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Understanding the climate and financial impacts of land-use decisions

GUIDE

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ACKNOWLEDGEMENTS

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Delivered by the Federation of Canadian Municipalities, the Green Municipal Fund (GMF) is a $1.65 billion endowment from the Government of Canada. GMF helps municipalities implement sustainability projects and emission-reducing policies—creating lasting environmental change, improving your quality of life, and driving sustainable economic growth in your community and across Canada.

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Introduction

Land use development patterns are one of the greatest underlying contributors to Canada's greenhouse gas emissions. This means the land use decisions that municipalities make also represent one of the greatest opportunities to lower emissions.

Low-density developments, common across Canada, encroach on farmlands and natural areas, consuming carbon sinks and destroying habitats and ecosystems. This destruction of natural assets, and the ecosystem services they provide, increases a community's exposure to climate risks as well as its reliance on traditional built infrastructure, which is costly to build, maintain and replace.

Lower-density communities also often feature automobile-oriented design and segregated land use, which create low walkability and can contribute to poorer community health and well-being. Once a low-density community has been built, it's very difficult (and expensive) to change its energy performance and the behaviours it encourages. This is known as the "lock-in effect."

But we can also lock in much more sustainable infrastructure and behaviours simply by embedding low-carbon considerations into our land use decisions. With climate targets fast approaching, that's good news. And, as you'll see in the sections that follow, building this way is also good news for your municipality's bottom line and residents' well-being.

This guide will help you understand how land use decisions can achieve these positive lock-in effects.

DID YOU KNOW?

Each new development that does not advance a municipality's climate objectives will need to be retrofitted between 2030 and 2050 to keep emissions within the threshold needed to limit global temperature increases to 1.5°C.

Municipalities can save a lot of future effort and expense by making low-carbon land use development decisions now.

WHO THIS GUIDE IS FOR

This guide aims to give municipal elected officials and staff (e.g., land use planners, asset managers, etc.) a high-level understanding of how land use decisions impact their municipality's greenhouse gas (GHG) emissions and fiscal sustainability.

We'll outline the sources of GHG emissions associated with different types of residential development. Then we'll compare the emissions intensity and financial implications, plus a few important co-benefits, of three development patterns commonly found in Canadian communities:

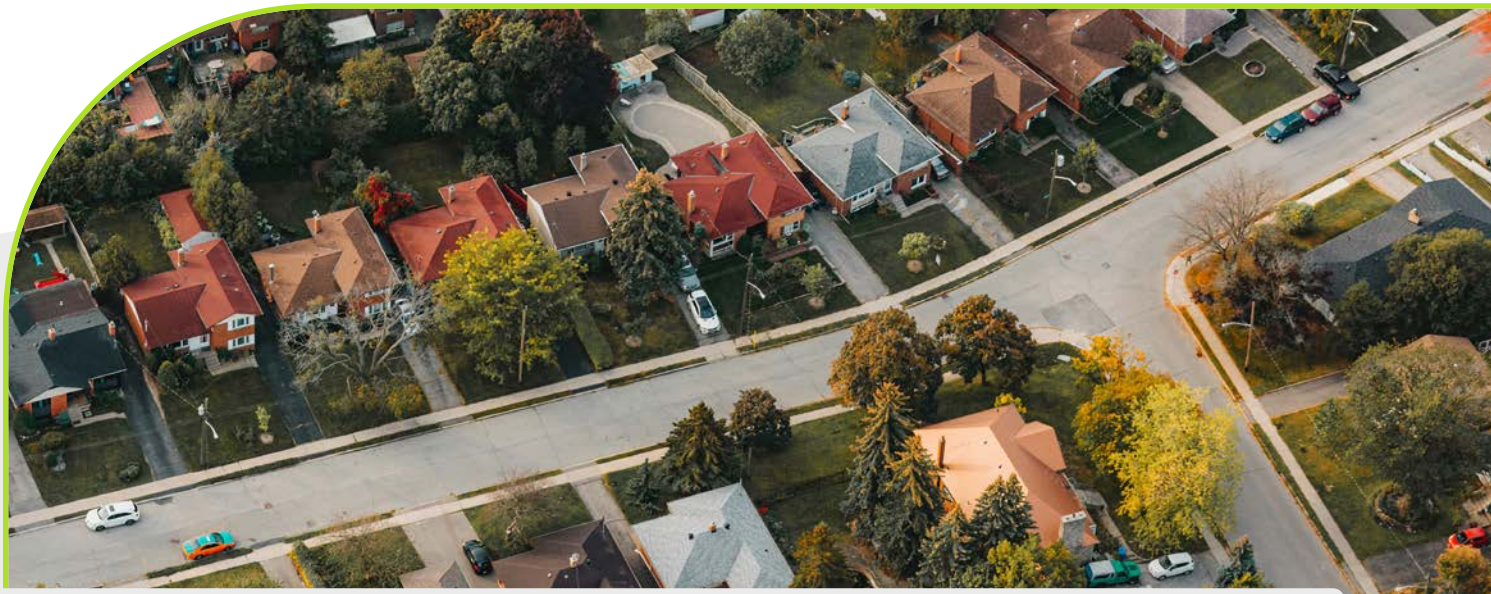
- low-density residential developments
- medium-density transit-oriented developments
- high-density mixed-use infill developments

SCOPE AND LIMITATION OF THIS GUIDE

This guide is not intended to be a land use decision-making tool. The values used in the guide are for demonstration purposes only, given that the costs and revenues associated with land development can vary widely from one project to another and from one community to another. However, the conclusions about the development patterns presented in this guide should remain the same.

We've developed the **Land Use Impact Calculator (LUIC)** as an accompanying practical tool to this guide. Whether you use our default numbers or your own data*, you can play around with LUIC to help you identify which type of development(s) make sense for your community.

You can find more information on LUIC here.



*LUIC users acknowledge that calculations made by the Land Use Impact Calculator are limited to the accuracy of the data and information that is inputted by the user. Thus, LUIC users agree not to rely solely on the calculations or information provided because it may be based on imperfect or inaccurate data.

How land use decisions impact climate

There are three key emissions sources associated with land development:

- **building emissions**
- **embodied emissions** (sometimes called embodied carbon) and
- **transportation emissions**

BUILDING EMISSIONS

The *types* of buildings we choose to build impacts the climate. Building emissions depend on the following:[1]

- size of the building
- area of shared interior walls, floors and ceilings
- airtightness
- insulation rating and window performance
- energy systems and fuel sources

EMBODIED EMISSIONS

The *materials* we choose to build with also have climate repercussions. Building materials contain embodied emissions, which are created when materials are harvested and during manufacturing processes. This is also known as embodied carbon. Natural materials like wood and stone have low embodied emissions; heavily processed materials like concrete, steel and glass have high embodied emissions.

The materials we use to build infrastructure like roads and water/wastewater systems also contain embodied emissions. The asphalt, metal, plastics and other materials used in built infrastructure are all made through process-heavy means. When more of these materials are required for land use development and infrastructure maintenance (for example, because of longer roads), embodied emissions are going to be higher.

DID YOU KNOW?

The built environment generates 40 percent of annual global CO_2 emissions.

Building operations account for 27 percent of those emissions. The embodied carbon from building and infrastructure materials are responsible for the other 13 percent[2].

1 Rode, P., Keim, C., Robazza, G., Viejo, P., & Schofield, J., 2014, **Cities and Energy: Urban Morphology and Residential Heat-Energy Demand**

2 **https://architecture2030.org/**

TRANSPORTATION EMISSIONS

Land use decisions can also significantly impact transportation emissions. Personal transportation emissions vary greatly depending on vehicle type and distances travelled. Consider a trip made by bike versus by car, or a bus that transports 100 passengers versus 100 people making similar trips in personal vehicles.

Shorter travel distances and fewer vehicle trips reduce transportation emissions. A new neighbourhood can be designed with this in mind.

How land use decisions impact municipal finances

When a new development is built, capital (one-time) costs are incurred. There are also ongoing service costs plus operations and maintenance (O&M) costs.

The total infrastructure costs of a development can depend on a variety of factors, including:

- road length and width
- water, sanitary and stormwater services
- municipal service provision (e.g., police and emergency services)

There are other costs as well, but for simplicity this guide will focus on these ones.

New developments also generate new revenues for municipalities to pay for these costs. Municipalities typically require residential developers to pay fees per housing unit, often called development cost charges (DCCs), to help pay for the connection and maintenance of infrastructure and services to new developments. Depending on provincial or territorial legislation, municipalities may be able to choose to charge different DCCs for different types of developments. For example, they may charge less per unit of dense housing than per unit of detached housing.

Municipalities also pay for infrastructure and service costs through property tax collection and user fees for certain services like police, emergency services, transit, water and wastewater. These are typically charged on a per dwelling basis, usually regardless of the distance from the point of service provision.

DID YOU KNOW?

Co-benefits are "the positive effects that a policy or measure aimed at one objective might have on other objectives."[3] Sustainable community planning can improve co-benefits like health/well-being and social inclusion in the following ways.

Promoting physical health and well-being by design

The design of the built environment plays an important role in shaping people's health and physical-activity habits:

- Mixed-use infill developments usually mean higher rates of physical activity because people can walk or roll to do their shopping, errands and other daily activities.[4]
- Close and frequent transit stops in these developments result in high ridership.[5]
- Improved air quality from decreased vehicle exhaust emissions is one of the most immediate co-benefits offered by transit-oriented and mixed-use developments.[6]

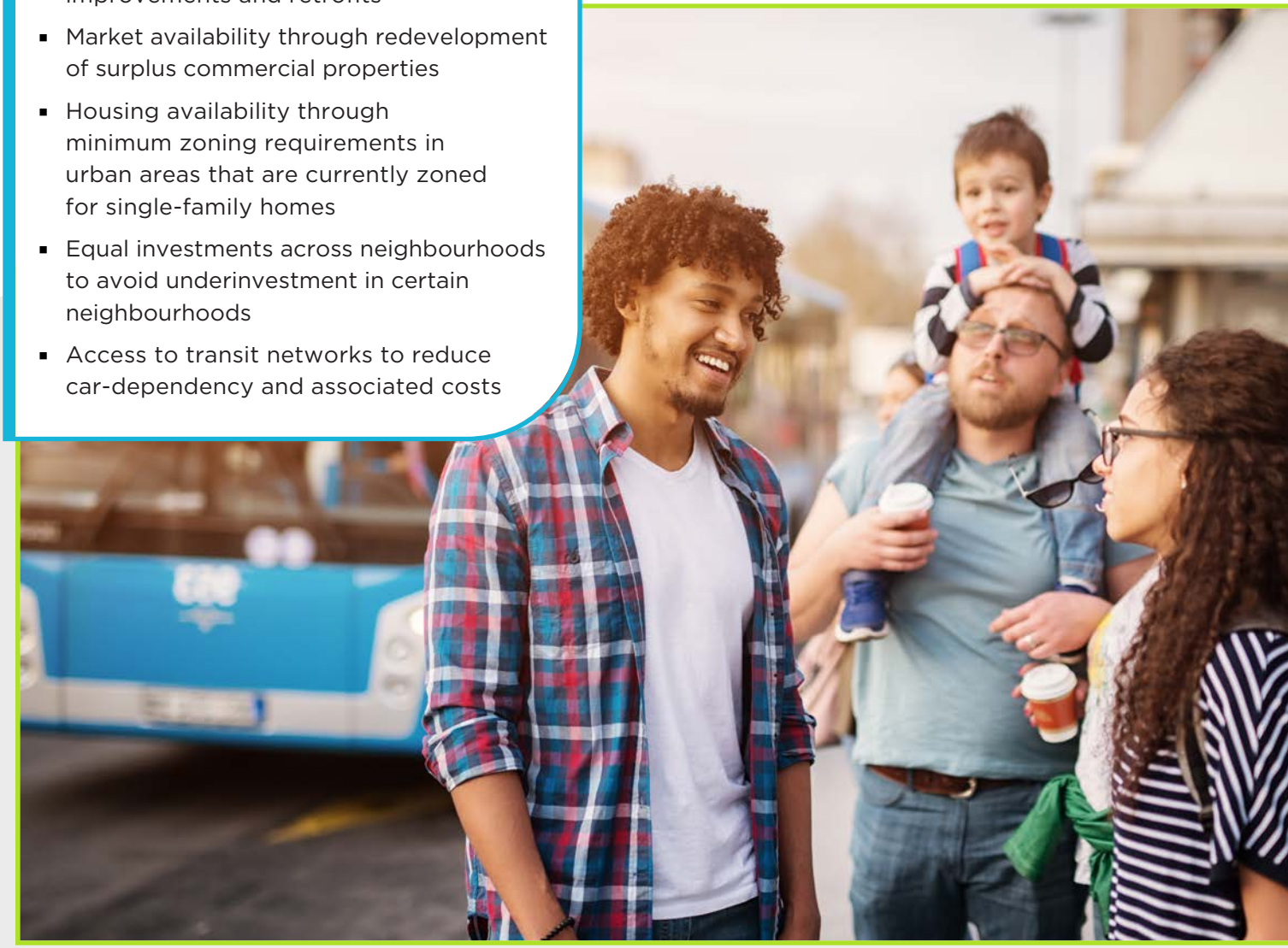
3 *Ibid., 12*
4 BuilderSpace, 2016. **4 City Design Factors That Promote Physical Activity**
5 *Ibid.*
6 Health Canada, 2021. **Health Impacts of Air Pollution in Canada 2021 Report**.

DID YOU KNOW?

Supporting social inclusion through affordability

Mixed-use infill developments do not directly increase housing affordability, but municipalities can support affordability with the following actions:[7]

- Homeowner incentives for home energy improvements and retrofits
- Market availability through redevelopment of surplus commercial properties
- Housing availability through minimum zoning requirements in urban areas that are currently zoned for single-family homes
- Equal investments across neighbourhoods to avoid underinvestment in certain neighbourhoods
- Access to transit networks to reduce car-dependency and associated costs



7 *Ibid.*

Comparing three common types of residential development

We've generated a high-level comparison of the GHG emissions, costs and revenues between three hypothetical development scenarios that represent three residential development patterns typically found in Canadian communities:

- high-density mixed-use infill
- medium-density transit-oriented with bus rapid transit
- low-density residential

Each development scenario assumes a residential area of 40 hectares, built to current building energy efficiency standards. Table 1 details the housing mix assumptions for each development type. Please refer to Appendix B for further, more detailed assumptions behind the calculations.

Table 2 gives an overview of the financial and climate implications and some important co-benefits (in this case social inclusion, health/well-being and walkability) for these three scenarios.

FCM's new **Land Use Impact Calculator** (LUIC), a simple and user-friendly open-source tool that explores the climate and financial implications of different land use development scenarios, can be used to generate comparisons like the one presented in this guide.

We encourage you to try LUIC, along with the many other helpful tools and resources listed in Appendix A, to assess potential impacts of development decisions in your community.

Download the tool for free **here**.

Table 1. Housing-mix assumptions for our three development scenarios, each using 40 hectares

Dwellings	High-density Mixed-use Infill	Medium-density transit-oriented with Bus Rapid Transit	Low-density Residential
Single-detached homes	0	200	750
Row/townhouses	200	100	0
Apartment under six storeys	1,700	700	0
Apartment over five storeys	3,100	1,500	0
Total new dwellings	**5,000**	**2,500**	**750**

Table 2. Overview of three different development types

(Please refer to Appendix B for further, more detailed assumptions behind these calculations.)

Development scenarios	High-density mixed-use infill	Medium-density transit-oriented	Low-density residential
Description of development pattern	◗ Built on previously developed land (e.g., parking lots) ◗ Mix of land uses: various housing types, retail services, employment areas, community services, etc. ◗ Street-level retail and services with multi-unit residential on higher floors ◗ Compact street grid conducive to efficient transit and active transportation ◗ Centralized space/water heating/cooling and district energy systems are common; these can increase energy efficiency	◗ Can be infill or greenfield development ◗ Primarily residential, with some commercial uses ◗ High density (mixed-use zoning) around the transit station to low density (residential zoning) a few blocks away ◗ Short transit ride from urban centres ◗ Continuous grid street network conducive to efficient transit and active transportation ◗ Total road length is moderate ◗ Some centralized space/water heating/cooling; district energy systems are rare	◗ Typically greenfield development ◗ Primarily residential with closed network street patterns ◗ Typically served by a main highway with a series of narrower internal streets ◗ Low-density, segregated land uses limit viability of transit service and active transportation ◗ Total road length is high ◗ Independent space water heating/cooling; district energy systems extremely rare

Housing	High-density mixed-use infill	Medium-density transit-oriented	Low-density residential
Housing density	Moderate to high	Moderate to high	Low

Transportation	High-density mixed-use infill	Medium-density transit-oriented	Low-density residential
Active transportation use	Moderate to high	Moderate	Low
Transit use	High	Moderate to high	Low
Car use	Low	Moderate to high	High

Energy and emissions	High-density mixed-use infill	Medium-density transit-oriented	Low-density residential
Annual home energy use (GJ per unit)	40–50	40–110	110
Embodied carbon in buildings	High High-rise buildings typically constructed of concrete, rebar and glass	Low Row/townhouses and single-detached homes typically constructed of wood and brick or stone	Low Row/townhouses and single-detached homes typically constructed of wood and brick or stone
Embodied carbon in infrastructure	Low Capitalizes on existing infrastructure; total length of road and underground services is low	Medium Requires new infrastructure; total length of road and underground services is moderate	High Requires considerable new infrastructure; total length of road and underground services is high
Annual home emissions (tCO_2e per household)	2.85–3	2.85–5.8	5.8
Annual transportation emissions (tCO_2e per household)	5	6.6	9.6

Financial implications	High-density mixed-use infill	Medium-density transit-oriented	Low-density residential
Total development cost charges	High due to higher total number of households	Medium due to moderate number of households	Low due to low number of households
Municipal revenues	High due to higher total number of households	Medium due to moderate number of households	Low due to low number of households
Infrastructure one-time capital costs (per household)	Low Capitalizes on existing infrastructure; total length of road and underground services is low	Medium Requires new infrastructure; total length of road and underground services is moderate	High Requires considerable new infrastructure; total length of road and underground services is high
Annual infrastructure operations and maintenance (per household)	Low Total length of road and underground services is low	Medium Total length of road and underground services is moderate	High Total length of road and underground services is high
Land purchase, construction costs	High	Higher as gets closer to transit stations	Medium to low

Co-benefits	High-density mixed-use infill	Medium-density transit-oriented	Low-density residential
Social inclusion	Medium to high	Medium to low	Low to medium
Physical health and well-being	Medium to high	Medium	Low to medium
Walkability	Medium to high	Medium to low	Low

KEY TAKEAWAYS

As you can see from the overview in Table 2, there are significantly different climate and financial outcomes for each development scenario.

Overall, when compared to lower-density development, higher-density development offers the following:

- lower annual GHG emissions per household
- lower transportation emissions per household
- lower one-time capital costs per household
- lower annual operations and maintenance costs per household
- higher municipal revenues
- more co-benefits, offering better outcomes for social inclusion, physical health/ well-being and walkability

Emissions

Different housing types and infrastructure requirements can result in vastly different emission profiles for each type of development scenario. Table 3 summarizes these.

Table 3. Emissions production comparison[8]

One-time embodied GHG emissions (tCO_2e)	High-density Mixed-use Infill	Medium-density transit-oriented with Bus Rapid Transit	Low-density Residential
Home construction	170,874	82,098	18,315
Road construction	Negligible new roads	8,428	18,870
Total embodied emissions	**170,874**	**90,526**	**37,185**
Total embodied emissions per household	**34.2**	**36.2**	**49.6**

Annual GHG emissions (tCO_2e)	High-density Mixed-use Infill	Medium-density transit-oriented with Bus Rapid Transit	Low-density Residential
Home energy emissions	14,850	7,125	4,358
Vehicle emissions	25,000	16,500	7,200
Total annual emissions	**39,850**	**23,625**	**11,558**
Total annual emissions per household	**8.0**	**9.5**	**15.4**

8 See Appendix B for detailed assumptions.

High-density mixed-use infill scenarios tend to have the most *total* embodied and annual emissions of the three development types, but on a per household basis they are the lowest emitter of the three. This is due to the far greater number of homes and residents in a high-density scenario.

Medium-density developments usually create fewer one-time embodied emissions and have lower annual emissions than high-density scenarios. The per household emissions tend to be modestly higher in a medium-density scenario, but still low compared to a low-density scenario.

While low-density scenarios tend to have the lowest total embodied and annual emissions of all three scenarios, per household they are by far the highest emitters.

Costs

Capital costs

As we saw in the overview in Table 2, each development scenario has different infrastructure needs. This can result in significantly different total and per-household infrastructure costs for each scenario.

The further away from the urban core the development, the greater the total costs of road, water, sanitary and stormwater infrastructure. This means costs can range from very low for a high-density infill scenario, which utilizes existing infrastructure and services, to very high for a low-density scenario, which requires building new infrastructure and services.

With most roads and services already in place, high-density infill developments incur the lowest total capital costs of the three development scenarios.

Operation and maintenance costs

Costs to operate and maintain services and infrastructure can also vary widely between development types. High-density infill developments tend to have the greatest total annual O&M costs, but their per household cost is often the lowest.

Operation and maintenance (O&M) costs of sanitary and stormwater services, as well as police and emergency services costs, are based on a per household value, which is generally the same per household regardless of the development type.

However, road maintenance and water service O&M costs differ across development types. Road O&M costs are calculated on a per-meter basis, so the more roads a development has, the greater the maintenance required. Similarly, the longer the water service infrastructure, the higher the costs, because of greater likelihood for damage and leaking.

Revenues

Municipal revenues include development cost charges (DCCs), property taxes and water/wastewater fees. Each revenue is administered on a per household basis. DCCs are a one-time revenue while property taxes and water/wastewater fees are annual fees.

New low-density developments, with the fewest DCCs collected and the highest one-time capital costs, can incur significant capital debt. In contrast, a new medium-density development's DCCs can come fairly close to offsetting its capital debt, while high-density developments can be built without incurring any capital debt, assuming no major infrastructure upgrades are required.

Payback periods

Annual municipal revenues should exceed annual operation and maintenance (O&M) costs in any development scenario, with the excess used to pay off any debts.

In general, this would take less time in a medium-density scenario than in a low-density scenario.[9] A high-density scenario may have no payback period at all, because these types of developments can be built without incurring any debt.

9 This assumes consistent year-over-year operation and maintenance costs and annual municipal revenues.

CASE STUDY:

ASSESSING CLIMATE AND FINANCIAL IMPACTS OF LAND USE DECISIONS IN PRINCE GEORGE, B.C.

Background

With a population of 74,000, Prince George is the largest city in northern British Columbia. It is currently experiencing moderate growth.

As part of its strategy to reduce carbon emissions and dependence on fossil fuels, the city has set a growth target for 80 percent of new development to be near the down-town core and neighbourhood centres. The city's Official Community Plan[10] encourages higher-density development, infill development and redevelopment.

Municipal planners in Prince George piloted the Government of British Columbia's Community Lifecycle Infrastructure Costing (CLIC)[11] tool to compare two scenarios: a new low-density subdivision and a medium-density infill development. CLIC analysis revealed that the medium-density infill development scenario was the more responsible option from the per-spectives of both climate and finances because it had the following benefits:

- lower infrastructure capital costs
- lower annual operating costs
- higher revenues per hectare
- better climate outcomes with lower related costs

Approach

In 2016, the city participated in a pilot program to test the new Community Lifecycle Infrastructure Costing (CLIC) tool developed by the Government of British Columbia. CLIC enables municipal governments to assess the sustainability of their land use decisions by providing high-level cost comparisons of different residential development scenarios over a 100-year period.

The city used CLIC to compare two scenarios: a new low-density subdivision and a medium-density infill development.

10 City of Prince George. myPG: an Integrated Community Sustainability Plan for Prince George
11 Stantec. https://www.stantec.com/en/projects/canada-projects/c/clic-tool

Key findings

Using CLIC's long-range planning function, the city compared the low-density subdivision scenario with the medium-density infill development scenario.

Both development scenarios had similar land areas, residential areas and road lengths (see Table A).

Table A. Summary of characteristics of low-density subdivision and medium-density infill development (adapted from Prince George CLIC)[12]

Summary of characteristics	New low-density new subdivision	Medium-density infill development
Net density (units/hectare)	28	52
Gross area (hectares)	188	127
Projected population	8,635	10,824
Residential area	71%	70%
Connectivity	◗ Existing interconnected road network with some trail and bike network ◗ Some transit access ◗ Located 9.4 km from central business district	◗ Existing interconnected road, trail and bike network ◗ Transit access ◗ Located 1.0 km from central business district
Structure	◗ Single-family detached houses and townhouses	◗ Mix of single-family detached houses, narrow lots with single-family houses, townhouses, and mid-rise and low-rise apartments

12 Government of British Columbia, 2016. CLIC Tool Case Study: Prince George

CLIC analysis revealed that the medium-density infill development scenario was the more responsible option in terms of both climate and financial outcomes. The medium-density infill offered the following benefits:[13]

- **Lower infrastructure capital costs:** The infill development's easy access to existing infrastructure resulted in upfront capital costs that were almost 100 percent lower than those of the new low-density subdivision.
- **Lower annual operating costs per household:** The infill development resulted in 14 percent lower annual operating costs per household. In addition, the infill development also fit into the municipality's existing operation and maintenance (O&M) costs, whereas the low-density development's O&M costs would have required additional municipal operating budget.
- **Higher total revenue per hectare:** The infill development produced 61 percent more annual revenue per hectare over the modelled 100-year lifecycle.
- **Lower costs from better climate outcomes:** The infill development demonstrated lower costs for home energy and driving, as well as fewer costs arising from vehicle collision, air pollution and climate change.

Based on these results, the city presented a successful business case for planning decisions that prioritize compact development with a focus on livability and sustainability.

The city plans to use CLIC analysis from now on to inform its land use decisions.

Supporting plans, policies and programs

Over the past decade, Prince George has created numerous development incentives with initiatives to encourage higher-density development in existing areas (see Table B).

The city's Integrated Community Sustainability Plan is a community-wide climate plan with a suite of short-, medium- and long-term actions to guide Prince George in achieving its 2050 climate goals.

As part of its strategy to reduce carbon emissions and dependence on fossil fuels, the city set a growth target in this plan for new residential development: 80 percent was to be near downtown and neighbourhood centres to encourage infill development and redevelopment.[14]

The policy mechanism for implementing this target is the Official Community Plan, which "encourages higher density and infill development where vacant lands and redevelopment opportunities exist and where established services and infrastructure foster the potential for new housing."[15]

13 *Ibid.*
14 City of Prince George. **myPG: an Integrated Community Sustainability Plan for Prince George**
15 *Ibid.*

To encourage the implementation of its Integrated Community Sustainability Plan and Official Community Plan, the city has created or promoted numerous initiatives to densify existing areas, which are outlined in Table B.

Table B. Current and past development incentives in Prince George[16]

Downtown incentive program (low development cost charges, parking exemptions, flexible C1 zoning)	The city's downtown incentives encourage the development of high-density commercial and residential development by providing a 10-year tax exemption for eligible commercial and multi-family development downtown and an additional $10,000 grant per door for each new multi-family residential unit constructed in the downtown core. Development cost charges (DCCs) for downtown Prince George are within the lowest in the province: for multi-family medium-density to high-density development the DCC is $229.00 per unit; there are also reduced DCCs for small-lot subdivisions.
Multi-family housing incentives program	The city created a tax exemption bylaw (with five- and 10-year exemptions) in priority growth areas near services or with existing infrastructure and services while also updating/improving newer housing types. The term of this bylaw has seen a substantial increase in multi-family options in infill areas in the community.
Provincial property tax exemptions	Purpose-built rental housing projects that qualify for Prince George's downtown incentives or multi-family housing incentives may also qualify for the Government of British Columbia's municipal revitalization property tax exemptions.
Single-family housing incentives (secondary suites, narrow lot housing and DCC reductions for small-lot subdivisions)	Narrow lot housing areas are pre-zoned neighbourhoods the city approved in 2014 to accommodate future growth in infill lots. The city has also permitted detached secondary dwellings on lots with single- family housing to permit further infill density.

16 *Ibid.*

Conclusion

This guide has laid out the significant impact that residential land use development decisions can have on emissions, climate targets and municipal finances.

In terms of climate impacts, high-density/ mixed-use infill development scenarios outperform medium- and low-density development scenarios every time by producing fewer total embodied emissions and annual GHG emissions per household.

High-density developments are also the best performer from a financial perspective.

One-time capital costs for infrastructure and services are far lower per household in a high-density scenario than in a medium- or low-density scenario. In contrast, operating and maintenance costs for infrastructure and services are much higher per household in a low-density development scenario.

As a rule, medium- and high-density scenarios also generate more municipal revenues and have much shorter payback periods, and high-density developments may have no payback period at all.

Last but not least, for meaningful co-benefits like social inclusion, health and well-being, and walkability, medium- and high-density developments outperform low-density developments every time.

Table 4 summarizes the business case for higher-density development.

Table 4. The business case for higher-density development

High-density development offers the following clear benefits:
✔ Fewer total embodied GHG emissions per household
✔ Lower annual GHG emissions per household
✔ Lower transportation emissions per household
✔ Lower one-time capital costs per household
✔ Lower annual operations and maintenance costs per household
✔ Higher municipal revenues
✔ Can be built without incurring any debt
✔ Meaningful co-benefits such as improved social inclusion, health/well-being and walkability

APPENDIX A: Tools and resources

The following tools and resources may be helpful to municipal governments that want to assess the climate and financial impacts of land use decisions in their communities:

- **The Land Use Impact Calculator** is a simple, user-friendly open-source tool that FCM built to help municipalities and anyone else who is interested to explore the climate and financial implications of different land use development scenarios.

  Try out the tool by downloading the plug in.

- **BREEAM Communities** is a neighbourhood sustainability assessment tool municipalities can use to assess master-planning of new communities and regeneration projects.

  Learn more by visiting the BREEAM Communities website.

- **Community Lifecycle Infrastructure Costing (CLIC)** tool is designed for local governments to understand the long-term costs of land use decisions. The tool estimates cost implications over a 100-year period by applying infrastructure lifecycle costs to different land use planning and development scenarios. CLIC aims to inform the business case for developing compact, complete, connected and centered communities.

  Learn more by visiting the Government of British Columbia's CLIC website.

- **The Infill Data Explorer** is an online mapping tool that provides information on residential infill development. The tool allows users to explore potential infill development sites based on housing type, zoning description, total tax assessment, parcel lot area, and services and amenities.

  Learn more by visiting the City of Edmonton's Residential Infill website.

- **Envision Tomorrow (ET)** is an open-access scenario-planning package that allows users to analyze how their community's current growth pattern and future growth decisions will impact a range of measures, from public health to fiscal resiliency and environmental sustainability.

  Learn more by visiting the Envision Tomorrow website.

- **MATSim** is an open-source framework for large-scale transportation simulations. It can be used for microscopic modelling of traffic and behaviour to understand how transportation impacts a network.

  Learn more by visiting the MATSim website.

- **Model City Infrastructure (MCI)** is a tool to help municipalities understand the long-term infrastructure implications of land use decisions by evaluating the long-term financial performance of various types of neighbourhoods. The tool looks at municipal spending on long-term infrastructure in different neighbourhoods and the tax revenue and utility fees collected from them.

  Learn more by visiting the City of Kelowna's MCI website.

APPENDIX B: Development Type Scenario Assumptions

1. Average annual GHG emissions and energy use per household

Scenario	Apartment	Row/ townhouse	Single-detached home
GHG emissions (tCO_2e)[17]	2.97	2.85	5.81
Energy use (GJ)[18]	42	91	112

2. Annual household transportation emissions

Scenario	High-density mixed-use infill	Medium-density transit-oriented with bus rapid transit	Low-density residential
GHG Emissions (tCO_2e)[19]	5.0	6.6	9.6

3. Embodied carbon

Scenario	One-time GHG emissions (tCO_2e)
Kilometre of two-lane road[20]	880
Kilometre of four-lane road[21]	2014

17 NRCan Office of Energy Efficiency. Residential Sector - GHG Emissions.
18 Statistics Canada. Household Energy Consumption, by type of dwelling, Canada and Provinces.
19 Canada Mortgage and Housing Corporation, 2000. Greenhouse Gas Emissions From Urban Travel: Tool For Evaluating Neighbourhood Sustainability.
20 Lokesh, K., Densley-Tingley, D. and Marsden, G., 2022. Measuring Road Infrastructure Carbon: A 'critical' in transport's journey to net-zero.
21 *Ibid.*

Scenario	One-time GHG emissions (kCO_2e)
Dwelling in an apartment building over five storeys (per m^2)[22]	388
Dwelling in an apartment building under six storeys (per m^2)	376
Row/townhouse dwelling (per m^2)	132
Single-detached dwelling (per m^2)	132

4. Estimated average home size[23]

Scenario	Square metres (m^2)
Dwelling in an apartment building over five storeys	75
Dwelling in an apartment building under six storeys	120
Row/townhouse dwelling	150
Single-detached dwelling	185

5. Assumed new road construction for each development approach[24]

Scenario	Two-lane road (km)	Four-lane road (km)
High-density mixed-use infill	negligible	negligible
Medium-density transit-oriented with bus rapid transit[25]	5	2
Low-density residential	10	5

22 Embodied carbon values derived from modelling work performed for the City of Vancouver's Climate Emergency Action Plan, 2020.

23 NRCan Office of Energy Efficiency Residential Housing Stock, **Tables 21 and 24 Residential Sector - Canada**.

24 Estimated average length of new road based on estimated average distance from periphery of a typical mixed-use walkable urban core.

25 The medium-density scenario considered here assumes bus rapid transit (BRT) services will operate on existing or new public roads. If the development were served by an independent BRT road system, or by light or heavy rail, the transportation infrastructure costs would be much higher.