



# From Individual Choices to Collective Impact: Quantifying the Role of Behavioural Changes in Greenhouse Gas Mitigation

Maryam Naghdizadegan Jahromi <sup>1</sup>, Sébastien Bruno <sup>1</sup>, Marius Le Maréchal <sup>1</sup>, and Stéphane Roche <sup>1,2</sup>

<sup>1</sup> Center for Research in Geospatial Data and Intelligence (CRDIG), Laval University, Quebec City, Canada

<sup>2</sup> Institute for Environment, Development and Society (EDS), Quebec City, Canada

Correspondence: Maryam Naghdizadegan Jahromi (Maryam.naghdizadegan.1@ulaval.ca)

**Abstract.** Household emissions, particularly from food consumption, represent a substantial yet underutilized component of urban greenhouse gas (GHG) emissions. While most research focuses on national or industrial scales, household behaviours remain underrepresented in local mitigation strategies. Addressing this gap requires approaches that account for both household choices and spatial context.

This study applies a behavioural–geospatial framework to survey data from Québec City households to quantify and spatialize diet-related GHG emissions. Meat consumption frequencies were converted into emissions using food-specific factors, and four realistic dietary scenarios were modelled at the district level.

The results reveal substantial intra-urban disparities. Districts with higher reported meat consumption exhibit significantly greater mitigation potential, independent of population size. When combined with sociodemographic indicators such as income, the analysis highlights spatial structuring of behaviours commonly perceived as private choices.

By transforming survey-based behavioural data into spatially explicit GHG information, this study expands geospatial analytics beyond infrastructure-based emissions and into the domain of lifestyle-driven carbon footprints. The proposed framework enables municipalities to identify high-potential districts, design targeted interventions, and integrate eco-conscious consumption into climate resilience and socio-ecological transition strategies.

**Submission Type.** Analysis, Case study.

**BoK Concepts.** [TA12] EO for societal and environmental challenges, [TA12-1] EO for climate change mitigation and adaptation

**Keywords.** GHG emissions, geospatial data, eco-behaviour, local GHG mitigation potential, eco-conscious consumption, Quebec

---

## 1 Introduction

Cities are key actors in climate mitigation strategies. However, municipal climate policies tend to prioritize sectors where spatial data infrastructures are already well established—such as transportation systems, building energy performance, and waste management networks. In contrast, food consumption—despite accounting for a substantial share of household greenhouse gas (GHG) emissions (Institut de la statistique du Québec, 2025; Kauppinen et al., 2010; Wu Yan et al., 2012)—remains largely absent from geospatial decision-support systems. In fact, dietary behaviour is typically framed as an individual lifestyle choice rather than as a spatially differentiated and policy-relevant component of urban climate action (Newell et al., 2021).

This framing is particularly problematic given that recent sustainability research has consistently identified meat consumption as one of the most carbon-intensive dimensions of household lifestyles (Barthelmie, 2022; Gaillac & Marbach, 2021). Nevertheless, most diet-related GHG assessments are conducted at national or global scales and rely on aggregated consumption statistics (Crippa et al., 2021; Poore & Nemecek, 2018). Such approaches overlook intra-urban variability and fail to capture the spatial heterogeneity of dietary behaviours within cities. Consequently, municipalities lack fine-

grained geospatial intelligence to identify where dietary transitions could yield the greatest emissions reductions or where targeted behavioural interventions may be most effective.

This paper addresses this gap by demonstrating how behavioural survey data can be transformed into actionable geospatial intelligence for urban climate governance. It builds upon a broader behavioural–geospatial framework developed for Québec City, in which household GHG-reducing behaviours are analysed spatially across multiple domains, including energy use, transportation, waste management, and eco-conscious consumption. Within this integrated framework, eco-conscious consumption emerges as a critical yet underexplored domain of climate action.

Focusing specifically on meat consumption as a measurable and high-impact behavioural indicator, this study operationalizes eco-conscious consumption using data from the “Baromètre de l’Action Climatique” survey (Champagne St-Arnaud et al., 2024). Diet-related GHG emissions are estimated and modelled under alternative behavioural scenarios. By spatializing these scenarios at the district level, the paper illustrates how smart behavioural data can be integrated into geospatial decision-support tools to inform targeted, location-based climate interventions.

## 2 Conceptual backgrounds: from eco-conscious consumption to smart geospatial data

In the broader research framework on which this study is based, household emissions are understood as the outcome of everyday behaviours shaped by socio-economic, cultural, and spatial contexts (Faber et al., 2012). This framework emphasizes that GHG-reducing behaviours are not randomly distributed but follow spatial patterns influenced by local infrastructures, services, and districts characteristics.

Among the domains identified in this framework, eco-conscious consumption includes behaviours related to purchasing choices and food habits. While energy and transport behaviours are commonly spatialized in urban studies, eco-conscious consumption remains difficult to translate into geospatial indicators. Diet, and particularly meat consumption, provides a unique opportunity to bridge this gap as behaviours are measurable through surveys, and are strongly linked to GHG emissions through established emission factors.

This makes diet an ideal case to demonstrate how behavioural data can be transformed into smart geospatial indicators aligned with the vision of actionable spatial data.

## 3 Data source: The “Baromètre de l’Action Climatique” Survey

The analysis relies on the dataset collected as part of the larger project investigating the spatial distribution of GHG-reducing behaviours across Quebec City and others Quebec Municipalities. The “Baromètre de l’Action Climatique” survey was conducted from October 2 to 14, 2024, and includes responses from 1,505 adult residents across all districts (Champagne St-Arnaud, V et al., 2024).

This survey was made as part of the UrbiGES project, which aims to develop a toolbox to help Quebec municipalities make their “climate plan” as part of the Quebec program named Accelerating Local Climate Transition (ATCL).

More than 100 behavioural and socio-demographic variables were collected and statistically weighted by municipal district, age, gender, education level, and household composition to ensure representativeness at the city scale. The goal was to assess what people are thinking, believing and doing about climate change and what are the correlations between these three categories and the geospatial environment. These correlations are then mapped to produce an easy-to-use, smart geospatial tool for the municipalities.

For this paper, we focused on food as one specific aspect of the subjects that were surveyed. Among the behaviours categorized under eco-conscious consumption, respondents reported the frequency of meat consumption and their willingness to reduce it, providing the basis for estimating diet-related GHG emissions at the individual level. This knowledge will help us to understand the geospatial distribution of GHG mitigation potential in Quebec City.

## 4 Methodology: From meat consumption to districts GHG

### 4.1 Estimating diet-related GHG emissions

As previously discussed, the GHG reduction potential associated with dietary change can be estimated based on individuals’ daily food consumption. In the context of Québec City, dietary patterns can be approximated using existing research on Québécois and Canadian food habits. Canada’s Food Guide provides evidence-based dietary guidelines (Government of Canada, 2026), while provincial initiatives assess the overall diet of Québec residents. In addition, the International Reference Center for Life Cycle Assessment and Sustainable Transition (CIRAIG) is developing a life cycle inventory database for consumption in Québec, including a food component (Patouillard et al., 2023). Similarly, the NutriQuébec

project, a web-based longitudinal population study, evaluates dietary habits among adults in Québec (Rochette et al., 2024). These sources provide relevant information on adult dietary behaviour, which can be converted into GHG emissions using food-specific emission factors (EFs).

The emission factors used in this study are derived from the DataFIELD database developed at the University of Michigan (Rose et al., 2019). Although emissions occur throughout the life cycle of food products (production, processing, transport, and waste), only production-stage emissions are considered here, as this stage represents the largest share of food-related emissions (Weber & Matthews, 2008). While the EFs were calculated for the United States, they are considered suitable for comparing behavioural scenarios, as the relative differences between food categories remain consistent.

Meat consumption frequencies from the Baromètre de l'Action Climatique survey were converted into estimated GHG emissions using these EFs (Rose et al., 2019), allowing the calculation of a baseline diet-related carbon footprint for each respondent.

To operationalize the model, four representative dietary scenarios were defined:

- Meat at every main meal (even distribution across meat types)
- Meat once per day (lower red meat relative to poultry)
- Low-meat diet (low-carbon meats a few times per week, no beef)
- Vegetarian

A weekly GHG footprint was estimated for each scenario. Breakfast was excluded, resulting in 14 main meals per week (Table 1).

**Table 1.** Composition of different weekly diets imagined - 14 meals per week (without breakfast)

	Beef (times per week)	Pork (times per week)	Poultry (times per week)	Vegetarian (times per week)	GHG footprint (kgCO <sub>2</sub> e/year)
Diet 1	4	4	6	0	1500
Diet 2	2	1	4	7	900
Diet 3	0	1	2	11	400
Diet 4	0	0	0	14	330

The calculated GHG footprint enabled comparison between different diets (Table 1). These results were then matched with the results from the barometer, to estimate the GHG reduction potential in different Quebec districts, using two different scenarios explained after.

To use the barometer results, we focused on the question “Do you, or do you intend to, reduce your meat

consumption”. Possible answers were “I already do”, “I intend to do it during the next year”, “I have no intention of doing it” and “I can’t in my situation”. The assumption made for the following results was that people that answered they were not already reducing their meat consumption were classified as having diet 1.

Then, two behavioural change scenarios were modelled in each Quebec districts:

- Meat consumption reduction scenario: modelled by the reduction potential if people currently considered having diet 1 changed to diet 2
- Vegetarian diet scenario: modelled by the reduction potential if people currently considered having diet 1 changed to diet 4

These scenarios allowed us to estimate the GHG reduction potential at the city level scale.

#### 4.2 Spatial aggregation

Individual results (from the barometer) were aggregated at district level to produce geospatial indicators representing current diet-related GHG emissions and potential GHG reductions under each scenario.

These indicators were mapped to reveal the spatial distribution of dietary emission patterns across Quebec City’s districts (Les Rivières, Beauport, Charlesbourg, La Haute-Saint-Charles (LHSC), Sainte-Foy-Sillery-Cap Rouge (SFSCR) and La Cité-Limoilou).

#### 4.3 Data and Software Availability

Relevant data from the survey are not available due to ethical restrictions; However, they are described in the referenced papers. The other data are available in the public databases which have been referenced.

### 5 Results: Spatial heterogeneity of dietary emissions and mitigation potential

Dietary patterns represent a significant component of household greenhouse gas (GHG) emissions in Québec City. Examining their spatial variability is essential for identifying where behavioural change could generate the greatest environmental benefits. A spatial perspective enables the targeted identification of districts in which dietary transitions may contribute most effectively to climate mitigation.

Figure 1 presents the district-level GHG reduction potential under the first dietary scenario. The results reveal substantial disparities across Québec City. LHSC exhibits the highest estimated reduction potential, whereas SFSCR and les Rivières show the lowest.

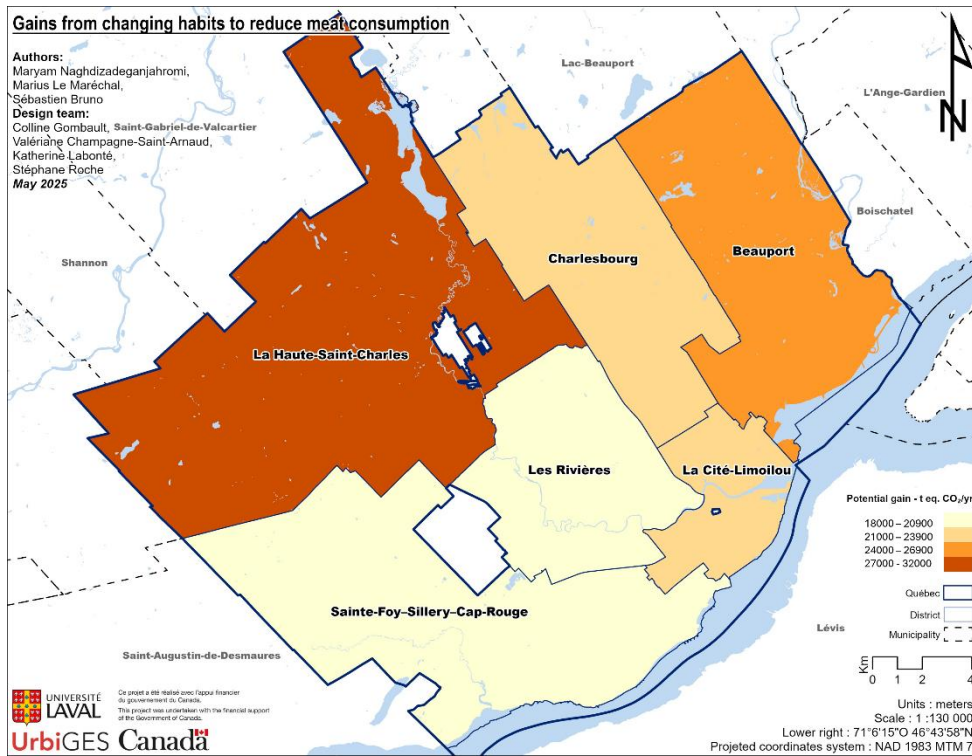


Figure 1. Map presenting the GHG reduction potential in each of the 6 districts of Quebec City for scenario 1.

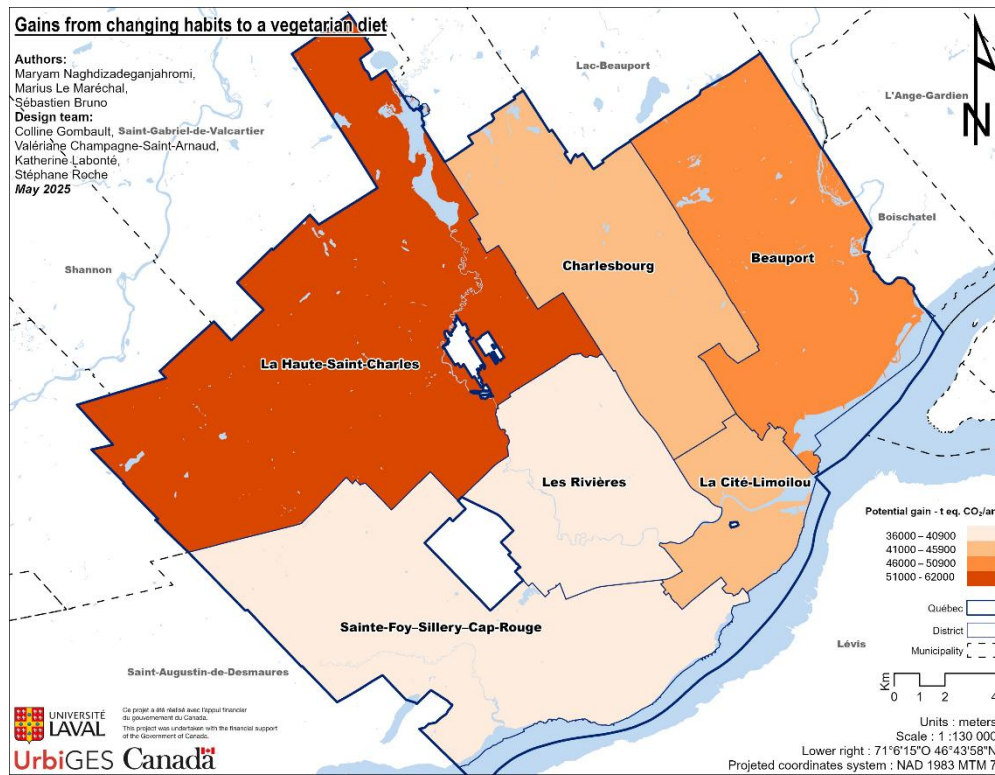


Figure 2. Map presenting the GHG reduction potential in each of the 6 districts of Quebec City for scenario 2.

These findings indicate that dietary behaviour—often treated as a non-spatial lifestyle choice—displays identifiable geographic patterns comparable to those observed in domains such as transportation or residential energy use.

Figure 2 illustrates the results for the second scenario. While the spatial pattern remains consistent—LHSC shows the highest reduction potential and Les Rivières and SFSCR the lowest—the magnitude of reduction differs. Overall, the second scenario yields higher GHG reduction potentials, highlighting the sensitivity of emissions outcomes to the degree of dietary change.

SFSCR and La Cité-Limoilou are among the most populated districts but exhibit comparatively low reduction potential.

The income distribution further illustrates spatial heterogeneity: LHSC has the highest proportion of higher-income households, while SFSCR and La Cité-Limoilou show lower shares. These patterns suggest that dietary emissions and their mitigation potential are influenced by behavioural and sociodemographic factors, rather than population size alone.

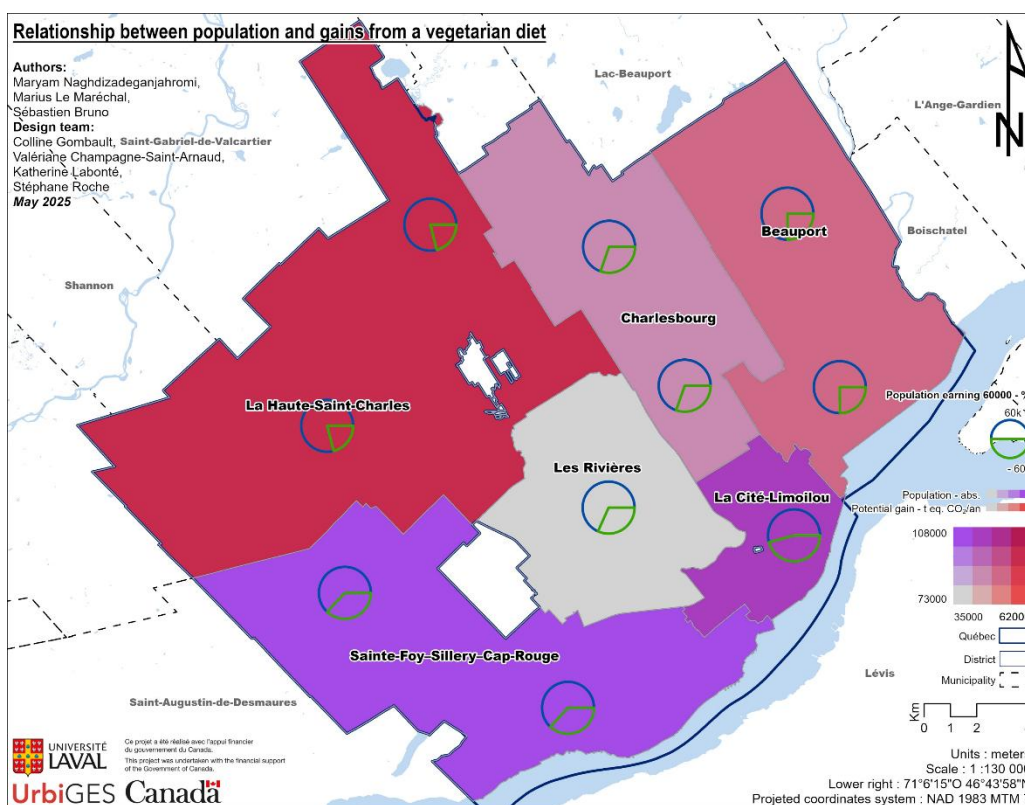


Figure 3. Correlation between population, GHG reduction potential and part of households earning more than 60 000\$CAD/

Figure 3 explores the relationship between district population (purple scale) and GHG reduction potential (red scale), with pie charts indicating the proportion of households earning more than CAD\$ 60,000 annually. This is based on the median household income in Quebec city in 2021 (Statistics Canada, 2023). Household income was included as a sociodemographic variable potentially associated with consumption behaviour. The results suggest that population size alone does not explain the spatial distribution of reduction potential. For instance, LHSC demonstrates the highest GHG reduction potential despite having a relatively low population, whereas

## 6 Discussion

This study provides a concrete application of the broader behavioural–geospatial framework by demonstrating how eco-conscious consumption can be operationalized through dietary behaviour and integrated into geospatial decision-support systems. Spatializing diet-related GHG emissions enables the identification of geographically differentiated mitigation potentials and supports the design of district-specific climate interventions. By intersecting reduction potential with sociodemographic variables, the analysis allows for the exploration of

relationships between spatial context and behavioural patterns.

As highlighted in the results, La Haute-Saint-Charles (LHSC) exhibits the highest GHG reduction potential despite having a relatively low population. This pattern can be explained by higher reported meat consumption frequencies within the district, combined with a limited intention to reduce consumption according to the Baromètre de l'Action Climatique survey (72%). In contrast, La Cité-Limoilou, although more densely populated (approximately 20% more than LHSC), shows a substantially lower reduction potential (approximately 25% less). These findings suggest that consumption behaviours commonly framed as “private choices” display identifiable spatial structuring.

Income distribution further contributes to explaining this pattern. LHSC has the highest proportion of higher-income households, and previous research indicates a positive association between income level and meat consumption (Andreoli et al., 2021; Barros & Wilk, 2021; Wiesli, 2025). Given the relatively higher cost of meat products, income may act as an enabling factor for more carbon-intensive diets. However, this relationship is context-dependent and may weaken in post-materialist settings, where cultural and social values increasingly shape consumption practices (Doyle & Richardson, 2025). These findings underscore the importance of integrating social science perspectives into geospatial climate analytics to better understand behavioural drivers and identify context-sensitive intervention strategies (IpBC/GIECo, 2025).

By converting survey-based behavioural data into spatially explicit GHG estimates, this study demonstrates how private consumption patterns can be incorporated into public climate planning tools. Scenario modelling further enables the anticipation of potential emissions reductions under alternative dietary transitions. In doing so, the approach extends geospatial analytics beyond infrastructure-based emissions and into the domain of lifestyle-driven carbon footprints.

More broadly, the framework enables municipalities to identify districts with higher dietary mitigation potential, spatially target awareness campaigns or food-related initiatives, and integrate food consumption into climate resilience and socio-ecological transition strategies. The study illustrates how non-traditional spatial data sources—such as behavioural surveys—can become actionable components of urban climate intelligence systems.

## 7 Conclusion

Dietary behaviour—particularly meat consumption—constitutes a significant yet underutilized lever for urban GHG mitigation. By applying a geospatial behavioural framework to survey data from residents of Québec City, this study demonstrates that diet-related emissions can be spatially quantified, mapped, and modelled using realistic behavioural scenarios.

The findings reinforce the importance of integrating eco-conscious consumption into geospatial decision-support systems and highlight the potential of smart behavioural data to support municipalities in designing targeted, district-level climate interventions. By making lifestyle-driven emissions spatially explicit, the approach broadens the scope of urban climate analytics beyond infrastructure-focused domains.

Future research could refine the emission factors by incorporating full life-cycle assessments, thereby better reflecting the Québec context. Additionally, dietary scenarios could be further calibrated to local consumption patterns using detailed datasets such as those generated by the NutriQuébec project. Such improvements would enhance both the methodological robustness and the policy relevance of geospatial dietary emission modelling.

### Declaration of Generative AI in writing

The authors declare that they have used Generative AI tools in the preparation of this manuscript. Specifically, the AI tools were utilized for language editing, improving grammar, and sentence structure, but not for generating scientific content, research data, or substantive conclusions. All intellectual and creative work, including the analysis and interpretation of data, is original and has been conducted by the authors without AI assistance.

### Acknowledgements.

This research was supported by funding from the Climate Action and Awareness Fund of Environment and Climate Change Canada.

## References

- Andreoli, V., Bagliani, M., Corsi, A., Frontuto, V., 2021. Drivers of Protein Consumption: A Cross-Country Analysis. *Sustainability* 13, 7399. <https://doi.org/10.3390/su13137399>
- Barros, B., Wilk, R., 2021. The outsized carbon footprints of the super-rich. *Sustain. Sci. Pract. Policy* 17, 316–322. <https://doi.org/10.1080/15487733.2021.1949847>

- Barthelmie, R.J., 2022. Impact of Dietary Meat and Animal Products on GHG Footprints: The UK and the US. *Climate* 10, 43. <https://doi.org/10.3390/cli10030043>
- Champagne St-Arnaud, V, Labonté, K, Olivier, A, Vincent, S-J, 2024. Baromètre de l'action climatique 2024 : Disposition des Québécoises et des Québécois envers les défis climatiques. Groupe de recherche sur la communication climatique.
- Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F.N., Leip, A., 2021. Food systems are responsible for a third of global anthropogenic GHG emissions. *Nat. Food* 2, 198–209. <https://doi.org/10.1038/s43016-021-00225-9>
- Doyle, J., Richardson, A., 2025. The moderating role of post-materialism in the relationship between income and red meat consumption. *Int. J. Sociol.* 55, 303–321. <https://doi.org/10.1080/00207659.2025.2473207>
- Gaillac, R., Marbach, S., 2021. The carbon footprint of meat and dairy proteins: a practical perspective to guide low carbon footprint dietary choices. <https://doi.org/10.1101/2021.01.31.429047>
- Government of Canada, 2026. Canada's food guide.
- Institut de la statistique du Québec, 2025. Empreinte carbone des ménages de 2017 à 2021.
- Kauppinen, T., Pesonen, I., Katajajuuri, J.-M., Kurppa, S., 2010. Carbon footprint of food-related activities in Finnish households. *Prog. Ind. Ecol. Int. J.* 7, 257–267. <https://doi.org/10.1504/PIE.2010.037779>
- Newell, P., Twena, M., Daley, F., 2021. Scaling behaviour change for a 1.5-degree world: challenges and opportunities. *Glob. Sustain.* 4, e22. <https://doi.org/10.1017/sus.2021.23>
- Patouillard, L., Greffe, T., Louineau, E., Muller, E., Bulle, C., 2023. Life cycle inventory database for consumption in Québec – Food consumption. <https://doi.org/10.5281/zenodo.8208610>
- Poore, J., Nemecek, T., 2018. Reducing food's environmental impacts through producers and consumers. *Science* 360, 987–992. <https://doi.org/10.1126/science.aag0216>
- Rochette, M., Rochefort, G., Laramée, C., Lapointe, A., Lemieux, S., Bélanger-Gravel, A., Desroches, S., Provencher, V., Lamarche, B., 2024. Local food procurement behavior and overall diet quality among adults in Québec: results from the NutriQuébec project. *Nutr. J.* 23, 143. <https://doi.org/10.1186/s12937-024-01045-w>
- Rose, D., Heller, M.C., Willits-Smith, A.M., Meyer, R.J., 2019. Carbon footprint of self-selected US diets: nutritional, demographic, and behavioral correlates. *Am. J. Clin. Nutr.* 109, 526–534. <https://doi.org/10.1093/ajcn/nqy327>
- S. La Branche, 2025. First Main report, Vol.1, Drivers of behavioral change and non change in transition times. IpBC/GiECo, Paris.
- Statistics Canada. 2023. (table). *Census Profile*. 2021 Census of Population. Statistics Canada Catalogue no. 98-316-X2021001. Ottawa. Released November 15, 2023. <https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/index.cfm?Lang=E>
- Weber, C.L., Matthews, H.S., 2008. Food-Miles and the Relative Climate Impacts of Food Choices in the United States. *Environ. Sci. Technol.* 42, 3508–3513. <https://doi.org/10.1021/es702969f>
- Wiesli, T.X., 2025. Meat consumption among different social groups and specific options for reducing it: a literature review of empirical research. *Front. Sociol.* 10. <https://doi.org/10.3389/fsoc.2025.1547663>
- WU Yan, WANG Xiaoke, LU Fei, 2012. The carbon footprint of food consumption in Beijing. *生态学报* 32, 1570–1577. <https://doi.org/10.5846/stxb201101140074>