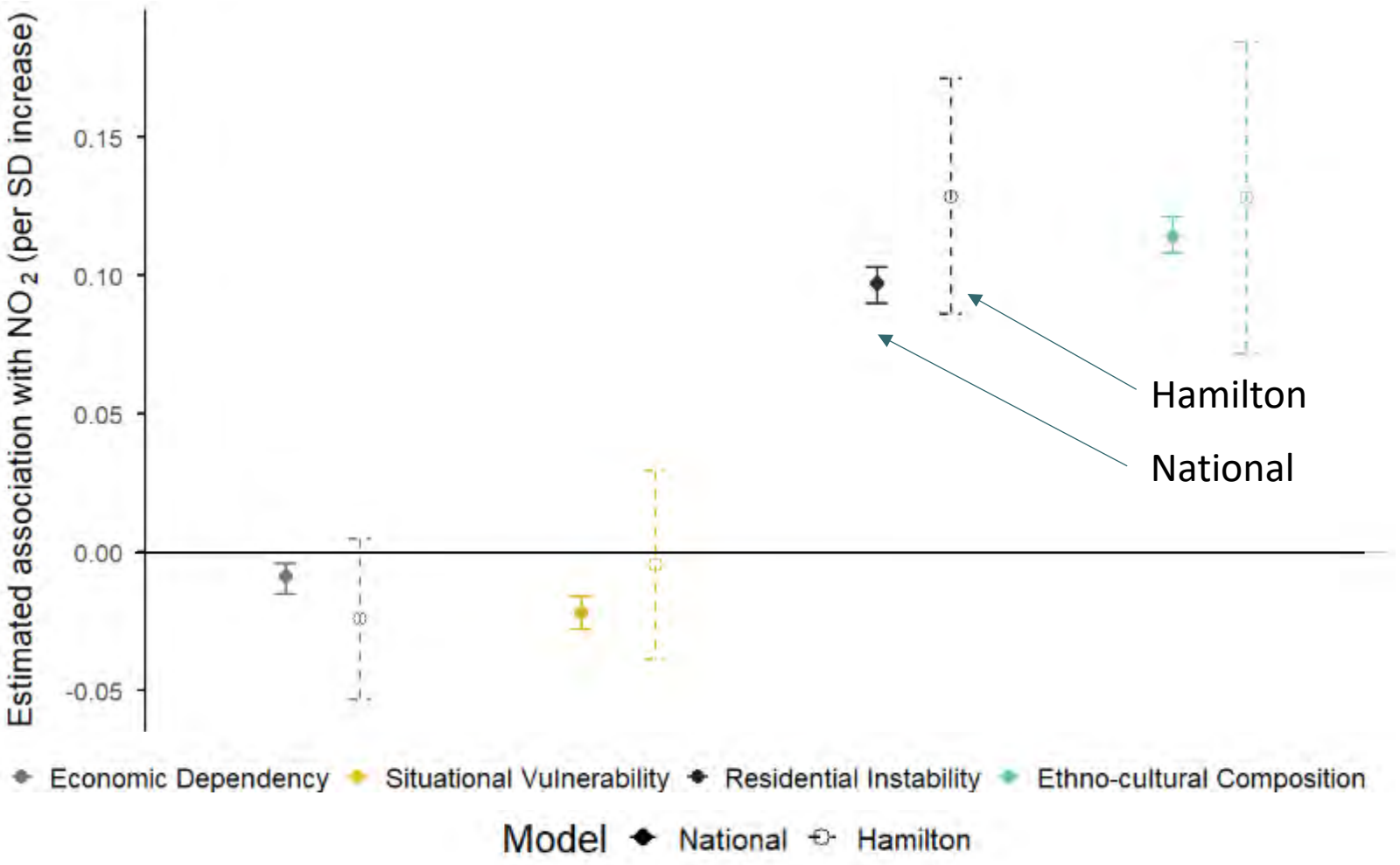
Associations Between SES Census Variables and NO_2 exposure SAR - Stratified Model



Ref: Fuller-Thomson et al. (in review)

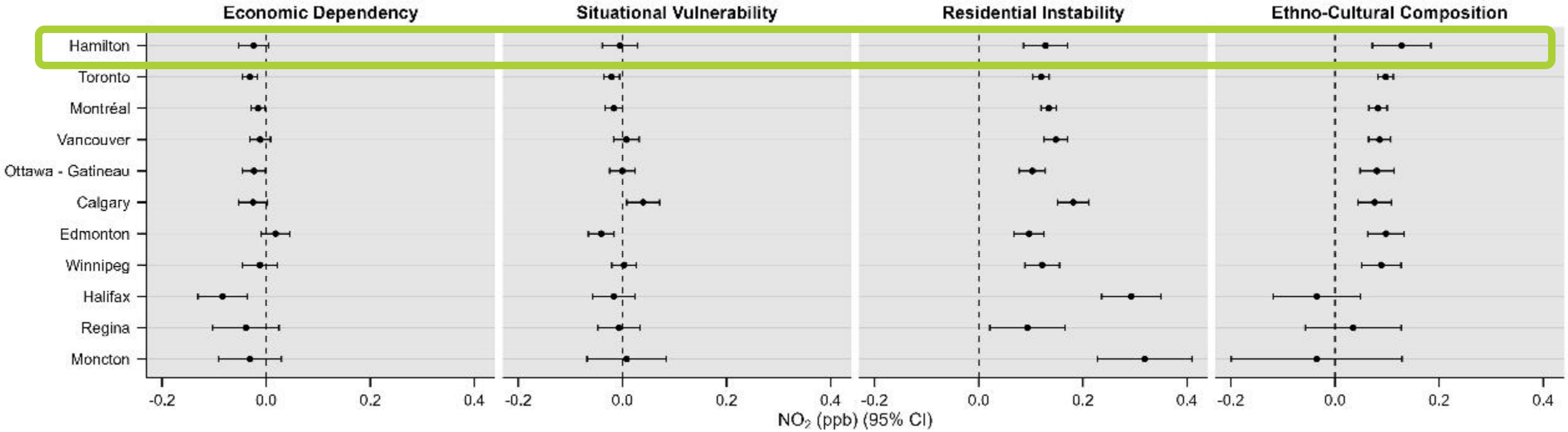
Associations Between CIMD and NO_2 exposure SAR Model

	SAR – Spatial Lag
Economic Dependency	−
Situational Vulnerability	−
Residential Instability	+
Ethno-cultural Composition	+



Ref: Fuller-Thomson et al. (in review)

Associations Between CIMD and NO_2 exposure SAR - Stratified Model



Ref: Fuller-Thomson et al. (in review)

Discussion: Key Takeaways

- Results suggest a tentative national pattern of poverty, racialized populations, and residential instability linked with higher NO_2 exposure
- Growing international picture of racialized populations & elevated NO_2 exposure in high-income countries

Ref: Fuller-Thomson et al. (in review)

Other work related to environmental justice and air pollution at Health Canada

Thank You – Any Questions?

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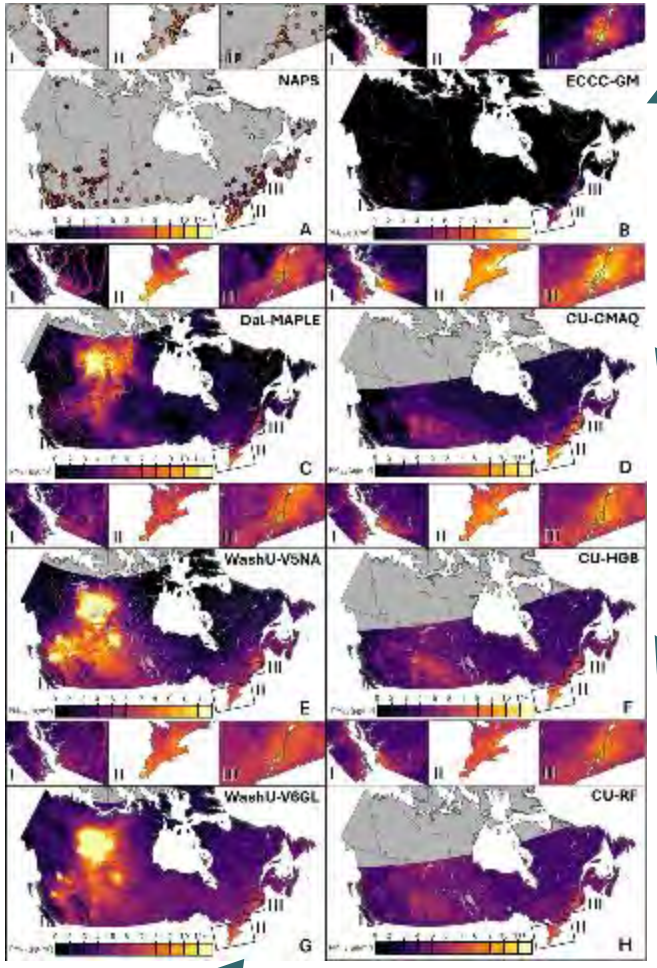
Methods

7 Exposure Models, 2002-2020



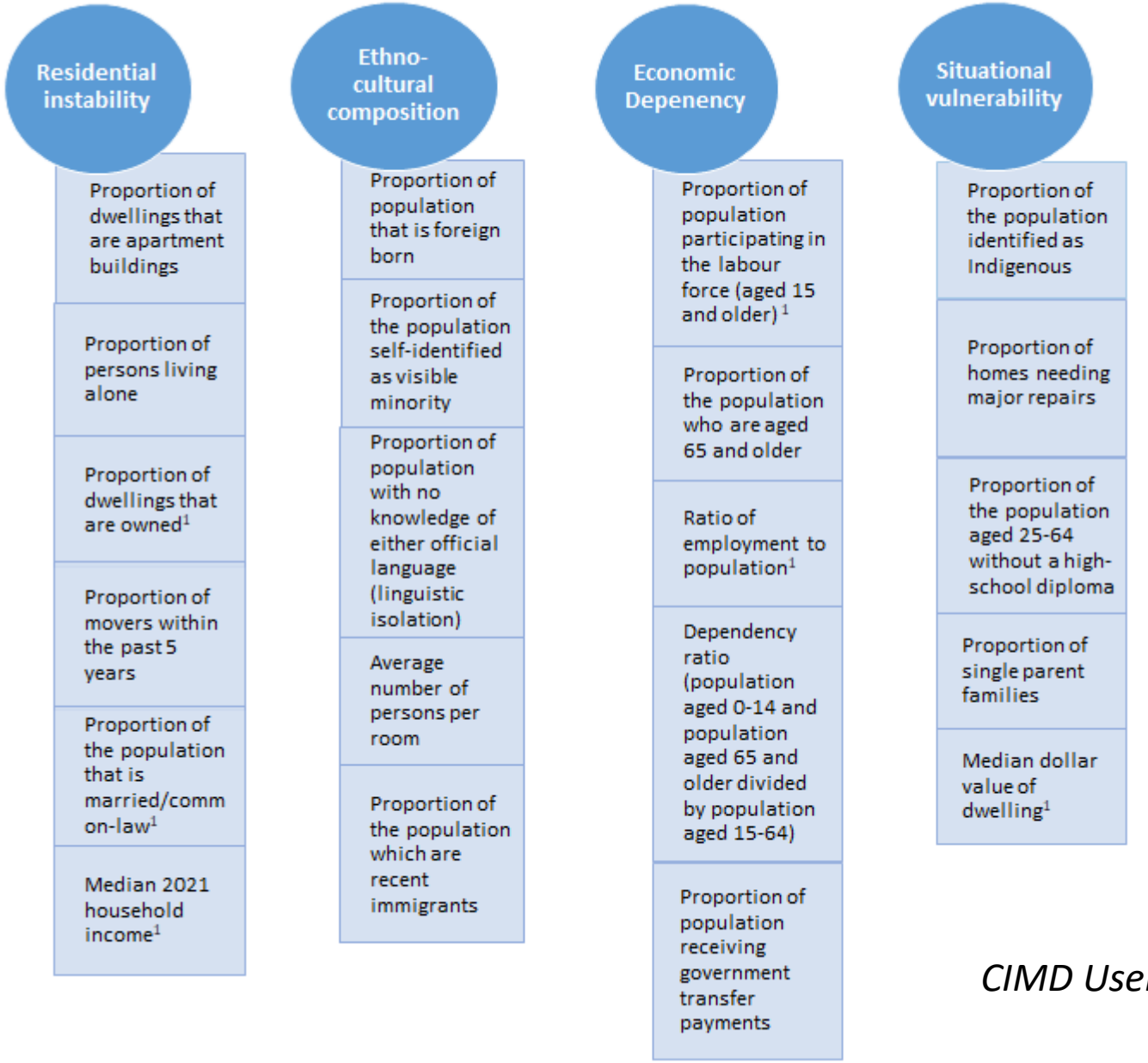
Chemical Transport Models

Satellite Models

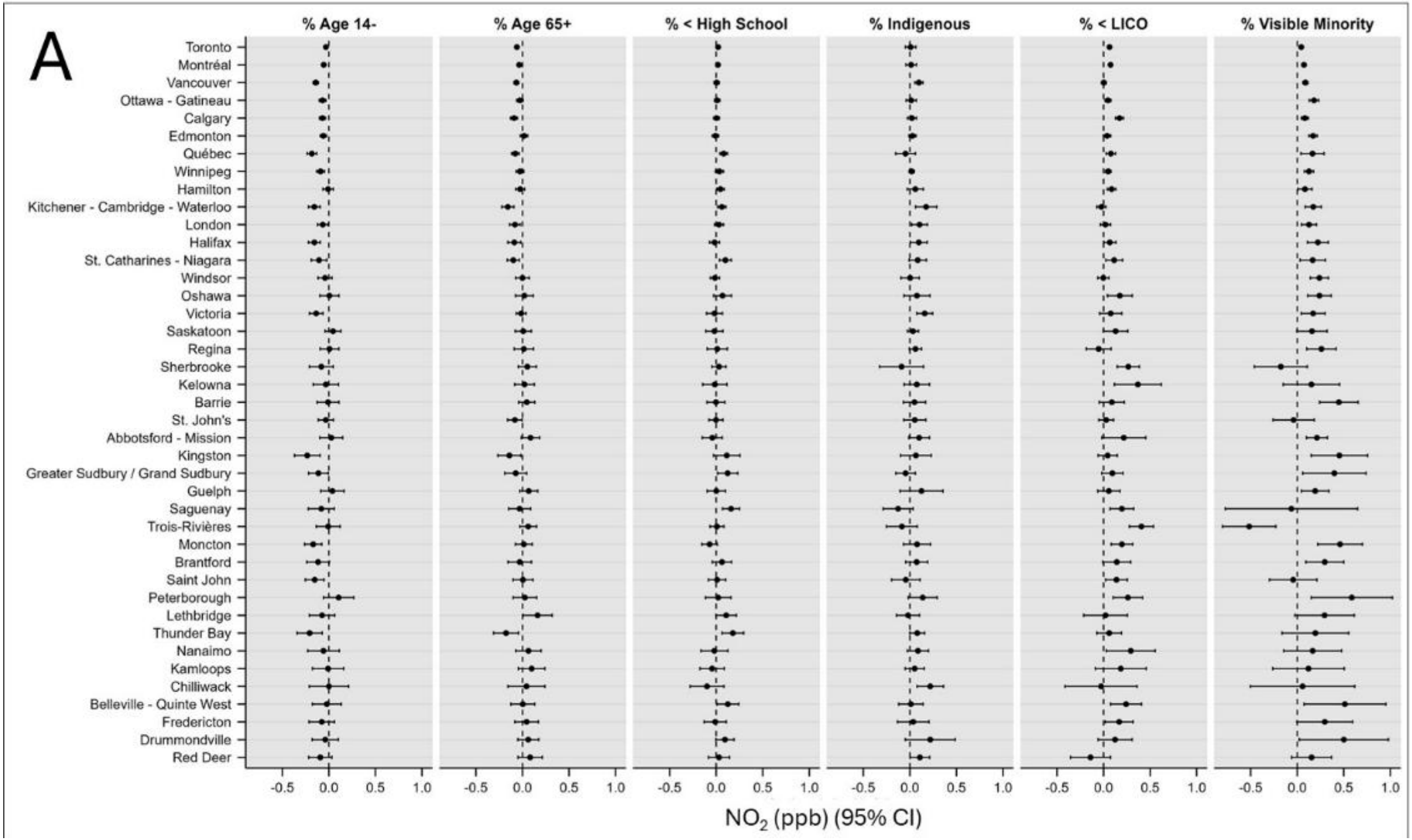
Machine Learning Models

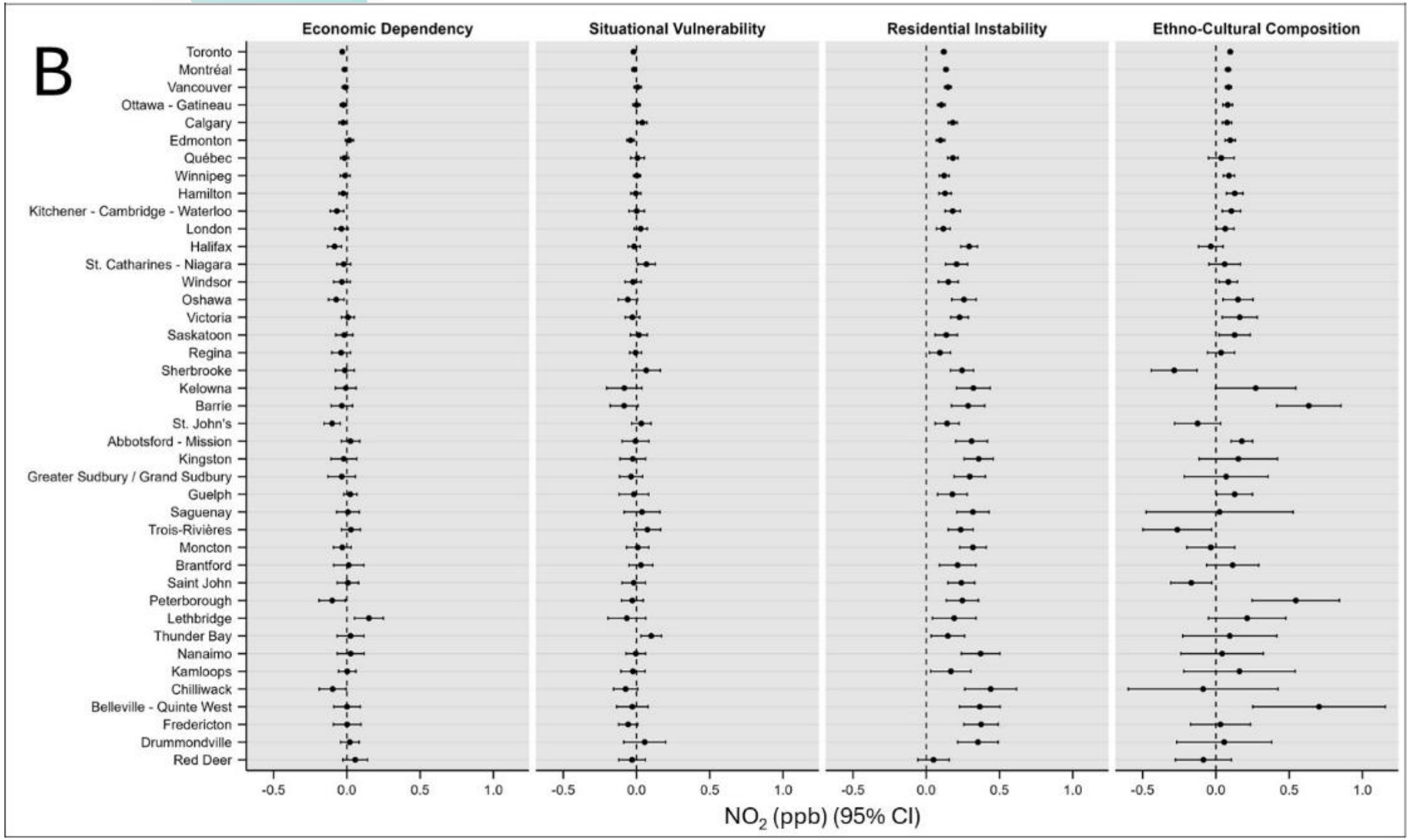
Ref: Pappin et al., 2026

The four dimensions of multiple deprivation and their corresponding indicators, Canada, 2021



CIMD User Guide, 2023


A
% Age 14-
% Age 65+
% < High School
% Indigenous
% < LICO
% Visible Minority
Toronto
Montréal
Vancouver
Ottawa - Gatineau
Calgary
Edmonton
Québec
Winnipeg
Hamilton
Kitchener - Cambridge - Waterloo
London
Halifax
St. Catharines - Niagara
Windsor
Oshawa
Victoria
Saskatoon
Regina
Sherbrooke
Kelowna
Barrie
St. John's
Abbotsford - Mission
Kingston
Greater Sudbury / Grand Sudbury
Guelph
Saguenay
Trois-Rivières
Moncton
Brantford
Saint John
Peterborough
Lethbridge
Thunder Bay
Nanaimo
Kamloops
Chilliwack
Belleville - Quinte West
Fredericton
Drummondville
Red Deer
-0.5
0.0
0.5
1.0
NO2 (ppb) (95% CI)


B
Economic Dependency
Situational Vulnerability
Residential Instability
Ethno-Cultural Composition
Toronto
Montréal
Vancouver
Ottawa - Gatineau
Calgary
Edmonton
Québec
Winnipeg
Hamilton
Kitchener - Cambridge - Waterloo
London
Halifax
St. Catharines - Niagara
Windsor
Oshawa
Victoria
Saskatoon
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-0.5
0.0
0.5
1.0
NO2 (ppb) (95% CI)

Methodology: Four Types of Regression Models

Ordinary Least Square Regression (OLS)

- Goal: Base case regression model
- Starting place for all regression modelling

Linear Mixed Effects Regression (LME)

- Goal: To see associations beyond CMA-level differences
- Adds a random intercept for CMAs

Simultaneous Autoregressive Model (Spatial Lag) (SAR)

- Goal: To see associations remain when accounting for spatial autocorrelation
- Adds a spatial lag component:
- $NO_2 = \beta(\%SES) + \rho Wy + \varepsilon$

Simultaneous Autoregressive Model by CMA (SAR - Stratified)

- Goal: Evaluate consistency of CMA-specific associations
- Stratifies analysis
- Keeps a spatial lag component

NOTE:

- Area-based analysis
- Z-score standardization
- Within CMAs Only